TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE: AN EXAMINATION OF RURAL SECONDARY SCHOOL LIFE SCIENCES TEACHERS' INTEGRATION OF TECHNOLOGY IN EASTERN CAPE PROVINCE

A thesis submitted in accordance with the requirements for the degree of

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At

RHODES UNIVERSITY

BY

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January 2024

DECLARATION

I, BRIAN SHAMBARE (19S3620), declare that the thesis, TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE: AN EXAMINATION OF RURAL SECONDARY SCHOOL LIFE SCIENCES TEACHERS' INTEGRATION OF TECHNOLOGY IN EASTERN CAPE PROVINCE, submitted for the qualification of DOCTOR OF PHILOSOPHY (ICT IN EDUCATION) at Rhodes University is my independent work.

All the references I have used have been indicated and acknowledged through complete references.

I further declare that I have not previously submitted this work to another university or faculty for the purpose of obtaining a qualification.

15 January 2024

SIGNED **DATE**

ABSTRACT

> It is important for teachers to prepare themselves for a world where technology is constantly changing and evolving. (Harari, 2018, p.249)

Rural education, particularly in the Global South, faces distinct challenges flowing from low socio-economic conditions, limited resources, and inadequate funding. These issues notably affect rural teachers' abilities to deliver quality education. Although technology integration offers potential benefits and rural teachers have increased access to various technologies, they frequently adopt these tools spontaneously without guidelines. While many teachers in rural schools choose specific technologies to address teaching challenges, technology has to be integrated with a clear pedagogical intent. The rural teachers' frequent adoption of technologies hints at technological pedagogical content knowledge (TPACK) development, consciously or unconsciously. However, the process of developing this expertise remains largely unknown. Furthermore, the development of TPACK among teachers in rural Global South schools, particularly those who did not receive formal or informal technology training during their initial teacher education or professional development, remains unclear. Therefore, this research delved into the practices, factors, and experiences influencing the development of TPACK, all from the perspective of Life Sciences teachers in rural schools. The voices of teachers in rural regions have been notably absent in the broader discourse of TPACK research, making the current study's insights particularly significant.

This qualitative and investigative study, located within the interpretivist paradigm, is grounded in Vygotsky's (1978) socio-cultural theory and Koehler and Mishra's (2006) Technological Pedagogical Content Knowledge framework. Seven Life Sciences teachers participated in the study. The teacher participants were purposively sampled from schools in the Joe Gqabi district in the Eastern Cape province of South Africa. Multiple data-generation instruments were employed. These included a questionnaire, semi-structured interviews, lesson observations, and sharing circle discussions. A thematic analysis approach, guided by the study's dual theoretical perspective, was applied to dissect and analyse the data.

The study's findings challenged the prevailing assumption that rural schools lack access to technological resources, unveiling that rural Life Sciences teachers in this research had access to diverse educational technologies. Nevertheless, despite improved technology accessibility, these teachers predominantly employed ‘simple skill-based’ technologies for content delivery, resulting in limited learner engagement. Notwithstanding the challenges posed by inadequate school infrastructure, limited electricity access, and poor Internet connectivity, this investigation found that Life Sciences teachers in rural settings who lack formal technology integration training demonstrated enthusiasm for incorporating technology into their teaching methods. Furthermore, these teachers exhibited strength in non-technological TPACK domains, such as content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK), while demonstrating limited expertise in technology-related domains, such as technological knowledge (TK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK).

The study uncovered nuanced factors, practices, and experiences contributing to TPACK development among rural Life Sciences teachers. These include learning from their learners, collaborating with peers, and engaging in self-directed learning. The study also proposed a new theoretical perspective to the existing TPACK framework to cater for technology integration in rural school contexts. Overall, this research provided a unique perspective on TPACK development in rural schools, particularly in the Global South. The study recommended targeted investments in professional development, promoting peer collaboration, and fostering a culture of self-directed learning. Furthermore, the current research emphasised the importance of recognising the evolving educational landscape as a two-way knowledge exchange between teachers and learners to foster TPACK development in rural schools.

Keywords: Technology integration; science education; TPACK; socio-cultural theory; rural education; Life Sciences.

LIST OF PUBLICATIONS

	JOURNAL ARTICLE	AUTHORS	JOURNAL	YEAR OF PUBLICATION
1	A Critical Review of Teaching with Virtual Lab: A Panacea to Challenges of Conducting Practical Experiments in Science Subjects Beyond the COVID-19 Pandemic in Rural Schools in South Africa.	Brian Shambare & Clement Simuja	Journal of Educational Technology Systems (JETS)	2022
2	Understanding rural secondary school teachers' perceptions and attitudes on the use of ICT for teaching and learning.	Brian Shambare, Clement Simuja, & Adedayo Theodorio	Journal of African Education (JAE)	2022
3	The Pedagogical and Technological Experiences of Science Teachers in Using the Virtual Lab to Teach Science in Rural Secondary Schools in South Africa.	Brian Shambare, Clement Simuja, & Adedayo Theodorio	International Journal of Technology-Enhanced Education (IJTEE)	2022
4	Educational technologies as pedagogical tools: Perspectives from teachers in rural marginalised secondary schools in South Africa	Brian Shambare, Clement Simuja, & Adedayo Theodorio	International Journal of Information and Communication Technology Education (IJICTE)	2022
5	Understanding the enabling and constraining factors in using the Virtual Lab to teach science through scientific experiments in rural schools in South Africa	Brian Shambare, Clement Simuja, & Adedayo Theodorio	International Journal of Information and Communication Technology Education (IJICTE)	2022
6	Online learning experiences during schools lockdown: Case of learners in a Nigerian higher education institution	Theodorio, Adedayo Olayinka, Clement Simuja, Brian Shambare & Oluwasola Babatunde Stephen	International Conference on Smart, Secure and Sustainable Nation | S3N'2022	2022
7	Investigating teacher teachers' strategies for integrating technology into teaching to develop technological pedagogical content knowledge.	Theodorio, A.O., Simuja, C., Mataka, T, W., & Brian Shambare.	In C. H. Stevenson-Milln (2023). Book of Proceedings. Available at https://www.saarmste.org/conference.	2023
8	Unveiling the TPACK Pathways: Technology Integration and	Brian Shambare, Clement Simuja	Computers and Education Open	Abstract accepted for Article

	Pedagogical Evolution in Rural South African Schools		(CAOE): Editors: Punya Mishra and Mathew J. Koehler	publication in 2024
	BOOK CHAPTERS			
9	BOOK TITLE: Information and Communications Technology in STEM education: An African perspective.			
	Promoting Pre-Service Teachers' TPACK Development in an Education Science Course.	Theodorio, A.O., Kenneth Ngcoza., Clement Simuja., & Brian Shambare	Routledge	2023
	BOOK TITLE: Research and Innovations in Virtual Laboratory Practices in Engineering Education.			
10	Integration of Virtual Laboratory: Perspectives and experiences of teachers in rural schools in a developing country	Brian Shambare, Clement Simuja	Springer's Education Innovation Series	2023
11	Self-regulated learning in online lab environments.	Ishmael Nyirenda, Clement Simuja, Brian Shambare,	Springer's Education Innovation Series	Under review
	BOOK TITLE: Exploring Technology-Infused Education in the Post-Pandemic Era			
12	Adapting Virtual Laboratories in Post COVID-19 Pandemic Learning Landscapes: An Exploration of Science Teacher Perceptions and Adoption in Rural Schools.	Brian Shambare & Clement Simuja	IGI Global	Chapter proposal accepted. Book to be published in 2024
13	Rural School Teachers Leveraging Pandemic Teaching Experiences for Technology Integration in the Post-Pandemic Classrooms.	Clement Simuja & Brian Shambare	IGI Global	Chapter proposal accepted. Book to be published in 2024

DEDICATION

From street kid to PhD graduate…
A path marked by adversity and destiny's hand,
Left orphaned at the tender age of three months, thrust into a world of turmoil,
Where aspirations wane, and optimism slips away.

This thesis is a tribute to my siblings, Royce Shambare and Rodwell Muzanenhamo,
Who left the classroom's threshold to toil in the fields,
Their ambitions momentarily set aside,
So that I could pursue my education.

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I deeply appreciate the research participants' generous contribution of time and knowledge. Without their involvement, this research would not have been feasible. Their willingness to share their experiences has enriched the findings and added depth to the final analysis.

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LIST OF ABBREVIATIONS AND/OR ACRONYMS

B.Ed.	BACHELOR OF EDUCATION
CK	CONTENT KNOWLEDGE
DBE	DEPARTMENT OF BASIC EDUCATION
ECDoE	EASTERN CAPE DEPARTMENT OF EDUCATION
ICT	INFORMATION AND COMMUNICATION TECHNOLOGY
ICTs	INFORMATION AND COMMUNICATION TECHNOLOGIES
PCK	PEDAGOGICAL CONTENT KNOWLEDGE
PTD	PROFESSIONAL TEACHER DEVELOPMENT
TD	TEACHER DEVELOPMENT
PK	PEDAGOGICAL KNOWLEDGE
TCK	TECHNOLOGICAL CONTENT KNOWLEDGE
TK	TECHNOLOGICAL KNOWLEDGE
TPACK	TECHNOLOGICAL PEDAGOGICAL AND CONTENT KNOWLEDGE
TPK	TECHNOLOGICAL PEDAGOGICAL KNOWLEDGE
SCT	SOCIO-CULTURAL THEORY
SMT	SCHOOL MANAGEMENT TEAM
UNESCO	UNITED NATIONS EDUCATIONAL, SCIENTIFIC, AND CULTURAL ORGANISATION
NGO	NON-GOVERNMENTAL ORGANISATION
SGB	SCHOOL GOVERNING BODY
RQ	RESEARCH QUESTION

CHAPTER ONE: INTRODUCTION AND BACKGROUND

> Equipping teachers with the triple-edged sword of technology, pedagogy, and content knowledge empowers them to orchestrate captivating learning experiences. Just as a sword's edges must work in harmony, TPACK's fusion enables teachers to navigate modern education adeptly. (Mishra & Koehler, 2006, p.1023)

1.1 INTRODUCTION

This research investigated the development of rural secondary school Life Sciences teachers' TPACK by unpacking the factors, practices, and experiences that guide the development of this expert knowledge. Chapter One begins by providing the study's background and briefly describing the research context. Next, the problem statement and the significance of this research are outlined. Then, the study objectives, research questions, and the definition of key terms ensued. An overview of the thesis folds the chapter.

1.2 BACKGROUND TO THE STUDY

The United Nations Educational, Scientific and Cultural Organisation (UNESCO) strongly advocates for quality science education for all school learners, propelled by multifaceted rationales. Primarily, science education in secondary schools is believed to spark inquisitiveness about the world, playing a fundamental role in fostering learners' scientific thinking (Abdurrahman, 2023; Kolb & Kolb, 2018; Schauble et al., 1995). Consequently, science education equips learners with critical thinking abilities, enabling well-informed decision-making and the acquisition of competencies crucial for their educational journey and prospective careers. Secondly, science education is pivotal in identifying, motivating, and preparing individuals aspiring to pursue careers in science-related domains (Hill & Uribe-Florez, 2020; Passarelli & Kolb, 2023). This emphasis is vital to ensuring a steady supply of professionals in the scientific realm, which significantly contributes to a country's economic development and the welfare of its populace. Thirdly, the progression of scientific knowledge and its subsequent societal applications hinges on a populace that is informed and adept in scientific literacy (Hodson, 2014; Hofstein & Lunetta, 2004; Holbrook et al., 2022). However, despite the persistent advocacy from UNESCO, governments, and numerous non-governmental organisations (NGOs) for quality science education for all, this aspiration remains elusive and often a dream deferred for most secondary school learners in rural and disadvantaged communities.

Most rural secondary schools, especially in the Global South, are typically remote and underdeveloped. Consequently, science teaching-learning in these schools encounters a distinct set of formidable challenges compared to their more affluent urban counterparts. These challenges encompass essential infrastructure deficiencies, including libraries, classrooms, and science laboratories. These challenges are compounded by the subpar service delivery, which regrettably impedes the quality of science education in rural secondary schools. The cumulative impact of these factors perpetuates a vicious cycle of poverty among learners, their families, and the rural community, which inevitably affects the overall educational environment (Assey & Babyegeya, 2022). This challenge is further exacerbated by the inadequate funding that characterises most rural schools, compromising the quality of science teaching and learning. Faced with these restrictive conditions, many science teachers in rural secondary schools turn to educational technologies to plug some of the gaps associated with science education in rural schools (Shambare et al., 2022). However, the limitations of science teachers in effectively integrating technology into rural science education often outweigh their strengths.

The limitations science teachers encounter in successfully integrating technology can be partly attributed to their insufficient knowledge of technology integration in the classroom. Historically, the criteria for teacher competence included mastery of subject matter (content knowledge) and effective teaching methods (pedagogical knowledge) (Shulman, 1986). Shulman (1987) subsequently argued that while having a firm grasp of the subject matter and employing effective pedagogical strategies were essential, they alone could not adequately define a competent teacher's knowledge. Shulman (1987) then introduced the concept of 'pedagogical content knowledge' (PCK) to describe how teachers approach the presentation of specific content. PCK represents the amalgamation of content knowledge (CK) and pedagogical knowledge (PK) into a framework that defines how particular subject areas are structured, adapted, and delivered using methods that enhance understanding for learners (Shulman, 1986). (Shulman, 1986). While Shulman's perspective remains pertinent (Shulman, 1987, 2013), a notable shift from the teacher knowledge discourse of the 1980s is the proliferation of innovative technologies in the teaching-learning spaces, even in remote and rural schools.

Consequently, there is an increasing need for teachers to go beyond merely learning to use technologies and ultimately to acquire knowledge of technology as a concomitant facet to ensure effective technology integration. In this regard, several scholars have asserted that the integration of technologies in teaching is significant in science classrooms (Afgan, 2015; Nelson et al., 2019; McCrory & Reiss, 2023). This observation is because while technology is applied to many fields, it has a privileged and core place in science education. As McCrory (2014, p.243) puts it, science classrooms are "a natural place for technology use since so much of science today depends on technology." More so, integrating technologies in rural science teaching becomes central to providing authentic learning experiences that align with current issues, real-world experiences, and challenges to cultivate deep, meaningful, and active learning. This objective is vital for mastering essential science skills and concepts among learners in rural secondary schools (Constantinou et al., 2018; Kazmi, 2023). However, despite the benefits of integrating technology in science teaching, increased technology access, and even ownership of various technology tools, most teachers merely tend to focus on technology use without proper technology integration. According to Koehler and Mishra (2009), meaningful technology integration occurs when there exists a deliberate pedagogical intent behind selecting specific technologies to enhance distinct teaching methodologies. This intent should be firmly rooted in curriculum-related and teaching-learning activities.

Further, Leahy and Mishra (2023) argue that technology integration into teaching can only occur when the teacher possesses specialised knowledge to teach with technology. This teacher knowledge is called 'technological pedagogical content knowledge' (TPACK) (Kohler & Mishra, 2006). TPACK describes a teacher's knowledge foregrounded in an intricate understanding of the multifaceted transactions between technology, content, and pedagogy, capitalising on this conception to craft suitable and context-bound teaching approaches. TPACK, thus, serves as the bedrock for proficient teaching with technology, demanding an appreciation for "epistemological theories and how technologies can advance knowledge, introduce new epistemologies, or reinforce existing ones" (Koehler & Mishra, 2007, p. 2). (Kohler & Mishra, 2007, p.2). Therefore, possession of TPACK by science teachers in rural secondary schools would mean that they could effectively enhance their science teaching by harnessing the potential inherent in successful technology integration.

In addition, existing literature highlights that TPACK is not static but rather is an emergent knowledge form whose nature varies depending on the context, which differs from country to country and from one school to another, including from teacher to teacher (Gentles & Haynes-Brown, 2021; Kohler & Mishra, 2007; Leahy & Mishra, 2023; Mohebi, 2022). Similarly, Cox and Graham (2009, p.47) point out that "the effect of different contexts is that the nature of TPACK is unique, temporary, situated, idiosyncratic, adaptive, and specific and will be different for each teacher in each situation." This evolving nature of TPACK implies that there are no standard and fixed parameters or 'blanket approaches' to qualify and describe its nature and how it develops in teachers. Consequently, the question of how teachers develop TPACK has continued to be explored by scholars and remains a subject of recent academic articles in the educational technology space. For example, Harris and Wildman's (2020) seminal literature review identified 1246 articles, 293 chapters, 28 books, and 404 theses that studied teachers' TPACK development. In support, Zou et al. (2023), in a bibliometric analysis spanning 1608 empirical TPACK studies from 2000 to 2022, demonstrated a growing scholarly interest in TPACK.

Nonetheless, it is worth noting that most of these studies have predominantly focused on pre-service teachers, especially in the Global North, with relatively fewer investigations in the Global South. For example, Valtonen et al. (2019) conducted a study examining the TPACK development of 148 pre-service teachers over a three-year educational programme in Finland, while Luo et al. (2023) conducted quantitative research in China, concentrating on the evolution of TPACK among 1192 pre-service early childhood teachers. These researchers and others who have explored pre-service teachers' TPACK development concur that technology courses serve as the foundational stepping stones for initiating their journey towards building TPACK.

What remains unclear in the literature is how TPACK develops and what factors and experiences contribute to its development in science teachers in rural secondary schools. This concern pertains to teachers who did not undergo formal or informal training in technology integration during their initial teacher training programmes. Furthermore, it applies to those who may or may not have participated in professional development training sessions focused on technology integration into their teaching. Notwithstanding, these rural secondary school science teachers, particularly in the Joe Gqabi district, seem to integrate innovative technologies in their practice occasionally and at their discretion and effort. This observation suggests that, at some juncture in their teaching careers, these secondary school science teachers in rural locales have, perhaps inadvertently and in the absence of explicit guidance, commenced the development or are in the process of developing a semblance of TPACK.

However, there is limited knowledge about how and when teachers develop this specialised and situated knowledge type. Therefore, this evokes a desire to answer pressing questions, such as how science teachers in rural secondary schools, devoid of formal or informal training on integrating technology in classrooms and without guidelines, could understand the complex, dynamic, and transactional interactions among content, pedagogy, and technology. Further, it is also unclear how science teachers in rural secondary schools develop TPACK. Similarly, there is a dearth of understanding regarding the prominent knowledge domains within the TPACK framework of teachers in rural secondary schools. By offering insights into how this specialised, complex, and context-dependent knowledge develops, this study sought to close this gap and advance the literature on TPACK development. Additionally, from the perspectives of Life Sciences teachers in rural secondary schools, the study sought to determine which practices, factors, and experiences influence TPACK development.

1.3 SITUATING THE STUDY

Teaching science has long been identified as a complicated and complex activity. At the heart of this complexity lies the inherent ‘abstract’ nature of science, necessitating learners to possess advanced cognitive abilities to logically interconnect chains of arguments and reconstruct meanings to comprehend these ‘abstract’ scientific principles (Dewey & Bentley, 1949; Firdaus & Robandi, 2022; Passarelli & Kolb, 2023). Furthermore, all three major branches of science (biology, chemistry, and physics) and their respective sub-disciplines employ specialised scientific terminologies, which further compound the complexity. Beyond these challenges, teaching science in rural schools presents an even more formidable task due to a range of unique difficulties specific to the context of rural science education.

In their investigations into the challenges of science teaching and learning in South African rural schools, Mtsi and Maphosa (2016) identified numerous hindrances stemming from the absence of crucial facilities. These scholars emphasise that the dearth of science infrastructure, including laboratories, hinders the process of science teaching and learning in rural areas. Similarly, Ramnarain and Hlatswayo (2018) observe that the absence of science teaching equipment in South Africa constrains the effectiveness of science education in most rural schools. Likewise, Bantwini (2017) affirms that most rural schools lack the resources necessary for meaningful science education, and their classrooms are ill-suited for science teaching and learning. These conclusions were drawn from classroom observations of science lessons in the rural schools of the Eastern Cape province and responses to questionnaires. Several other researchers, such as Tsakeni et al. (2019), Ramnarain (2020), Shambare et al. (2022) and Shambare and Simuja (2022), have also documented similar findings.

To address these obstacles, integrating technology into teaching has emerged as a potential avenue to improve science education. This approach led to significant technology distributions to schools by the South African government and numerous non-governmental organisations. Notably, in the rural Eastern Cape province, the provincial government provided tablets and laptops for every learner and teacher and computers, televisions, and satellite infrastructure for schools across the region. This initiative was confirmed by Mr Fundile Gade, an Executive Council Member (MEC) for Education, in his 2021/2022 Budget and policy speech delivered at the Provincial legislature. The MEC reported the following:

> Madam Speaker, we continue to advocate for technology integration. The Department has invested in the technology roll-out in which 22 000 laptops were procured and distributed to teachers (Eastern Cape Department of Education 2021/22 Budget and Policy Speech, 2021, p.10).

This extensive provision of technology to schools is seen as highly advantageous for science teaching and learning for several compelling reasons. Firstly, technology is regarded as an essential component of the nature of science (Shambare & Simuja, 2022). Secondly, there is a symbiotic and bi-directional association in which both are affected by and affect each other (Agunbiade et al., 2017). Third, technology tools are considered the bridges between daily life and science lessons (Contant et al., 2018). Although some science teachers working in rural school contexts, through their self-determination, are integrating technology to meet prospective learners' learning needs, little is known regarding how they are developing TPACK to teach with technology. Teaching science in rural school environments is a distinct and crucial context. Integrating technology in rural science classrooms makes it even more critical due to the need to tap into the potential benefits that technologies could offer to enhance rural science teaching.

However, to realise the full potential of technologies in science teaching in rural schools, science teachers should possess TPACK (Mishra & Koehler, 2008). TPACK, thus, becomes:

> The basis of effective teaching with technology requires 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 learners face; knowledge of learners' prior knowledge (Koehler & Mishra, 2006, p.66).

Therefore, teachers' TPACK is essential to enable them to be intelligent technology users for pedagogical purposes in any situation. Consequently, it becomes crucial to understand how science teachers in rural schools develop TPACK. Thus, this research aimed to investigate the development of rural secondary school Life Sciences teachers' TPACK by identifying the factors guiding the construction of this expertise.

1.4 STATEMENT OF THE PROBLEM

Integrating new technologies in teaching often presents challenges that may prove daunting even for seasoned teachers, including secondary school science teachers in rural schools. To Warr and Mishra (2023), since these technologies have come to stay, teachers should possess TPACK to teach effectively with the technologies. Niess (2011, p.24) posits 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 were trained during a period where initial teacher training programmes did not focus on knowledge of technology in teaching but instead on two knowledge types: CK and PK (Cox & Graham, 2009; Niess & Gillow-Wiles, 2017). A teacher had to demonstrate competency in the two knowledge domains to be regarded as competent in a specific learning area. Therefore, the researcher contends that most science teachers in rural secondary schools already have PCK from their initial teacher training. This is in line with the findings of many other scholars in educational technology (Leahy & Mishra, 2023). The researcher also aligns with the notion that most science teachers possess PCK, drawing from his experience as a science teacher in a rural secondary school setting in South Africa.

However, with the rising prevalence of technology, many secondary school science teachers in rural schools in South Africa now encounter technologically adept learners within technology-infused classrooms. This context starkly contrasts with the traditional training they initially received. Most of these teachers have not undergone formal training in technology integration, resulting in a notable gap in their technological knowledge. In response to this challenge, the

Basic Education Department in the Eastern Cape province has been implementing various technologies in schools. Additionally, many professional teacher development workshops focusing on diverse hardware and software packages are being conducted to provide teachers with the requisite skills for effective technology-based teaching. However, it is crucial to note that some science teachers in rural secondary schools may or may not have attended these workshops. While the technology training workshops are essential, this approach to teacher development suggests that teachers should merely be trained to use the technologies (Koehler & Mishra, 2009; Shambare et al., 2022; Spangenberg & De Freitas, 2019). The anticipation, however, is that by demonstrating technology skills to use the various hardware and software, the teachers would then integrate the technology tools in their classrooms effectively.

As a former science teacher in a rural secondary school for ten years, the researcher has first-hand experience attending many workshops on technology skills. Currently, as a District Curriculum Official, the researcher continues to organise and facilitate technology workshops for teachers in line with his job performance agreement. However, as Koehler and Mishra (2006) argue, this focus on technology skills is fundamentally flawed in developing the 'deep understanding' to enable teachers to develop TPACK mainly because the approach is context-neutral. Yet, technology integration in teaching is not context-free and depends on factors such as the grade, subject, learner background, types of available technologies, including individual teacher attributes such as their philosophy, teaching style, and experience (Koh & Chai, 2011; Kohler & Mishra, 2006; Spangenberg & De Freitas, 2019). The researcher's contention is not that technology training workshops are not helpful. However, despite their valuable contribution, such context-free methods most likely fail since they focus more on technical skills without developing TPACK (Koehler & Mishra, 2006). Put differently, simply knowing how to use technology is not the same as knowing how to teach with it.

Therefore, consistent with other TPACK researchers (Hanshaw et al., 2022; Neiss, 2011; Sastria, 2023), the researcher observed that out of their effort and without guidelines, the science teachers in rural secondary schools in the Joe Gqabi district in the Eastern Cape province somehow integrate technologies in their classrooms to meet their learners' needs. Further, this study assumes that the teachers could likely unknowingly be developing TPACK. This further hints at the likelihood of more profound and more intricate TPACK development sources beyond the scope of technology-based training. Thus, the interest of this exploratory investigative case study is to understand how science teachers in rural secondary schools, who are not formally technologically trained, are developing TPACK to teach the digital native learners in the Joe Gqabi district. There seems to be a dearth of empirical research that has articulated how secondary school science teachers in rural schools develop technological pedagogical content knowledge, particularly in South Africa, compared to the Global North. In support, scholars such as Cox and Graham (2009), Bingimlas (2018), and Bwalya and Rutegwa (2023) assert that technology research has so far given little insight into understanding how rural science teachers develop technological pedagogical content knowledge. Similarly, in South Africa, the few available studies on teachers' TPACK were conducted by Jita (2016), Tunjera and Chigona (2020), Bernardesa and de Andrade Neto (2020), Major and McDonald (2021), and Ramnarain and Penn (2021). All these studies have focussed on pre-service teachers' TPACK development, 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. Importantly, research thus far has shed little light on how access to a range of technologies from which to select for teaching or awareness of many of the content-specific methods in which technologies can be utilised contributes (or not) to teachers' TPACK. Hence, there is a knowledge gap on teachers' TPACK in general and science teachers in rural secondary schools in particular. Thus, this research aimed to contribute new knowledge on how teachers develop TPACK from the perspective of Life Sciences teachers in rural secondary schools in the Joe Gqabi district.

1.5 SIGNIFICANCE OF THE STUDY

Like in many countries, the South African government and several NGOs have taken strides to ensure technology-infused teaching in all schools. As a result, almost all teachers currently have access to various technology tools for teaching (Shambare & Simuja, 2022). For example, as a Subject Advisor working with secondary school science teachers in rural schools, the researcher in his line of duty has observed teachers' lesson plans with some pedagogical intent to integrate various audio-visual technologies, from simple PowerPoint presentations and YouTube videos to more complex technologies like animations and simulations. This observation is consistent with Koehler et al. (2008) that teachers can, indeed and often unknowingly, develop technological pedagogical and content knowledge at any level, from lesson planning to assessment processes. Thus, this research is significant as it investigated how Life Sciences teachers in rural secondary schools without formal technology integration training can develop TPACK.

First, the researcher's professional experience supervising Life Sciences teachers in rural secondary schools in the Joe Gqabi district awakened his desire to conduct this study. One of the researcher's key responsibilities is teacher development in teaching with technology. Therefore, the researcher's professional goal is to understand how Life Sciences teachers develop TPACK in rural schools. Understanding strategies, best practices, and the contexts in which the teachers develop TPACK might inform education officials (like me) on what support science teachers require to build or enhance their TPACK. Further, the Life Sciences teacher participants are expected to have opportunities to share experiences and better understand their TPACK. Moreover, from their TPACK understanding, the teacher participants may become more thoughtful about improving to become better secondary school science teachers in the increasingly technology-rich teaching environment.

Second, this research does not purport to inaugurate a new line of inquiry regarding teachers' TPACK development. Other researchers have explored this area (for example, see Dnyaneshvar et al., 2020; Hanshaw et al., 2022; Neiss, 2011). However, what sets this research apart is its distinct focus on the context-bound and situated perspective of teachers' TPACK development. This study's distinctive feature lies in its specific embedding within rural science teaching, with a dedicated emphasis on Life Sciences teachers. The rural educational landscape and the domain of Life Sciences teaching represent a critical yet underexplored context within academic inquiry. The dearth of attention from researchers towards rural school settings and the specific domain of Life Sciences teachers underscores the uniqueness and significance of this research. Therefore, the investigation into the development of TPACK among Life Sciences teachers in rural secondary schools emerges as a compelling and worthwhile area of study.

Third, as already discussed, research on teachers' TPACK is still in the infancy stage in the Global South, and much remains unknown in this direction. As the researcher began his literature review, it appeared that the present study might be the first endeavour to examine science teachers' TPACK development in rural secondary schools in South Africa. Therefore, the researcher expected this study to extend the knowledge frontiers by filling an exciting and worthwhile research gap on Life Sciences teachers' TPACK development. Further, although this investigation was conducted in the Joe Gqabi district, and its scope would limit its generalisability, the researcher envisaged that the results would provide a foundation for future studies in other educational settings. Moreover, as the focus on teachers' TPACK development has become more globalised, readers from similar contexts worldwide might probably transfer the present study's implications to their contexts.

1.6 RESEARCH OBJECTIVES

This study's main objective was to examine Life Sciences teachers' TPACK development in rural secondary school contexts.

THE SPECIFIC OBJECTIVES ARE:

- To understand how rural secondary school Life Sciences teachers integrate technology into their teaching.
- To understand how rural secondary school Life Sciences teachers describe their pedagogical technological content knowledge.
- To gain insights into the sources of pedagogical technological content knowledge rural Life Sciences teachers draw upon in their teaching.

1.7 RESEARCH QUESTIONS

Table 1 shows the following research questions and how data was generated and analysed from the objectives.

Table 1. Research questions

RESEARCH QUESTION	NARRATIVE	DATA GENERATION TOOL	ANALYTICAL FRAMEWORK
How do rural secondary school Life Sciences teachers describe their ways of integrating technology?	Integrating technologies in classrooms continues to evolve, and how teachers integrate technology is as varied as the kinds of technologies available. The secondary school Life Sciences teachers in rural schools facilitated a deeper understanding of their ways of integrating technologies through their self-description of lived teaching experiences with technologies and how these interactions with technology tools offered them opportunities to construct and develop TPACK.	• Questionnaire • Semi-structured interviews • Sharing circles	• TPACK
How do rural secondary school Life Sciences teachers describe their technological pedagogical content knowledge?	TPACK, as an emergent knowledge form, is complex and context-dependent (Kohler & Mishra, 2007). The "effect of different contexts is that the nature of TPACK is unique, temporary, situated, idiosyncratic, adaptive, and specific and will be different for each teacher in each situation" (Cox & Graham, 2009, p.48). Through their self-reported TPACK, the secondary school Life Sciences teachers in rural schools facilitated a better understanding of their TPACK development in the rural secondary school context.	• Questionnaire • Semi-structured interviews • Lesson observations • Sharing circles	• TPACK
What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?	Vygotsky's (1978) notion of mediation of knowledge suggests that human knowledge is mediated and developed using 'tools.' This approach assumes that the uses of the tools are critical to knowledge development and ongoing learning. Through their individual and collective voices and self-reported practices, the rural secondary school Life Sciences teachers, who lack formal training in technology integration and without guidelines, facilitated a better understanding of the sources of TPACK from which they draw in their teaching.	• Questionnaire • Semi-structured interviews • Lesson observations • Sharing circles	• TPACK and SCT

1.8 RESEARCH METHODOLOGY OVERVIEW

This investigation was located within the interpretivist paradigm. The research used a qualitative case study method focusing on the experiences of the participants' TPACK development. Data were generated using a questionnaire, semi-structured interviews, lesson observations, and sharing circle discussions. Seven teacher participants were purposively drawn from a population of Life Sciences teachers in rural secondary schools in the Joe Gqabi district in the Eastern Cape Province (South Africa).

1.9 DEFINITIONS OF TERMS

The terms used in this study are defined here:

Educational Technology – "The study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources" (Cox & Graham, 2009, p. 62).

Integrating technology – "Technology integration is integrating technology into a curriculum to improve learning in a particular subject area or across multiple disciplines. Technology is effectively integrated into the classroom when learners can select technology tools to help timely information acquisition, information analysis and synthesis, and professional presentation." (Koehler & Mishra, 2008, p. 6).

Pedagogical Content Knowledge (PCK) - Integrates pedagogy and content to understand how these relate to successful teaching (Shulman, 1986). To put it another way, ways of presenting and formulating the subject that make it understandable to others fall under the category of pedagogical content knowledge.

Technological Pedagogical Content Knowledge (TPCK) - The application of technological tools to deliver PCK (Mishra & Koehler, 2006).

TPACK – The new abbreviation for TPCK (Koehler et al., 2007).

Rural area: Refers to any place not considered an urban area. Statistics South Africa (2011, p. 1) states that "rural areas are subdivided into tribal areas and commercial farms. For example, villages are settlements in tribal areas. A village has boundaries encompassing not only populated areas but also agricultural areas, e.g., grazing land, cropland, or forested land. Villages are usually under the jurisdiction of tribal authorities, headed by chiefs, while sub-chiefs are direct principals of villages".

1.9 STRUCTURE OF THE THESIS

This thesis is structured into nine chapters as outlined below:

Chapter One: Introduction and background - presents the research's core concepts about its background, objectives, and significance. This chapter mainly concerns situating the subject under investigation within its global and local contexts. The chapter closes by outlining the thesis's organisational structure.

Chapter Two: Literature review - outlines the most recent and pertinent studies on the topic. The research questions in Chapter One guided the literature review. The literature was sourced from credible databases like Web of Science, Science Direct and Google Scholar. The reviewed literature was primarily from the international context due to the limited TPACK literature in South Africa. The literature review concentrated on TPACK development in secondary school teachers.

Chapter Three: Theoretical framework - presents the SCT and the TPACK as theoretical and analytical frameworks, respectively. In addition, this chapter explains the justification for selecting the theories and how they were applied in this study. The chapter ends by acknowledging the theories' limitations.

Chapter Four: Research methodology - explains and justifies the methodology used. The research is in an interpretivist qualitative research paradigm, employing a case study method. This chapter also explains and justifies the sample size and sampling criteria. Furthermore, the strengths and weaknesses of data generation techniques are discussed. This chapter articulates in detail how the study's research objectives, questions, and methodology are coherent. The data analysis process, triangulation, and research trustworthiness are also addressed in this chapter. The chapter ends by discussing this study's ethical considerations.

Chapters Five, Six and Seven: Results analysis and presentation - present the study's findings for Research Questions 1, 2 and 3, respectively. These chapters' main focus was the data generated using questionnaires, semi-structured interviews, sharing circles, and non-participatory observations. The study's findings are presented in these chapters honestly and precisely and are coherent with the methodology. The findings are organised into themes from the data analysis guided by the research questions. To ensure trustworthiness, great care is taken to present teachers' answers in their own words.

Chapter Eight: Discussion of findings - discusses the study's findings. The results are contrasted with previous literature that was explored in Chapter Two. By making suggestions and implications that are practical and helpful, the discussion of the results demonstrates originality and insight. This chapter provides a thorough discussion of the research questions, and it also justifies the study's conclusions.

Chapter Nine: Recommendations and Conclusions is this study's last chapter. The chapter gives a synopsis of the entire research and summarises the key findings from which recommendations are drawn. Additionally, it outlines new knowledge generated from the present research, makes suggestions, and points out any gaps that might be used as future research focus points.

1.10. CHAPTER SUMMARY

This chapter presented a justification for examining Life Sciences teachers' TPACK development. It was noted that integrating technology in classrooms could support excellent and productive science teaching, enhancing learning outcomes. It is imperative to pay close attention to science teachers' TPACK if this cherished dream is to come true. The reality, however, shows that most educational researchers have not consistently paid attention to rural science teachers' TPACK development. It is shown that the current study is necessary because there is a lack of knowledge, specifically regarding Life Sciences teachers' TPACK development in rural teaching contexts. Moreover, the background to the study, problem statement, significance of the study, research objectives and questions, and definition of keywords were all covered in this chapter. This chapter concluded with a description of the thesis organisation and a chapter summary. The following chapter critically examines Teachers' TPACK development literature to give the research a theoretical foundation.

CHAPTER TWO: LITERATURE SYNTHESIS

> In the company of giants navigating the landscape of ideas. The trajectory spans time, partnered with luminaries whose insights paved the way for our exploration. Just as a wanderer traverses diverse terrains, we tread the intellectual pathways of literature, seeking junctions where our questions intersect with age-old inquiries. Through this dialogue with the past, we find resonance, dissonance, and inspiration - a continuum of thought that fuels the evolution of knowledge. (Whelan, 2016, p.405)

2.1 INTRODUCTION

This study's main objective was to examine Life Sciences teachers' TPACK development in rural secondary schools. The researcher posed three questions to foreground the empirical aspect of the study and establish a starting point for the analysis and interpretation of the findings (see Section 1.7). The research questions guided the literature review. According to Haddaway et al. (2015, p.44), a literature review is "a systematic and comprehensive analysis of the literature relevant to a research topic."

In this research, the literature review allowed the researcher to correlate the present study's findings to other research on the topic. Specifically, the literature review sought to:

- present fundamental knowledge on the study topic (Liao, 2017)
- identify past research to avoid replication (Snyder, 2019)
- recognise and credit other scholars (Xiao & Watson, 2019)
- identify gaps and contradictions in prior research and justify why this research was crucial.

When considering the literature relevant to this research, it was crucial to acknowledge the multifaceted nature of the subject under examination. This study identified three principal categories of literature: empirical studies, theoretical frameworks, and case studies. Empirical studies furnished concrete data and insights, theoretical frameworks established a basis for the analysis and interpretation of findings, and case studies facilitated an exploration of practical applications. During this study's literature synthesis, the researcher adopted a multi-layered approach that combined elements of a systematic literature review, bibliometric analysis, and qualitative content analysis. As previously discussed, the primary goal of the literature review was to present a comprehensive and in-depth overview of the existing literature while also critically analysing and synthesising the information.

This chapter drew on the most recent and pertinent literature on technology integration in teaching and the development of teachers' TPACK. Specifically, the chapter synthesised literature from various sources, including peer-reviewed academic journals, books, conference proceedings, and reputable electronic databases. The researcher meticulously selected sources aligned with the current research objectives and contributed to a well-rounded understanding of the topic. The key databases consulted included Google Scholar, Scopus, Science Direct, and Web of Science, and the search terms encompassed science education in rural schools, technological pedagogical content knowledge, technology integration in rural schools, and challenges of technology in rural education.

The current chapter is structured into sections. First are the sections that cast the present study in its context: the concept of rurality, rural secondary schooling contexts, and science education in secondary schools. Second are the sections on technology integration in content and pedagogy, followed by science teachers' TPACK development. This was followed by a discussion on measuring teachers' TPACK and a synopsis of the literature demonstrating TPACK development and the research gaps from 2005 to 2023.

Since all forms of teacher knowledge are situated and context-dependent, researchers have made it explicit how context is a crucial component of TPACK development (Kohler & Mishra, 2007; Mohebi, 2022; Warr & Mishra, 2023). Along the same line, Leahy and Mishra (2023) highlight TPACK as a fluid form of knowledge that takes on distinct characteristics depending on the specific context, varying from one school to another. Likewise, Cox and Graham (2009) note that the effect of various contexts is that the nature of TPACK is distinct, transitional, situated, eccentric, and dynamic and will differ for each teacher in each context. Therefore, it was crucial to cast this study within its research context: rural secondary schooling. Hence, the following two Sections, 2.2 and 2.3, concisely describe this study's context.

2.2 RURALITY AND THE RURAL CONTEXT

This section seeks to establish a perspective on 'rurality' as understood within the context of this study. The term 'rurality' poses a challenge in precise definition, as it is interpreted diversely by different scholars. Some scholars define ‘rurality’ through a location-based lens, considering aspects such as proximity to urban centres (Cloke, 2006; Krauss et al.,2016; Paradise et al., 2022). Conversely, other scholars base their definitions on demographic variables encompassing population size, household income, access to essential services like healthcare and education, and population growth rate (Bennett, 2018; Moseley, 2023; Shambare et al., 2022). This complexity in defining ‘rurality’ is echoed by leading rural education scholars such as Cloke (2006) and Nachtigal and Director (2019), who underline the contextual nature of this term and its subjective delineation. Evidently, the interpretation of ‘rurality’ is contingent upon the definer and the intended purpose of the definition. Thus, it is clear that regardless of the standpoint adopted, ‘rurality’ remains a multifaceted concept that demands appreciation from various standpoints. In alignment with this understanding, this study embraces a pragmatic approach to defining ‘rurality’, drawing upon UNESCO’s rural profile (2005, p. 36) as follows:

- Topography (bridges to school, conditions of roads);
- Availability of lifelong learning opportunities;
- Distance to towns;
- Access to social services;
- Transport infrastructure (taxis, roads, buses);
- Civil society and political organisations’ activities;
- Access to information technology;
- Communities’ economic, educational and health status; and
- Availability of facilities and services (electricity, sanitation, water).

From the above profile, White and Downey (2021) propose an insightful perspective, suggesting that while it might seem convenient to perceive ‘rurality’ as a passive and unchanging backdrop, in reality, it embodies an actively composed assemblage of resources, agencies, and dynamic forces. These elements play a pivotal role in shaping the social dynamics and actual experiences within which teaching and learning unfold. Hence, comprehending the dynamic nature of the rural context, encompassing its fundamental resources, agencies, and influential forces, becomes paramount to devising context-specific solutions for rural education. The ensuing section delves deeper into the specific context of teaching within rural secondary schools, aiming to illuminate this educational context's intricacies and distinctive features.

2.3 THE RURAL SECONDARY TEACHING CONTEXT

As a microcosm of its community, a school mirrors the intricate interplay of prevailing political, social, and economic dynamics, rendering it inseparably intertwined with the community it serves. Drawing from this perspective, the present study underscores the critical importance of comprehending the contextual nuances inherent in rural secondary schools. Consequently, this section provides a comprehensive description of the research context, shedding light on the myriad factors influencing science teaching within these settings. At the heart of this research is the foundational belief that the environments in which learners are taught significantly influence the quality of teaching and learning, a premise supported by scholars such as Gray et al. (2016) and White and Downey (2021). Notably, the rural context has a well-documented history of negatively affecting rural education. A widely accepted consensus exists regarding the correlation between poverty and the efficacy of teaching and learning in rural schools (Hlalele, 2014; Nepembe & Simuja,2023). For instance, Hlalele and Mosia (2020) conducted a study that explored the influence of teachers' sense of community on the sustainability of rural learning environments in the Free State province of South Africa. Their findings suggest a direct relationship: as the socio-economic status of learners' families and schools diminishes, the likelihood of achieving desired learning outcomes diminishes in tandem. This correlation implies that the level of resources available for science teaching in impoverished rural schools directly affects the potential for meaningful science education, creating a significant hurdle to effective learning in these contexts.

Despite extensive efforts to enhance rural teaching conditions in several countries, including South Africa, many rural educational settings grapple with pervasive poverty and social deprivation. These circumstances often manifest as challenges stemming from low socio-economic status, inadequate school infrastructure and resources, and critical shortages of teachers, notably in subjects such as the sciences (White & Downey, 2021). For instance, in the rural Tabora region of Tanzania, Assey and Babyegeya (2022) conducted a study to investigate the influence of various rural factors on the educational quality provided by rural schools. The research assumption was that poverty at the community and family levels could significantly impair the quality of teaching and learning. The researchers assert that rural poverty-linked factors and education share a deeply intertwined relationship in various ways. They explain that "the interaction among a set of poverty-related and education-related variables is capable of generating a vicious cycle of education deprivation and poverty and also a vicious cycle of positive interaction between education and income" (Assey & Babyegeya, 2022, p.89).

While teachers in rural secondary schools equip learners with valuable linguistic and cultural resources through their educational experiences, it is imperative not to underestimate the profound importance of the experiences that learners bring from their daily lives at home and within their communities. If learners' lives are marked by enduring material and social impoverishment outside the school environment, establishing a symbiotic relationship between their home experiences and school teachings becomes unfeasible. With an in-depth exploration of the literature surrounding the rural teaching context, several notable challenges emerge, as discussed below.

First, rural areas often grapple with poverty, limited livelihood opportunities, and deficient human resources, leading to a notable deficit in quality school teaching and learning (Cloke, 2006; Mbonambi et al., 2023; Rupavath, 2022). Gray et al. (2016) highlight a significant challenge for effective rural teaching – most governments' limited awareness of rural school conditions and dynamics. This lack of understanding contributes to a scarcity of insight into the nature of rural teaching (Dar, 2021). Furthermore, rural communities frequently face economic, social, and political exclusion, marginalising rural secondary school teachers. Consequently, they are omitted from the national education discourse (Du Plessis & Mestry, 2019). As a result, the needs of rural secondary school teachers often go unaddressed, particularly in curriculum practices and policy provisions, as the prevailing focus tends to mirror the urban teaching context. Therefore, in this investigation aimed at comprehending the development of Life Sciences teachers' TPACK in rural secondary schools, it was crucial to consider the contextual factors influencing the development of teachers' TPACK.

Some studies indicate a dearth of understanding regarding how rural communities perceive their schools and what constitutes effective rural teaching and learning (Assey & Babyegeya, 2022; Du Plessis & Mestry, 2019; Hlalele, 2014). For instance, Gray et al. (2016) propose that rural residents, including teachers and learners, value high-quality rural teaching to enhance rural education. Nevertheless, there seems to be a disconnect between the needs of rural communities and the expectations related to teaching and learning. This disconnect arises from education systems' failure to acknowledge the ways of life, context, and values held dear by rural communities (Cloke, 2006). For instance, Nemes and Tomay (2022) categorise rural values into community, cultural, and ecological.

To Nemes and Tomay (2022), ecological values encompass elements such as open spaces, cultural and natural landscapes, a pristine environment, and opportunities for food production. On the other hand, Cultural values in rural areas centre around traditional beliefs, customs, rural culture, artistic expressions, and folklore. In contrast, community values revolve around social networks, unique communication methods, mutual trust, kinship ties, and understanding within the community (Nemes & Tomay, 2022). However, these intrinsic values often receive minimal attention in curriculum policies, resulting in the predominance of foreign values being taught in rural school settings. Furthermore, rural individuals, including science teachers and learners, form a solid connection to their surroundings (Pedersen, 2018). Consequently, the notion of 'place' becomes crucial in rural teaching and learning. The sense of attachment to nature significantly influences the connection to a place in rural areas, shaping the relationships with and meanings of the land, the significance it holds, and the rootedness within family dynamics (Little & Derr, 2020; Pedersen, 2018).

Following the above, Pedersen (2018) argues that places in rural communities are pedagogical because their contexts shape the nature and effectiveness of teaching and learning experiences. Consequently, a commonly shared aspiration among rural inhabitants is to continue living in their rural birthplaces, where they can maintain close ties with their families. In rural settings, these families often constitute a lasting extended network of relatives (Little & Derr, 2020, p.34). Despite the profound meanings attached to 'place' by rural communities, the value of 'place' and context has predominantly been overlooked within the educational agenda. This oversight is mirrored in educational research, where a substantial portion of studies on rural education fails to account for the specific importance of 'place' (context) in the rural areas where education takes place (Hlalele, 2014; Nachtigal & Director, 2019). For instance, as briefly discussed in the significance of this study (see Section 1.5), there exists a paucity of research on TPACK in rural secondary schools. This gap persists despite Rupavath's (2022, p.67) observation that there is a compelling aspect to the connection of rural people to their 'place,' enabling them to transcend the challenges posed by limited infrastructure and scarce resources. These could potentially represent areas deserving greater scrutiny within the realm of rural education. Moreover, rural populations and their contexts are frequently subjected to notions of inferiority, thereby diminishing their influence and significance. This, in turn, significantly impacts how rural parents perceive education, often contributing to diminished parental involvement in rural areas.

Third, it is crucial to note that populations in rural areas are geographically dispersed, forming the backdrop against which this study was undertaken. In rural contexts, secondary schools are notably distant from learners' homes (Du Plessis & Mestry, 2019; Nouah et al., 2023). This geographic dispersion results in lengthy distances to schools, compounded by substandard road conditions and limited learner transportation, which result in rural learners often having to trek long distances. Moreover, this spatial arrangement renders attendance on rainy days impossible due to the inaccessibility of roads. Moreover, most areas in rural settings lack fundamental services such as running water, healthcare, sanitation, electricity, and educational resources. Collectively, these deficiencies can substantially impede rural learners' access to quality science education.

Fourth, the challenges associated with rurality often find expression in rural schools, where inadequate infrastructure and insufficient resources are pervasive (Nouah et al., 2023). This inadequacy in rural school infrastructure, which frequently goes overlooked, is a significant impediment to providing quality science education in rural areas (Du Plessis & Mestry, 2019). For instance, rural schools often grapple with inadequately sized classrooms, damaged windows, deteriorating structures, limited or absent sanitation facilities, and unreliable access to electricity. Moreover, schools in rural areas contend with meagre resources, including limited availability of books, libraries, educational technologies, and science laboratories (Department of Education, 2019). Considering these circumstances, White and Downey (2021) caution that a profound connection exists between the physical infrastructure of schools and the quality of teaching and learning. These experiences suggest that the school's physical infrastructure exerts a pivotal influence on the quality of science education (Hlalele, 2014; Nouah et al., 2023; Nachtigal & Director, 2019). Consequently, well-resourced rural schools appear more adept at surmounting the myriad challenges associated with rurality, while inadequately resourced schools often struggle to do so, thereby diminishing the quality of science teaching and learning.

Fifth, rural secondary schools continuously face worrying high teacher turnover. Most rural secondary schools fail to recruit and retain highly qualified science teachers with proper teacher training, credentials, and experience (Gray et al., 2016; Hlalele & Mosia, 2020; Nemes &

Tomay, 2022). Furthermore, once recruited into rural schools, science teachers often find themselves required to be proficient in multiple subject areas, engage in multi-grade teaching, and work amidst demanding teacher-to-learner ratios (Hlalele, 2014; Jakachira, 2020; Kokela & Malatji, 2023). Consequently, the prospect of working in rural schools with limited cultural and social amenities dissuades many secondary school science teachers. Even those initially interested in working in rural settings may find the working conditions prohibitive for prolonged tenures (Opoku et al., 2022). Therefore, competent secondary school science teachers frequently transfer to urban schools, leaving behind predominantly underqualified and unqualified teachers in rural schools. For instance, a substantial body of research examining teacher demographics underscores that many teachers in rural secondary schools lack the qualifications and expertise needed for the subjects they are tasked to teach (Gray et al., 2016; Watson, 2023). This shortage of qualified science teachers emerges as one of the most critical factors contributing to subpar rural teaching, particularly in science education.

Sixth, another significant challenge in the rural secondary schooling context is the substantial out-migration of rural youth to urban areas. This exodus has led to entire generations of youth being absent from some rural communities. More so, the departing youth often constitute the more educated and resourceful members of the rural population, leaving behind predominantly elderly residents (Muktiar & Sharma, 2019). To exacerbate the situation, many presumed economically active adults in rural areas remain unemployed, resulting in a low economic status (Bouchard & Wike, 2022). This has also contributed to high levels of adult illiteracy in rural communities, further diminishing parental involvement in their children's education. Additionally, most rural secondary school teachers serve numerous single-parent households, where the family head often, often a child, possesses limited education (Assey & Babyegeya, 2022; Hlalele & Mosia, 2020; Pedersen, 2018). Collectively, these factors have contributed to the absence of parental involvement in rural secondary schools.

The preceding review underscores that rural secondary teaching contexts are complex and typified by deprivation, low socio-economic status, and poverty, which negatively affect the quality of rural teaching, particularly science teaching. This contextual backdrop mirrors the conditions prevalent in the Joe Gqabi district, where the current study was undertaken. The Joe Gqabi District predominantly encompasses rural areas, notably Mount Fletcher (renamed Tlokoeng in March 2022) within the Elundini Local Municipality, serving as the location for all research sites. Most learners in this district hail from rural households heavily reliant on subsistence farming and government social grants as their primary sources of income. Compounded by a scarcity of resources, most schools in the Joe Gqabi district have been designated with a quintile one ranking, aligning with their rural setting and the consequential lack of resources. In South Africa, a quintile one ranking denotes a school catering to children from the lowest 20% of households in terms of income or expenditure (DBE, 2013). Typically, these households are in rural and remote areas and confront a heightened risk of poverty. Consequently, schools designated as quintile one are entitled to receive free or subsidised educational services. As White and Downey (2021) posited, the extent of rurality and remoteness typically correlates with a decline in the standard of education. For instance, the latest 2022 census data reveals that only 16.4% of Mount Fletcher residents passed matric, with a mere 4.9% possessing a higher education qualification (Statistics South Africa, 2023). This stark reality underscores elevated levels of illiteracy among the adult population in the area, contributing significantly to diminished parental engagement in their children's educational pursuits.

Further, consistent with Du Plessis and Mestry's (2019) observation in their exploration of teachers' perceptions and experiences of rural teaching in White River in the Mpumalanga province, most schools in the Joe Gqabi district have insufficient classrooms, dilapidated buildings, and lack resources such as science and technology facilities. For example, the following images capture the scarcity of resources in the current study's schools, which are the research sites. Figure 1 depicts the researcher standing in a rundown science laboratory repurposed into a storage area. The illustration further highlights cupboards, initially intended to house scientific apparatus, which now serve as repositories for obsolete examination question papers.

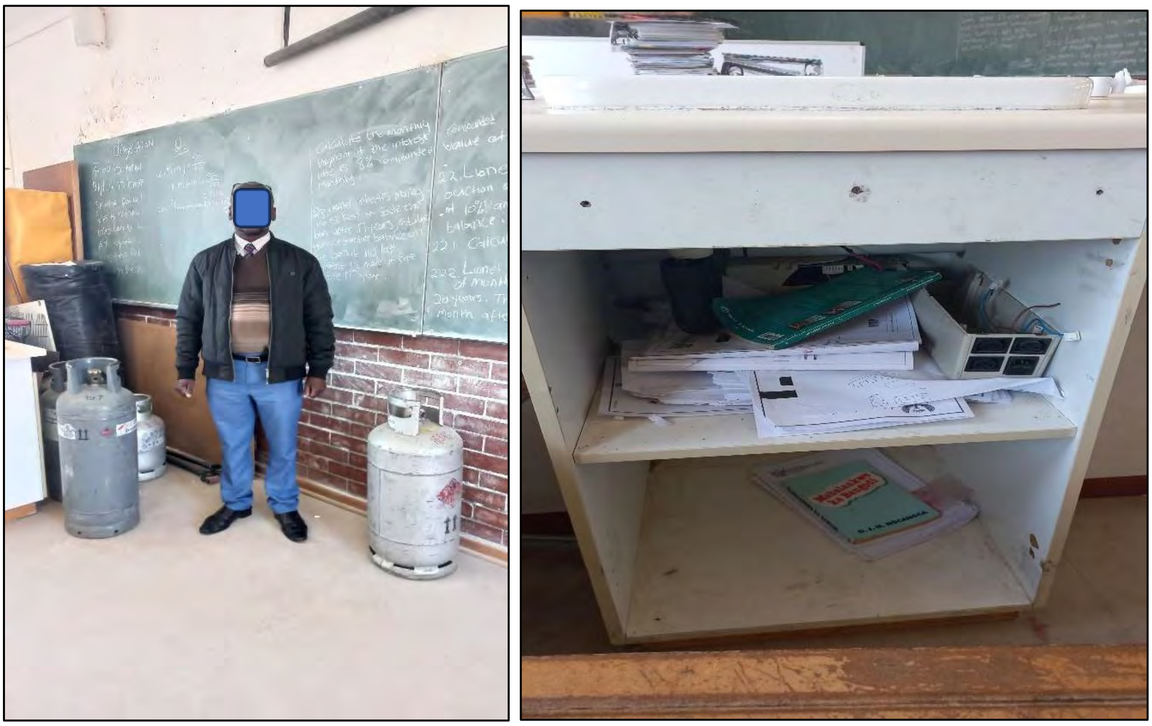


Figure 1: Researcher in one of the school science laboratories

Figure 2: Example of poorly resourced laboratories in rural schools

Parallel to Figure 1, Figure 2 is a visual representation showcasing the inadequate availability of suitable science facilities or under-resourced laboratories within the selected research sites and across most rural secondary schools. This scarcity of proper science resources can significantly impact learners' quality of science learning experiences, potentially hindering their engagement and understanding of scientific concepts. To tackle the challenges stemming from resource deficiencies, the Eastern Cape Department of Education (ECDoE) and various NGOs supplied educational technologies to all schools in the Joe Gqabi district, aligning with the approach implemented across schools in the Eastern Cape province. This initiative aimed to enrich the landscape of education. Having delved into the rural context, it is equally imperative to illuminate the nature of science education within the secondary schooling framework. This rationale is particularly pertinent as this study focuses on science education. Consequently, the subsequent section delves into the intricate nature of science education itself.

2.4 THE NATURE OF SCIENCE EDUCATION IN SECONDARY SCHOOLS

This section provides a synopsis of the nature of science in the secondary schooling context. Again, it must be noted that defining science and what constitutes the nature of science in secondary schools is a complex undertaking due to the plethora of science definitions found in the literature. Nonetheless, despite the diverse array of science definitions, they share fundamental characteristics that are aptly encapsulated in Hodson's definition (2014, p. 26):

> Science is a body of knowledge that represents the current understanding of natural systems and the process whereby that body of knowledge has been established and continually extended, refined, and revised. Both elements are essential: one cannot make progress in science without understanding both. Likewise, in learning science, one must understand the body of knowledge and the process by which this knowledge is established, extended, refined, and revised.

The above definition indicates that science is both a form of knowledge and the method through which that knowledge is created. Zimmerman (2023) further identifies science as comprising two categories: domain-general knowledge and domain-specific. Domain-general knowledge describes the scientific method involving deductive reasoning, problem-solving techniques, and methods for synchronising theory and data (Passarelli & Kolb, 2023). These investigative methods and techniques, forming the basis of science, include observing, asking questions, comparing measurements, making predictions, and recording and analysing findings (Hodson, 2014; Holbrook et al., 2022; Zimmerman, 2023). Indeed, secondary school learners are frequently characterised as having many of these methods and techniques due to their natural curiosity and love of discovery. Rob and Rob (2018) claim that these innate tendencies show that learners are prepared to participate in science learning. Domain-specific knowledge, on the other hand, refers to the learners' understanding of scientific concepts in various study fields. By definition, scientific principles refer to "those thoughts or general notions of the common qualities of objects or events that assist us to understand the natural world around us" (Schauble et al., 1995, p.49). This definition encapsulates the essence of scientific principles, emphasising their role in enabling learners' comprehension of the intricacies of the natural world.

Further, it is commonly known that science is constructed to include both domain-specific and domain-general information. Therefore, Life Sciences teachers in rural secondary schools must acquire these two types of science knowledge to teach effectively. Hodson's (2014, p.26) definition of science makes the crucial distinction that teaching science requires the harmonious interaction of both domain-specific and domain-general knowledge. Furthermore, Kolb and Kolb (2018, p.28) refer to the epistemology of science as "a means of knowing, or the values and the beliefs present in the nature of the evolution of scientific knowledge." Kolb and Kolb (2018, p.28), thus, argue that at the secondary schooling level, the nature of science should be thought of as recognising the abstract nature of this reasoning, and they advise that science should be viewed as:

> [T]entative (subject to change); empirically based (based on and derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination, and creativity (involves the invention of explanation); and socially and culturally embedded.

The teacher must consider how to incorporate science learning in the classroom. According to Silberman (2007, p.18), secondary school learners' science learning experiences should be guided by a "major science idea" or "key notions", such as energy transformation. The learner's discovery of significant scientific ideas will create the groundwork for future science education in secondary schools (Maknun, 2023; Silberman, 2007). However, the process of developing scientific conceptual knowledge involves more than just one phase. Vygotsky (1978) asserts that explaining scientific ideas to learners does not guarantee their ready assimilation. Thus, according to Kolb and Kolb (2018), scientific concepts are not taught in isolation; they serve as the foundation for scientific inquiry and use the numerous techniques and approaches found in domain-general knowledge. While it is highly enticing to suggest that science teachers base their learning activities on a key scientific idea, research indicates that doing so may provide difficulties given that there is worry about the lack of science content expertise among many science teachers (Holbrook & Rannikmae, 2007; Rahman, 2019; Schunk & Zimmerman, 2023). These insights underscore the need to balance the pedagogical aspirations with the practical realities of teachers' subject content proficiency.

Furthermore, just conducting a scientific inquiry does not guarantee that a learner will comprehend the scientific idea being researched. According to Maknun (2023), learners acquire working hypotheses, which change due to teaching or experience. At the same time, it may seem like the ideal circumstance to give learners a space to experience a range of scientific events; such exposure without guidance or teaching might be troublesome. Learners build notions based on their experiences but may also develop misconceptions if they do not receive the proper teaching (Djelil & Sanchez, 2023). Though they might appear relatively harmless, Firdaus and Robandi (2022) contend that misconceptions could represent a barrier to understanding and learning science if they persist.

Similarly, Holbrook et al. (2022) contend that learners' misconceptions about the nature of science could reflect their evolving understanding, which serves as the foundation for subsequent lessons. Although it is crucial to help learners create their functioning scientific beliefs, this method depends on the teacher's sound pedagogical content knowledge to support their knowledge acquisition. The fact that many teachers lack science understanding and, as a result, lack the confidence to teach it may make this complex (Constantinou et al., 2018; Dabbagh & Castaneda, 2020; Leonard & Leonard, 2003). Therefore, there is a need for secondary school science education to provide meaningful learning opportunities. Vygotsky (1978) highlights the importance of aligning learners' conceptual science development with their daily experiences. Designing activities that build on learners' existing knowledge can facilitate a developmental approach to teaching science.

Therefore, since science education demands conceptual and domain-general knowledge, teachers must adeptly craft learning opportunities encompassing both realms. Constantinou et al. (2018) stress the importance of learners engaging in scientific enquiry, which is essential for practising science. Likewise, Dabbagh and Castaneda (2020) note that engaging in scientific research directly connects learners with the natural and artificial world, enriching their understanding. In summary, this section rationalises the nature of science education in secondary schools by emphasising the need to address learners' evolving understanding of scientific concepts, bridging their daily experiences with scientific development, and the essential balance between conceptual and domain-general knowledge in teaching science. The following section justifies the need for science education in secondary schools.

2.5 JUSTIFICATION FOR SCIENCE EDUCATION IN SECONDARY SCHOOLS

This section outlines the objectives of science teaching-learning and underlines the value of scientific literacy. Over the past decades, science teachers and researchers have offered divergent viewpoints on the intent and objectives of secondary school science education

(Herron, 1971; Hodson, 2014; Schauble et al., 1995). Their opinions on the objectives of science education include the following:

- Fostering learners' creativity;
- Enhancing citizens' technological and scientific literacy;
- Enabling citizens to contribute to their society actively; and
- Cultivating learners' scientific thinking.

To Hill and Uribe-Florez (2020), the primary goal of science education is to offer learners a solid grasp of the nature of science. This allows learners to develop more profound insights into the world by studying science as a 'way of doing' and a 'way of knowing.' Hence, scientific knowledge becomes the basis for making crucial decisions about problems and issues that affect people's daily lives and for creating informed citizens who can take the initiative to solve any problems or issues (Firdaus & Robandi, 2022). The importance of science in secondary school education has been highlighted by the mounting evidence of learners' ability to learn the subject (Darmawansah, 2023; Hodson, 2014; Holbrook et al., 2022). Secondary school learners are often characterised as persistent and inquisitive world explorers. Nelson et al. (2019) assert that secondary school learners learn and think like scientists through daily experiences as they observe, develop hypotheses, experiment, and review. Exposing secondary school learners to science education at this formative stage in their cognitive development, aspirations, and inquiries is not just for those with an affinity for science. It is for all learners, including those in rural secondary schools, to assist them in becoming scientifically literate.

Regarding scientific literacy, McCrory (2014, p.7) defines it as "the citizens' ability to engage with science-related issues and with science ideas reflectively." It is founded on the idea that citizens will be more capable of making choices that will improve their lives if they have a fundamental knowledge of science and its place in the world. In addition to scientific knowledge and what scientists do, essential elements of scientific literacy include understanding the nature of science (McCrory & Reiss, 2023). The secondary schooling period offers an exceptional opportunity to acquire scientific skills and abilities. Science education in this period allows learners to foster their natural curiosity about how the world works through social interactions and teamwork in experience-rich contexts (Major & McDonald, 2021). With these opportunities, one might expect science education to flourish in secondary schools, even in rural settings. However, considering the challenges associated with rural teaching, this outcome is not entirely predictable, as discussed in Section 2.3.

Based on these factors, an increasing emphasis is placed on recognising the pivotal role of science education in preparing learners for future citizenship, as highlighted in studies by Hodson (2014) and Maknun (2023). This emphasis is coupled with a call for a more contextualised approach to science education tailored to meet the specific needs and realities of the learners. Central to this adaptation is considering learners' prior knowledge and individual contributions to the teaching-learning environment, as underscored in the research by Constantinou et al. (2018). Traditionally, a prevailing notion existed that learners did not bring substantial knowledge into the classroom, often resulting in teacher-dominated teaching methods (Schunk & Zimmerman, 2023). However, in the last three decades, there has been a growing awareness among science education researchers and teachers regarding the necessity of placing the learner at the core of all teaching-learning activities. This shift in perspective has driven the development of various science teaching approaches that actively involve learners in their science education.

Essentially, one of the most popular approaches to modern science teaching stems from the theories of constructivism (Passarelli & Kolb, 2023), which focus on the individual learner, their learning activities, and their processes of knowledge construction. According to constructivism, learning is an active process through which the learners' experiences and interactions with their environment allow them to build knowledge (Rob & Rob, 2018). Constructivism further claims that learning becomes most meaningful when the tasks and contexts are authentic and hold meaning for learners (Dabbagh & Castaneda, 2020). From a constructivist perspective, learners' experiences represent spaces where many ideas and identities can converge, encouraging them to contribute to the content and shape their contexts.

Therefore, researchers in science education seem to have a consensus that effective science teaching ought to be mediated within appropriate contexts that encourage new knowledge construction (Hodson, 2014; Holbrook et al., 2022). There is strong evidence that contextualising science teaching-learning can help to enhance learners' science attitudes, process skills, decision-making, and creativity (Holbrook & Rannikmae, 2007; Rahman, 2019; Reyes, 2013). Therefore, context-based education is entrenched in traditions that assume that context is crucial for successful teaching and learning. This understanding implies that in science teaching approaches, the learners should find solutions to real-life problems by possessing the abilities to make observations, pose questions, plan and conduct experiments, and collect, analyse and interpret data to construct meanings (Hodson, 2014; Maknun, 2023; Schauble et al., 1995). Along that line, it has been suggested that teaching science in the real world and authentic context is vital to provide learners with what Kolb (1984) calls science experiential learning. According to Kolb (1984, p.38), experiential learning is "the process whereby knowledge is created through the transformation of experiences." Although experiential learning focuses on the teaching-learning process and not the learning results, learners and teachers can realise improved learning results due to teaching approaches supporting scientific knowledge development through deeper science learning. Moreover, Kolb's (1984, p.21) science learning model asserts that experiential learning "is a holistic, integrative perspective on learning that combines experience, perception, cognition, and behaviour." According to the experiential learning notion, learning is mediated using learners' understandings of the world around them, focusing on the teaching-learning process and not the learning outcomes. In Kolb's (1984) experiential learning model, science learning takes place in four stages: "(a) a concrete experience; (b) reflective observation; (c) abstract conceptualisation; and (d) active experimentation" (Kolb & Kolb, 2018, p.28) as shown in Figure 3 below.

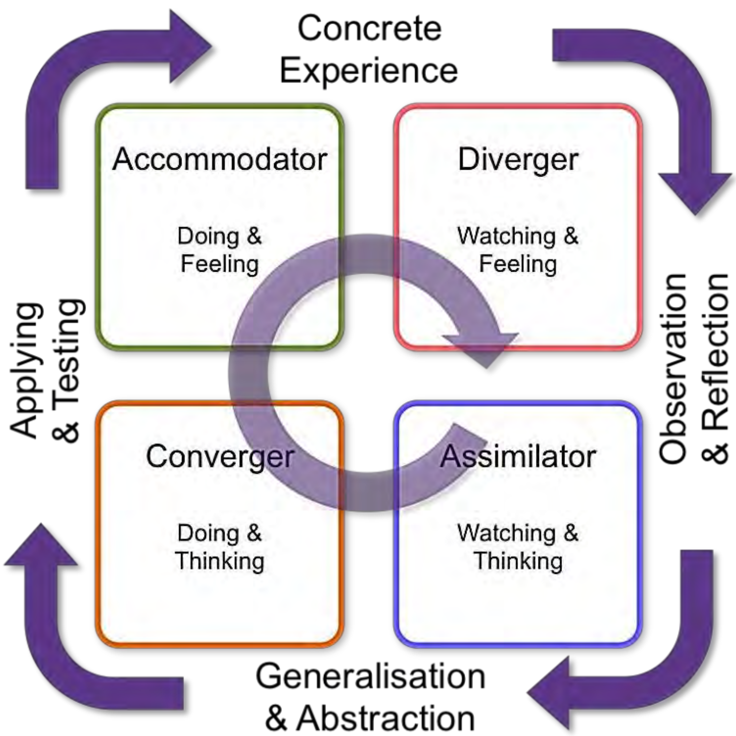


Figure 3. Kolb's four-step principle [Adapted from Kolb (1984, p.28)]

First, the learners should have a concrete experience that triggers the learning process. Second, the learners proceed to observe what they are experiencing or seeing reflectively. Third, the learners use their reflections to conceptualise abstract concepts regarding the observed phenomenon. Fourth, the learners should develop an experiment to test their observations and findings. This experimentation may give rise to a new experience that repeatedly starts the learning cycle.

When applying Kolb's (1984) four-step principle to classroom pedagogy, Life Sciences teachers must integrate reflection as a critical aspect of their experiential instruction. During this process, the teachers become facilitators of learning instead of sources of information and knowledge. On the other hand, Silberman (2007, p.12) views experiential learning as "(i) involving learners in concrete activities that enable them to 'experience' what they are learning about and (ii) the opportunity to reflect on those activities." While active involvement in science is crucial, Silberman (2007) emphasises the need to reflect on the activities to determine if learners are learning. The reflection process would then facilitate learners' integration of the learned knowledge into their prior knowledge. Considering the above discussions, overwhelming evidence from the literature supports science teaching. However, most secondary schools in the rural Eastern Cape province of South Africa do not have such requisite facilities to advance science teaching. In such cases, contemporary educationists see technology as a solution to the lack of resources. The following section discusses technology integration in pedagogy and content.

2.6 TECHNOLOGY INTEGRATION IN PEDAGOGY AND CONTENT

Technology integration in teaching remains an ever-evolving process, with the methods employed by teachers varying as widely as the types of available technologies. This diversity has rendered the definition of technology integration complex and elusive, as it is also contingent on teachers' individual conceptions of how technology should be incorporated. To begin defining technology integration, the researcher is cognisant that an agreed-upon definition is still to emerge (Cox & Graham, 2009; Ertmer, 1999; Setiawan et al., 2019). For example, Ertmer et al. (2000, p.98) define technology integration as "the philosophy and practice of using varied technologies to support active, engaged learning." Meanwhile, Firdaus and Robandi (2022, p.4) view technology integration as "implementing different forms of technology into classroom instruction to enhance teacher instruction and learner learning."

According to Falloon (2020, p.83), technology integration "is the process of intentionally choosing technology tools that enhance specific teaching strategies during the teaching and learning process." From the above definitions, scholars in the educational technologies discipline agree that meaningful technology integration "should be rooted primarily in curriculum content-related learning process, and secondarily in savvy use of educational technologies" (Shah, 2022, p.21). This study adopts Falloon's (2020) definition of technology integration because it underscores a pedagogical intention to use certain technologies for specific content.

Regarding technology integration in pedagogy and content, Pedró (2009, p.66) adds that "successful technology integration should also include theories about technology integration and the application of research findings to promote the teaching-learning process." This definition suggests that teachers must have some pedagogical intention to augment the learning experience using a technological tool. Niess and Gillow-Wiles (2017) provide evidence for this claim by defining the pedagogical intention as the methods for choosing appropriate technology tools, the ability to show how those technology tools will be utilised, the ability to assess those technologies, and the ability to tailor the application of those technologies in ways that tackle teaching issues. In addition, Berger and Wolling (2019) indicate that teachers' only use of applications, such as YouTube, to obtain videos epitomises a low level of technological integration. On the other hand, creating multi-media exhibitions comprising simulations and animations exemplifies a higher level of integration.

Further, teachers investigating questions such as "How can one take what they already have and enhance it through technology?" demonstrate the knowledge type that might promote technology integration to a higher degree (Berger & Wolling, 2019, p.15). This view is consistent with Koehler and Mishra (2007, p.58), who states that:

> [T]echnology integration approaches that do not reflect disciplinary knowledge differences, the corresponding processes for developing such knowledge, and the critical role of context ultimately are of limited utility and significance, as they ignore the full complexity of the dynamic realities of teaching effectively with technology.

However, technology integration discourse reveals a spectrum of perspectives among teachers. Technology integration implies leveraging cutting-edge tools like laptops, wearable devices, and tablets for some. Others interpret it as an initiative focused on providing widespread access to technology, such as seen in the Eastern Cape province, involving the planning and execution of lessons incorporating mobile educational apps or utilising online and offline teaching programs like Kahoo! Alternatively, for some, it involves the creation of videos or simulations to enhance the comprehension of scientific concepts or introducing learners to Virtual Labs for exploration and experimental work. However, some teachers still perceive technology integration in the context of more traditional tools such as overhead projectors, chalkboards, or textbooks.

Further, technology can offer learners opportunities to acquire and demonstrate creative competencies in an innovative structure that is otherwise unattainable in the traditional classroom environment (Falloon, 2020). Not only must the technology be used, but choices about integrating it into the learning environment must be deliberate and support learners by, for example, enhancing their comprehension of concepts. Teachers might also find technology appealing because it provides access to various alternative instruction options that expose them to how and what learners understand. While technology integration, as a phrase, is often used in educational settings, it is not clear that everyone means the same thing when they use that phrase, as seen in the above examples.

Existing definitions of technology integration are explored in this section and combined to form an accepted understanding of this research's underpinnings. Farjon et al. (2019, p.84), who consider technology integration from a business perspective, observe that "the lack of a precise definition of technology integration has caused the term to be inappropriately associated with the most basic and limited data meshing procedures." This concept has also been found to be true in many teaching and learning environments. Strong technology integration may rely on the teacher's perception of its practical use and the perceived understanding of what the learners may obtain from using technology. Therefore, as technology encompasses the tools used to deliver content more effectively, the definition of technology integration should be determined by how and why technology is used and not by how much or what kind of technology is utilised (Ahmadi & Reza, 2018; Warr & Mishra, 2023). Wong (2020, p.87) also emphasises this idea of intended use by stating, "It should be noted that technology, which is used to facilitate learning, is part of the teaching process and not an appendage to be attached at any convenient stage during instruction."

Building upon the preceding discussion, it becomes evident that technology integration extends far beyond the mere use of technological tools. Instead, it represents a purposeful element within the teaching process, involving thoughtful considerations of why and how technology is employed. This study defines technology as any digital device or any electronic tool, such as a laptop, tablet, or smartphone. Thus, merely introducing these digital devices into the classroom or establishing a computer lab enhances learners' access. However, proper technology integration necessitates a comprehensive approach encompassing electrical infrastructure and network capabilities, ensuring optimal functionality. Additionally, it involves equipping teachers with the requisite knowledge and skills to incorporate technology into their pedagogical practices effectively. Hence, merely providing digital devices to learners and teachers falls short without the necessary support to explore the full potential of these technologies and how their utilisation can enhance the teaching and learning processes. This is consistent with Okojie et al. (2006, p.65) that "effective integration of technology is achieved when learners can select technology tools to help them obtain information promptly, analyse and synthesise the information, and present it professionally." The researchers continue to point out that "the technology should become an integral part of how the classroom functions; as accessible as all other classroom tools" (Okojie et al., 2006, p.67). This improved definition now acknowledges the teacher's perceptions and the learners' role in assessing and using the technology. In support, Mishra and Koehler (2009, p.58) maintain that:

> [T]echnology integration approaches that do not reflect disciplinary knowledge differences, the corresponding processes for developing such knowledge, and the critical role of context ultimately are of limited utility and significance, as they ignore the full complexity of the dynamic realities of teaching effectively with technology.

The authors explain that technology integration into the teaching-learning environment can be seen through various lenses, and only through exploring each can one obtain a sense of what proper technology integration should look like. The definition of technology integration is complicated and hinges upon the teachers' perception of intended use. The teacher must consider the pedagogical potential of technology to enhance the lesson and learner understanding in obtaining the desired learning outcomes. Moreover, Leahy and Mishra (2023) urge teachers to go beyond utilising technology as "low-tech" presentation tools in the classroom. Several scholars have reported that simply introducing technologies in the teaching-learning spaces is insufficient to guarantee effective technology integration because technologies alone do not result in educational changes (Hanshaw et al., 2022; Jang & Tsai, 2013; Mishra & Koehler, 2007). Instead, educational changes depend on how teachers use technology (Koehler & Mishra, 2014). The pedagogical framework that supports this teaching approach entails pre-meditated and thoughtful considerations of which context-specific technology integrations are suitable and abolishes the idea of merely introducing technologies to the existing practices to report on technology use. Accordingly, Koehler and Mishra (2007, p.137) suggest that technology integration in teaching is a "knowledge system that comes with its own biases and affordances that make some technologies more applicable in some situations than others". Therefore, when technology classroom use is clearly thought after in line with curriculum designs, the separatist, "technocentric" approach to technologies as separate or add-on entities to teaching is avoided.

Lately, a pivotal impetus for integrating technology into teaching stems from the nature of today's learners (Creighton, 2018;Munyanyo & Simuja,2024). These contemporary learners have been immersed in technology since birth, incorporating it seamlessly into their daily lives and play tools. Prensky (2001, p.54), thus, referred to the modern learners as "the digital natives" since they were born during the digital era, which makes them 'inherent speakers' of the digital language. Oriji and Torunarigha (2020, p.4) went so far as to argue that "today's learners are no longer the same as the past generation that the educational system was designed to teach". In support, Jadhav and Takale (2020, p.1) maintain that "in the modern era, the use of chalk and duster is no longer enough" because most learners' learning needs require new teaching approaches to understand the topics better. This suggests that teachers are faced with a learner demographic entering formal education with considerably more advanced technological skill sets than their predecessors. Consequently, there is a growing advocacy among educationists to incorporate technology into the teaching methods tailored to these current learners' needs and proficiency levels.

Further, the literature suggests that technology has reshaped today's learners' mindsets about learning and accordingly altered their learning styles (Alhawsawi & Jawhar, 2021); their attitudes, aptitudes, expectations, and learning styles are consequently different from those of their predecessors (Sarıyalçınkaya et al., 2021;Simuja and Shikesho,2023). In this regard, Onyema and Daniil (2017, p.3) cautioned that "new learning styles will raise new pedagogic issues." Bearing this in mind, Pedró (2009), Creighton (2018), and Hanshaw et al. (2022) have suggested that integrating technology into teaching should be part of teachers' basic pedagogic practices to meet the learning styles of learners. Simultaneously, there is a surge in civic interest in technology integration in teaching due to most governments' enormous investments in school technologies. As Berger and Wolling (2019) argue, public interest in technology integration in teaching is justifiable because the people's taxes fund the budgets for educational technologies. Therefore, teachers are urged to integrate technology into teaching and transform their approaches since conventional methods are not appealing to technologically apt modern learners. However, fundamental questions have been posed on whether teachers possess the pertinent knowledge to integrate technologies into teaching. Hence, there is a need to shift the attention from simply focusing on technology integration in schools to understanding how teachers develop the 'specialised' TPACK needed to integrate technology into their practice effectively. Thus, the present study aimed to advance the TPACK development literature by providing insights into how this specialised, complex, and context-dependent knowledge develops among science teachers in rural schools. The following section discusses technology integration with a particular focus on science education.

2.7 EDUCATIONAL TECHNOLOGIES IN SCIENCE EDUCATION

Although educational technologies intersect with various academic disciplines, they are privileged and prominent in science education. Corroborating this assertion, McCrory's (2014, p.243) investigation of effective technology uses in science classrooms through the TPACK lens suggests that "science classrooms are a natural place for technology use since so much of science today depends on technology." Consequently, numerous scholars in the field of science education advocate for integrating educational technologies into science classrooms (Afgan, 2015; Nelson et al., 2019; Putri et al., 2022). This approach offers authentic learning experiences that resonate with contemporary issues, real-world scenarios, and challenges, fostering profound, meaningful, and active learning for mastering fundamental science skills and concepts. In this light, educational technologies in science education should be perceived as supplementary teaching tools that enhance the science teaching-learning process by providing experiential learning opportunities rather than being the primary focus themselves.

In recent times, there has been a notable upsurge in the inclination of science teachers towards integrating technology in teaching and learning. For instance, a study conducted by Vermette and Hzechter (2014) in Manitoba, Canada, which involved 433 science teachers in Manitoba, utilised the TPACK framework to examine technology integration practices. Their findings identified the following as the most prevalent reasons for science teachers' integration of technology:

> Promoting learner engagement (66%), teaching 21st-century skills as a way of the future (46%), using technology as best teaching practice (43%), and to stay current (36%) for hands-on interactive learning (30%), to vary teaching methods (29%), and to perform labs and demonstrations (19%) (Vermette & Hzechter, 2014, p.38).

Despite the vast array of educational technologies available to science teachers, there exists a tendency to gravitate towards certain technologies over others. Notably, PowerPoints are heavily utilised due to their visual appeal, capacity to capture learner attention, time-saving attributes, and ease of preparation and application, as documented in studies by Kriek and Stols (2010) and Vermette and Hechter (2014). However, contrasting findings emerge concerning adopting SMART Boards and interactive whiteboards in science education. While Vermette and Hechter (2014) note the widespread use of these technologies among science teachers, a study by Larijani and Abedi (2021) reveals that only a small fraction of teachers incorporate these tools into their teaching practices. Furthermore, the integration of videos was observed to be moderately common (Kriek & Stols, 2010;Conger et al.,2017), with occasional use of animations noted in studies by Olympiou and Zacharia (2014) and Olivier and Kruger (2022). These findings collectively portray a diverse landscape of technology integration in science education, as discerned through the lens of these researchers' investigations.

In addition, science teachers hardly or seldom use simulations (Chernikova et al., 2020; Jang, 2010; Vermette & Hechter, 2014). Further, Khashan's (2019) study aimed to investigate how secondary school teachers in Mississippi in the USA integrate technology in their classrooms. His findings reveal that microscopes, mobile phones, probe ware, and iPods were the least used in science classrooms. Furthermore, the literature review showed that articles on science and technology use did not contain modern technologies. Hence, the scope of the synthesis broadened to educational technology journals to unearth current science and educational technology trends that were absent in the technology use articles. Recent developments in science education technologies integration comprise augmented reality (AR) (Jaradat, 2020; Ramnarain & Penn, 2021), virtual reality (VR) (Oser & Fraser, 2015; Ramnarain & Penn, 2021; Rojas-Sánchez et al., 2023), robotics (Brady, 1984; Darmawansah et al., 2023; Vrontis et al., 2022), game-based science curriculum (Djelil & Sanchez, 2023; Hall et al., 2022; Squire, 2003), coding (Armoni et al., 2016; Greenberg et al., 2012; Jiang et al., 2023), artificial intelligence (AI) (Ashok et al., 2022; Holmes et al., 2023; Winston, 1992). Among these educational technologies, AR, VR, and AI are regarded as cutting-edge prototypes of simulations. Because this study's focus is TPACK, it is crucial to trace the genesis of this teacher's knowledge. Hence, the following section explores the origins of TPACK, that is, pedagogical content knowledge (PCK).

2.8 ORIGINS OF TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

The roots of TPACK can be traced back to Shulman's (1986) work on teacher knowledge. Formerly, the perception was that two distinct types of knowledge were essential for teacher proficiency: pedagogical knowledge and content knowledge (Shulman, 1986). Shulman (1987) then contended that possessing subject content knowledge and overall pedagogical methods, while indispensable, was not adequate to epitomise competent teacher knowledge. To capture the nuanced ways in which teachers contemplate how specific content ought to be presented, Shulman (1987) then argued for pedagogical content knowledge (PCK). Pedagogical content knowledge represents the combination of content and pedagogy into a conception of how certain aspects of content are arranged, modified, and presented through approaches that make it understandable to learners (Shulman, 1986; Shulman, 2015). The following sub-section delves deeper into pedagogical content knowledge.

2.8.1 Pedagogical Content Knowledge

Previously, teacher knowledge was understood as the content teachers needed to know and teach. This understanding was then challenged by a surge in academic scrutiny of the multifaceted nature of teacher knowledge (Niess & Gillow-Wiles, 2017). It was in this evolving landscape that Shulman (1986, 1987) brought forth the concept of pedagogical content knowledge (PCK). Shulman's (1986, 1987, 2015) framework for PCK is rooted in comprehending the prior misconceptions and understandings that learners bring to the subject matter and recognising the impediments and challenges to effective learning. To Shulman (1987), PCK encompasses seven key categories: pedagogy, content knowledge, learner traits, educational purpose, curriculum knowledge, educational contexts, and the knowledge of pedagogy and content. These categories can be summarised into two main components of PCK: "knowledge of contextual representations of content and learning difficulties with the content" (see Figure 4).

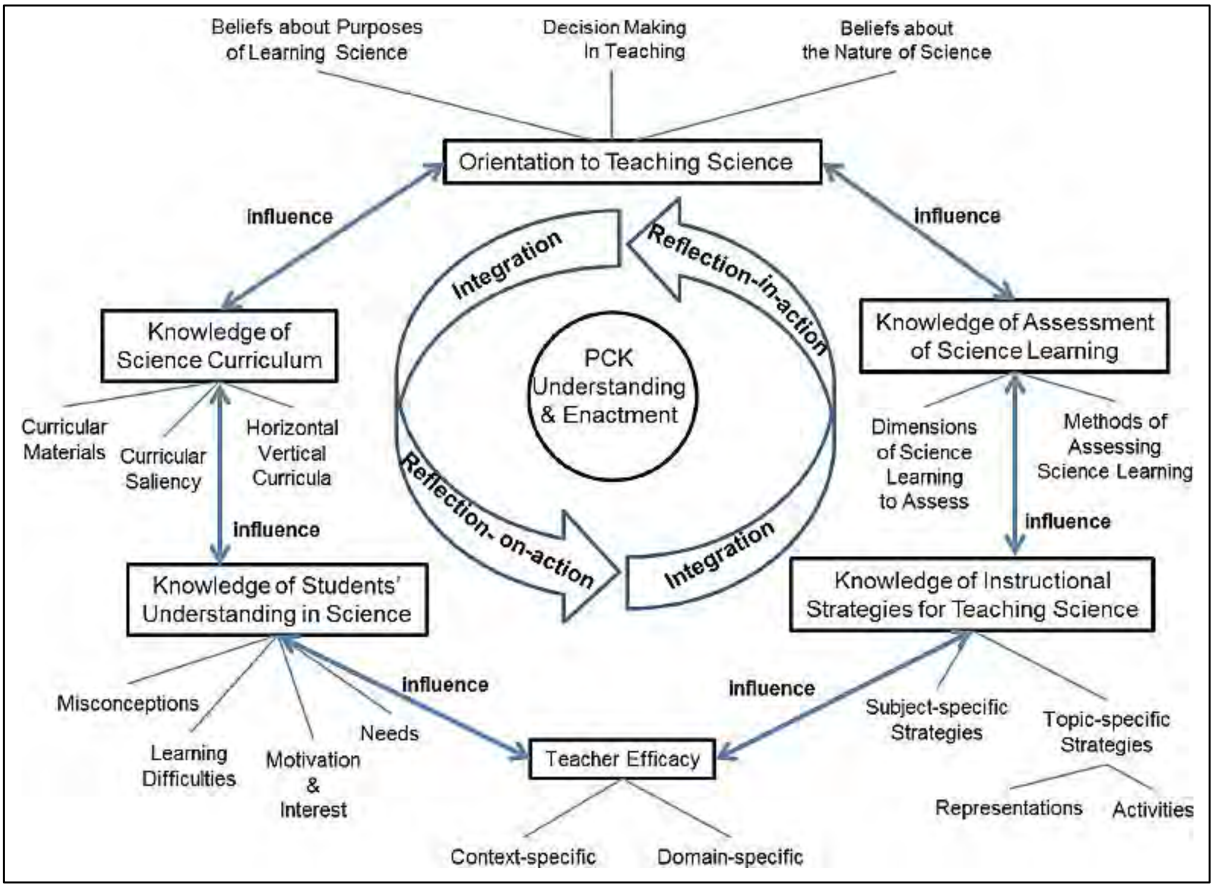


Figure 4: Hexagonal model of pedagogical content knowledge for science teaching. From: Park & Oliver, 2008, p. 279

This specialised teacher knowledge (PCK) is only valid in a teacher's domain for classroom practice. PCK is exclusive to teaching and thus draws a line between a subject teacher and a subject expert (Shulman, 1987). For example, Chan and Hume (2019, p.64) argue that "science teachers differ from scientists not necessarily in quantity or quality of subject matter knowledge, but in how that knowledge is organised and presented." Therefore, while scientists might possess in-depth content knowledge, they may not necessarily possess the skills to transform it into pedagogically accessible content tailored to diverse learners' needs. In contrast, science teachers are adept at adapting scientific subject matter knowledge for effective pedagogical purposes.

The definition of PCK lacks a unified consensus among scholars due to varied understandings of this concept (Shulman, 2015). For example, Evens et al. (2019, p.443) refer to PCK as "craft knowledge," which is an amalgamation of wisdom from initial teacher training (prior education) and continuous professional teacher development through their teaching career.

This knowledge centres on teachers' values and philosophies regarding learners' learning, the subject matter or content, and the curriculum (Phillips et al., 2017). At the same time, Van Driel et al. (1998) emphasised PCK as an essential component of craft knowledge, i.e., specific knowledge that shapes teachers' classroom pedagogic practices. On the other hand, Shulman (1987) differentiated teaching as a craft from teaching as a profession, where the teacher goes beyond just teaching to thoughtful practice. Specifically, Shulman (1987, p.15) defines PCK as:

> The most valuable forms of representations of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the most useful ways of representing and formulating the subject that makes it comprehensible to others.

Van Driel et al. (1998), however, argue that PCK is indefinable and elusive, while (Park & Oliver, 2008, p.198) view PCK as:

> A mixture of interacting elements, including views of learning, views of teaching, understanding of content, understanding of learners, knowledge and practice of children's conceptions, time, context, views of scientific knowledge, pedagogical practice, decision-making, reflection, and explicit versus tacit knowledge of practice, beliefs, or ideas, all of which interact and result in PCK.

Despite lacking a universally agreed PCK definition, the underlying views about PCK are the teachers' abilities to combine pedagogy, content, and curriculum. In addition, the teachers must consider learners' subject content misconceptions when presenting science concepts to enable learners to understand science content and procedures. This observation implies that teachers must go beyond the idea of 'this is how you get the correct answer' in science and instead rise above to a higher, more rounded appreciation of the 'whys' (Chan & Hume, 2019). For instance, "teachers must also understand learners' thought process to help them understand the 'why' questions" (Park et al., 2011, p.253). All these knowledge forms are elements of PCK. Thus, PCK may be understood as the teacher's knowledge to help learners understand science concepts and the reasons behind science methods. From this PCK perspective, Shulman (1987, p.12) advanced the following PCK underlying questions:

- How do teachers decide what to teach?
- How to represent it?
- Where do teachers' explanations come from?

- How to question learners about it?
- How to deal with problems of misunderstanding?

Therefore, a researcher must consider these questions to understand PCK as a TPACK foundation. According to Shulman's (1986) viewpoint on the above questions:

- Teachers draw their explanations from their content knowledge.
- What to teach is set in the curriculum, how to teach it is elicited from pedagogy, and
- The ability to address learners' misunderstandings comes from the knowledge of learners' common misconceptions.

Thus, PCK is premised on understanding pedagogical knowledge, content knowledge, curriculum knowledge, and learners' misconceptions. In addition to recognising the importance of PCK, Shulman (1986) points out that it is also crucial to understand the individual PCK elements: Content Knowledge (CK) and Pedagogical Knowledge (PK). Shulman (1986) defines CK as the teachers' knowledge of the subject content, while PK is the teachers' vast knowledge of teaching and learning methods, practices, or approaches. Accordingly, Shulman (1987) insists that teachers experience the coming together of pedagogy and content to transform the subject content in ways that learners understand. "This transformation occurs as the teacher interprets the subject matter, finds multiple ways to represent it and adapts and tailors the teaching materials to alternative conceptions and learners' prior knowledge" (Koehler & Mishra, 2008, p.56). Thus, the teaching-learning process must transcend beyond the grasp of the subject matter for teachers to start a dialogue about the most suitable and modern teaching strategies to teach using methods that enable involvement and attainment.

While Shulman's (1987) PCK perspective is still relevant, what is now different from the 1980s' teacher knowledge discourse is that innovative technologies are proliferating in the teaching-learning spaces, even in remote and rural schools such as the present research context. Consequently, the requirements and expectations for teacher knowledge have transitioned to the growing use of technology in educational settings. However, it is crucial to acknowledge Kind's (2009) critique of PCK, which underscores the need for an expanded view of teacher knowledge. Kind (2009) argues that PCK may not adequately address the dynamic and complex nature of teaching in contemporary educational settings, especially those influenced by technology. Kind's (2009) critique suggests that teacher knowledge should encompass not only the integration of technology into the curriculum but also the ability to adapt and evolve with rapidly changing technological advancements.

This expanded view of teacher knowledge becomes especially pertinent in remote and rural schools, where teachers may face unique challenges and opportunities in utilising technology for effective teaching. Therefore, while PCK remains a foundational concept for teacher knowledge, it is essential to consider Kind's critique to better address the multifaceted dimensions of teacher knowledge in today's educational landscape. Kohler and Mishra (2006) then expanded Shulman's (1986) concept of PCK to incorporate educational technologies into the teaching-learning discourse. This resulted in a new teacher knowledge form known as technological pedagogical content knowledge (TPACK). The following section, thus, discusses TPACK as teacher knowledge.

2.9 TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

This section presents TPACK as teacher knowledge for teaching. TPACK can be viewed as merging technology with pedagogy and content. It involves a "thoughtful interweaving of all three key sources of knowledge: technology, pedagogy, and content" (Koehler & Mishra, 2006, p.1029). As discussed in section 2.8.1, Koehler and Mishra (2006) advanced Shulman's (1986) PCK to articulate a teacher's knowledge of teaching with technology. This resulted in seven knowledge domains, as shown in Figure 5 below.

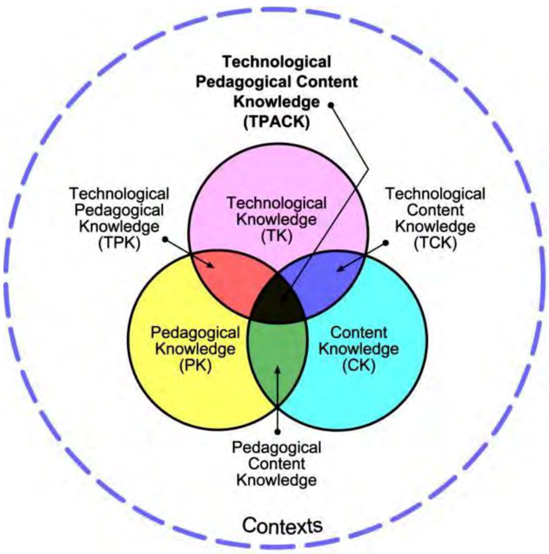


Figure 5. The TPACK framework with context adopted from http://www.tpack.org

The notion of TPACK is grounded mainly on three knowledge domains. First are the two domains of CK and PK, explained by Shulman (1987). The second is that of technological knowledge (TK). TK is the knowledge type required by teachers to use technologies. Afterwards, the three domains overlap. There is an overlap between CK and PK - an area that Chaipidech et al. (2022) describe as the marriage of content knowledge with the skills to present that content in ways that make it accessible to learners. The most significant area is the one in the centre of the framework where all three, TK, PK, and CK, interact to form TPACK.

Moreover, TK, PK, and CK interactions also result in distinct knowledge forms, as explained in chapter three (Section 3.4). These knowledge forms include Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK) and Pedagogical Content Knowledge (PCK). TPK includes understanding how "teaching and learning change when particular technologies are used" (Yulisman et al., 2019, p.182). On the other hand, TCK is about "how technology and content impact and limit one another" (Yulisman et al., 2019:179). Therefore, when PCK, TPK, and TCK merge in teaching, teachers can adapt lesson outcomes into context-based learning experiences. To achieve meaningful learning experiences, Koehler and Mishra (2007, p.76) suggest that "developing technological pedagogical content knowledge involves designing a coherent curriculum system, not a combination of isolated components that focus on just one of the three knowledge bases at a given time." This demonstrates the necessity to consider all the proverbial TPACK tripod's three legs for effective teaching, implying that if one of the legs is weakened or isolated, this can collapse the TPACK. Along the same line, Choi and Paik (2021, p.343) posit that:

> Teachers need to develop fluency and cognitive flexibility not just in each of these key domains - content, technology, and pedagogy - but also in the manners in which these domains interrelate so that they can effect maximally successful, differentiated, contextually sensitive learning.

Thus, effective technology integration yields the maximum potential to support teaching and learning by intentionally developing all three key domains (PCK, TPK, and TCK). Therefore, TPACK describes a teacher's knowledge foregrounded in an intricate awareness of the complex transactions between pedagogy, content, and technology and capitalising on this awareness to craft suitable and context-sensitive teaching approaches. Therefore, TPACK stands as the linchpin for successful technology-integrated teaching. For Life Sciences teachers in rural secondary schools, possessing TPACK signifies the capacity to enhance their science teaching through effective technology integration significantly.

Moreover, the literature highlights that technological pedagogical content knowledge is not static; instead, it emerges as a dynamic form of knowledge, its nature contingent on varying contexts - from country to country, school to school, and even among individual teachers (Gentles & Haynes-Brown, 2021; Koehler & Mishra, 2014; Mohebi, 2022). Likewise, Cox and Graham (2009, p.47) point out that “the effect of different contexts is that the nature of technological pedagogical content knowledge is unique, temporary, situated, idiosyncratic, adaptive, and specific and will be different for each teacher in each situation.” This evolving nature of TPACK implies that there are no standard and fixed parameters or ‘blanket approach’ to qualify and describe its nature and how it develops in teachers. The following section explores studies on how science teachers develop TPACK.

2.10 DEVELOPMENT OF SCIENCE TEACHERS’ TPACK: ADDING THE ‘T’ INTO PCK

One of the first requirements of teacher knowledge is for the teachers to know the science (content) they teach (CK) and how to teach it (pedagogy knowledge) (PK). The two knowledge kinds constitute pedagogical content knowledge (PCK) (Shulman, 1986, 2013). Beyond this, they must possess technology knowledge (TK) and, ultimately, how to teach science using technology (TPACK). This study assumes that secondary school Life Sciences teachers in rural secondary schools possess pedagogical content knowledge from their initial teacher training. This study uses Neiss’s (2011) model to understand how Life Sciences teachers in rural secondary schools develop TPACK. This model, inspired by Rogers’ (1995) model of the innovation-decision process, describes how teachers can develop TPACK by merging technological knowledge (TK) into PCK (see Figure 6).

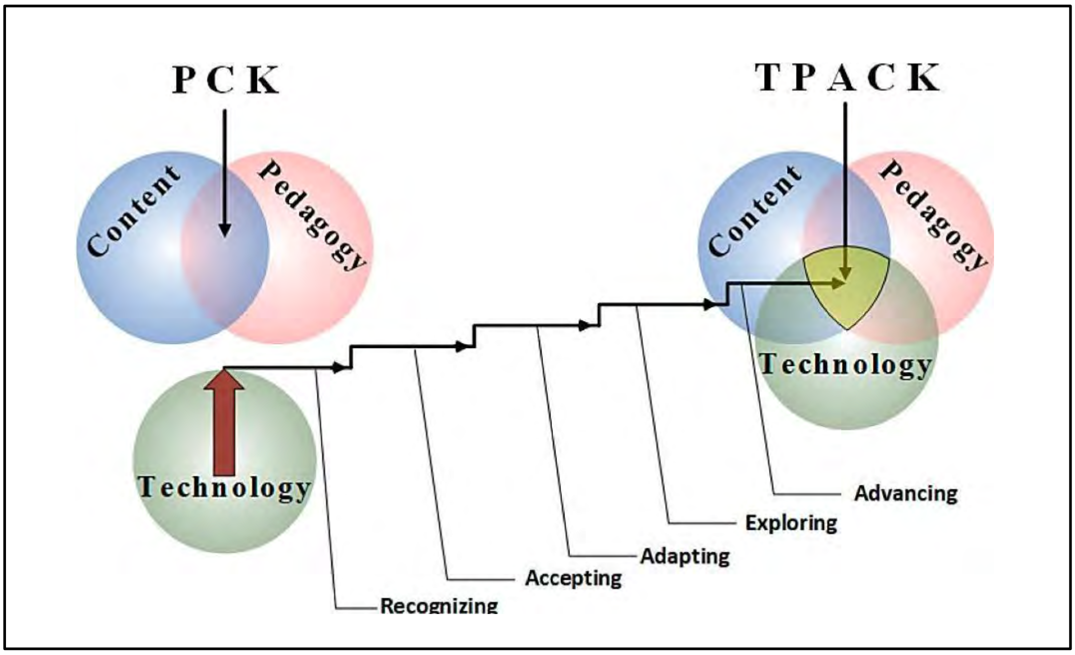


Figure 6: Development of teachers' TPACK as PCK and TK fuse to become TPACK (Neiss, 2011, p.32)

From this model, teachers progress through five stages as they develop TPACK to integrate technologies into teaching and learning (Neiss, 2011, p.33):

a) Recognising (knowledge): Teachers utilise educational technologies and acknowledge the importance of educational technologies in science but do not integrate them into their classrooms.
b) Accepting (persuasion): The teachers create favourable/unfavourable perceptions/attitudes of teaching using educational technologies.
c) Adapting (choice): The teachers participate in endeavours that point to either accepting or declining to teach using educational technologies.
d) Exploring (implementation): Teachers successfully integrate educational technologies into their teaching.
e) Advancing (confirmation): Teachers assess the effectiveness of integrating educational technologies.

While the model shows a linear development toward technological pedagogical and content knowledge, Neiss (2011) and Aldemir Engin et al. (2023) indicate that the movement from one level to another does not exhibit a systematic, steadily cumulative design. This observation implies that teachers may simultaneously draw on various TPACK domains as they develop technological pedagogical content knowledge. For example, at some point, teachers may demonstrate more TCK than TPK in their teaching. Therefore, McCrory (2008, p.78) points out that "learning to teach with technology can be a newfound, iterative experience that requires reflection and particular knowledge bases." This often involves constructing scenarios to teach with technologies followed by reflections on what would have transpired after the class; then, the teachers develop knowledge that they would use in subsequent teaching with the technologies. This knowledge is content- and context-specific and depends on the available technologies, the subject content, and the learners. These reflections on TPACK would then allow teachers to understand further how technological pedagogical content knowledge can support effective instruction. Specifically, McCrory's (2008, p.193) investigation focused on science teachers' TPACK in which she argues that:

> Technology should be used to do things that would otherwise be difficult or impossible to do, not to replicate the same things ordinarily done. She further argues that technology has a place in science classrooms when it is integral to the science being taught or when it solves a particular pedagogical problem.

McCrory's (2008, p.195) view of successful technology integration in science classrooms aligns with Koehler and Mishra's (2006) notion of TPACK to develop teachers' mindfulness of "where [in the curriculum] to use technology, what technology to use, and how to teach with it." In particular, McCrory (2008) advances the idea that teachers should consider the "where, what and how" of technology integration to develop TPACK for effective teaching with technologies. However, some studies have questioned whether TPACK exists in practice and how it can be observed (Angeli & Valanides, 2009; Bingimlas, 2018; Jang & Tsai, 2013). The following section, therefore, casts a torchlight on TPACK in classroom practice.

2.11 TPACK IN CLASSROOM PRACTICE: KNOWLEDGE IN ACTION

The complex nature of TPACK renders it challenging to observe in classrooms. Because of this, it is advantageous that teacher actions and knowledge are closely monitored as it may be a valuable gateway to understanding teachers' TPACK in action. However, some studies have shown that relying on teachers' actions to understand their TPACK is unreliable (Bingimlas, 2018; Jang & Tsai, 2013). Consequently, eliciting teachers' TPACK solely through classroom observations is insufficient. Studies on teachers' lesson planning and reflection yielded essential insights into teachers' TPACK development (e.g., Kartal & Çınar, 2022). To fully comprehend how teachers develop TPACK, researchers must consider their reflections and self-reported practices regarding their classroom behaviour (Kafyulilo et al., 2014). Choi and

Paik (2021) advocate for studying teachers' reflections on their teaching practices to bridge the gap between science lessons and TPACK. This approach is grounded in the belief that teachers' teaching practices mirror their knowledge and cognition (Chan & Hume, 2019; Shulman, 1987). In line with this perspective, the current study's methods, semi-structured interviews and sharing circles, aim to build upon previous research that relies on teachers' self-reported TPACK (e.g., Chaipidech et al., 2022; Cox & Graham, 2009; Durdu et al., 2017). Additionally, TPACK researchers have identified a necessity for studies on teachers' development of the individual TPACK elements (Aldemir Engin et al., 2023; Chan & Hume, 2019; Niess, 2011). Research has shown that teachers rarely concurrently draw on multiple TPACK elements (Cox & Graham, 2009; Kafyulilo et al., 2014; Kartal & Çınar, 2022). However, some studies show that teachers can develop all the TPACK components over time (Gentles & Haynes-Brown, 2021; Kohler & Mishra, 2007; Mohebi, 2022). Valtonen et al. (2019) show how carrying out lesson plan analysis, lesson observations, and interviews scaffolded teacher reflections and provided insights into their TPACK development.

Choi and Paik (2021) delineate the implementation of TPACK in practice as occurring in three interlinked stages: planning, teaching, and reflection, forming a continuous plan-teach-reflect cycle. In this cycle, teachers apply their TPACK when designing lessons, delivering them, and subsequently reflecting on their efficacy. Notably, Choi and Paik (2021) assert that the teaching process is characterised by the ongoing transformation of TPACK as it evolves from one form to another. This suggests that teachers frequently and often unconsciously develop TPACK without explicitly expressing it, rendering it somewhat elusive. It is essential to highlight that while many studies recognise teaching experience as a significant contributor to TPACK development (Firdaus & Robandi, 2022; Niess & Gillow-Wiles, 2017; Malikova, 2019), there exist inconsistent findings regarding the extent to which teaching experience influences TPACK development (Yulisman et al., 2019).

Understanding TPACK within classroom practice is crucial for gaining a comprehensive perspective on Life Sciences teaching in both theory and its application (Choi & Paik, 2021). This understanding aids in unravelling how teacher knowledge, encapsulated within TPACK, materialises in actual classroom settings. In line with this significance, the current study aimed to delve deeper into this aspect, aiming to elucidate how Life Sciences teachers in rural secondary schools translate their knowledge into classroom action, perceiving TPACK as knowledge actively applied within teaching contexts. The next section explores how TPACK is measured.

2.12 MEASUREMENT OF SCIENCE TEACHERS' TPACK DEVELOPMENT

Measuring teachers' TPACK is becoming more complex because of its situated and context-bound nature. Moreover, there are existing disagreements and controversies regarding TPACK and its constructs (Cox & Graham, 2009; Niess, 2011; Chan & Hume, 2019), which led to various approaches being suggested to measure teachers' TPACK. These include measuring teachers' TPACK through the assessment of lesson plans (Bingimlas, 2018), classroom observations (Choi & Paik, 2021), self-assessment surveys (Kafyulilo et al., 2014; Kartal & Çınar, 2022), and various tools, such as pre-and post-interviews, video recordings of teaching (Cox & Graham, 2009; Durdu et al., 2017). From these multiple ways of measuring teachers' TPACK, Chaipidech et al. (2022) found that self-reported evaluations, which do not reflect teachers' classroom practices, remained the most dominant data-gathering instrument. The following are some of the studies that demonstrate how science teachers' TPACK was measured.

First, in a study by Dursun (2019) conducted in Turkey, the TPACK development of four secondary school science teachers was assessed using technology teacher development. The data collection encompassed lesson plans, questionnaires, observations, and interviews. The study concluded that teacher development programmes significantly enhanced the teachers' TPACK. Additionally, the research identified that the teachers' pedagogical reasoning and the school context were influential factors in their TPACK development.

Second, Kartal and Dilek (2021) investigated eight science teachers' TPACK development in Australia using the interactive whiteboard (IWB)-based TPACK Comprehension, Observation, Instruction, and Reflection (TPACK-COIR). Firstly, the science teachers were trained to use the IWB during the TPACK Comprehension stage. Secondly, the teachers observed experienced teachers using the IWB during the TPACK Observation stage. Thirdly, the teachers planned and applied IWB-centred lessons during the TPACK Instruction stage. Lastly, in the TPACK Reflection stage, the teachers reflected on their TPACK and teaching. The data were collected using interviews and journal reflections. The findings reveal that the TPACK-COIR model enhanced the teachers' TPACK.

Third, Jang and Tsai's (2013) study in Taiwan examined 1292 secondary school science teachers to investigate if teachers' TPACK differs regarding gender and teaching experience. Data was generated using a 30-item TPACK survey consisting of four components: CK, TK, PCK, and TPACK. The findings indicate that the means of the technology-related components, such as TCK and TK, were generally low. Moreover, TK was significantly higher in males than females. In addition, experienced science teachers' PCK and CK were significantly higher than those of less experienced teachers. In contrast, the less experienced science teachers' TK was substantially higher than the experienced teachers. The significance of this finding lies in its implications for the relationship between teaching experience and the components of teachers' knowledge. The observed higher levels of PCK and CK among experienced science teachers suggest that as teachers accumulate more years of experience, they tend to develop a deeper understanding of how to teach specific scientific concepts effectively. This could be attributed to their exposure to various teaching scenarios, allowing them to refine their instructional strategies over time. On the other hand, the finding that less experienced science teachers possess higher TK raises exciting considerations. This might indicate that newer teachers, who often belong to a generation more immersed in technology, are more adept at incorporating technological tools into their teaching methods.

Fourth, Jen et al. (2016) investigated 99 (55 pre-service and 44 in-service) Taiwanese science teachers' TPACK-practical (TPACK-P) development. Data was generated using a 17-item TPACK-P survey describing their typical actions, responses, and views in various teaching contexts. The findings showed no significant differences between in-service and pre-service teachers' TPACK-P and that most of the teachers' TPACK-P was at levels 2 and 3, but their application was at Level 1. The difference between the teachers' knowledge about and application of TPACK-P was attributed to the need to engage teachers in more practical usage of technologies. The researchers concluded that it would be necessary for teachers to acquire skills from practically utilising the technologies for their TPACK to be further strengthened and developed.

Fifth, Yulisman et al. (2019) examined 88 science teachers' TPACK development in Banda Aceh City in Indonesia. The quantitative data gathered from multiple-choice test questions were analysed through inferential and descriptive statistics. The results show that CK dominated the science teachers' TPACK.

Sixth, Ocak and Baran (2019) investigated four in-service secondary school science teachers' TPACK development at a tablet-based teaching school in the USA. The qualitative data were gathered from video-recorded teaching sessions and interviews. In addition, the results showed that the teachers' overall TPACK was developed based on the observed TPACK design indicators such as lesson preparation, curriculum planning, choice of technology, and assessment methods. The observed actual teaching TPACK indicators comprised lesson entry behaviours, teaching strategies, technology-infused class management, assessment, and troubleshooting.

Seventh, Tanak's (2020) mixed-method research in Thailand examined the effect of TPACK-based courses on 15 science teachers' TPACK development. Data was gathered using lesson plans and a four-part TPACK survey. Data were analysed using the inductive approach and descriptive statistics. The results showed that the science teachers demonstrated a general understanding of TK rather than the amalgamated TPACK. In addition, the PK element was also dominant in the teachers' TPACK. The study also shows that those science teachers with low PK levels could not make the pedagogy-technology connection regardless of their high TK. Furthermore, the science teachers showed a mixture of pedagogy, content, and technology knowledge instead of integrating the three.

Eight, Kartal and Dilek's (2021) quantitative study in the USA examined science teachers' TPACK during a teaching methods course using a pre-post-test control (n = 23) and experimental group (n = 26). The experimental group was taught how educational technologies could be integrated into science teaching, implemented technology-enhanced science lessons, evaluated their lessons, and replanned and reimplemented them. The findings showed positive gains in integrating technology into science classrooms. The experimental class participants understood that technology integration in science teaching involves more than TK but requires interactions between science content, pedagogy, and technology. Moreover, the TPACK of the experimental group was significantly higher than the control group.

Ninth, Doukakis et al.'s (2021) quantitative investigation in Italy focussed on the TPACK evaluation of 1032 secondary school science teachers concerning the content, pedagogy, technology knowledge, and the amalgamation of these components. Data was gathered using Schmidt et al.'s (2009) TPACK instrument. Findings showed higher CK and TK ratings (average 4.37 and 4.18, respectively), while secondary school science teachers seemed less confident with their PCK and TCK (average 3.51 and 3.68, respectively).

Tenth, Long et al.'s (2022) quantitative exploratory factor analysis in China explored 204 in-service primary teachers' TPACK regarding using thinking tools. They revised a previous Chinese TPACK survey and established a six-component scale with 31 items. Findings indicated that most components of TPACK-TT did not differ significantly among teachers with various educational backgrounds and teaching experiences. However, male teachers displayed higher TK-TT and TPK-TT, bachelor's degree holders had more outstanding PK, and teachers with more thinking teaching experience showed higher TK-TT. Stepwise regression highlighted TPK-TT, TK-TT, and PK as essential predictors of in-service primary teachers' TPCK-TT.

Eleventh, Mensah et al.'s (2022) quantitative research conducted in Ghana examined the technological integration proficiency of 113 secondary school geography teachers. The study employed the TPACK model as a framework for analysis, utilising a TPACK survey questionnaire. Data analysis was performed using mean and standard deviation. The findings indicated that teachers fully grasped CK and PK in geography. However, the investigation revealed that teachers were less confident in TK and its application in teaching and learning than their proficiency in content and pedagogy. As a result, the study recommended incorporating ICTs into higher education courses to help learner-teachers better understand the role of specific technologies, hardware, and software in effective teaching and learning within their respective disciplines.

Twelfth, Galindo's (2023) recent publication in the Philippines evaluated the readiness of 67 teachers in terms of technology, content, pedagogy, and knowledge using the TPACK framework. Employing a quantitative approach, the research employed the established questionnaire developed by Koehler and Mishra (2008). Data analysis used Chi-Square Statistics (X^2) to identify significant associations between TPCK and profile variables. The findings indicated a noteworthy correlation between content knowledge and the area of specialization. Additionally, a significant association emerged between content knowledge and academic units. The researcher's action plan outlined in the study can serve as a valuable resource for future training, aiding in developing competencies such as CK, PK, TK, PCK, TCK, TPK, and TPACK.

Thirteenth, Luo et al.'s (2023) quantitative research in China zoomed into the relationships among the components of TPACK using a 29-item survey instrument administered to 1192 pre-service early childhood (EC) teachers. Guided by the TPACK conceptual framework, the study utilized path analysis of the good-fit TPACK model for data analysis. The model revealed that (1) TK, TPK, and PK were significantly related; (2) TK, TPK, and PK exerted direct positive influences on TPACK; however, (3) PK had a relatively smaller impact on TPACK. These findings suggest that early childhood education training should shift its focus from isolated TK and instead prioritise equipping teachers with adept pedagogical strategies for seamlessly integrating digital technology into instructional practices.

The present section provides a summary of different studies that measured science teachers' TPACK development, emphasising the role of teacher development programmes, technology integration, and differences in TPACK components based on factors like gender and teaching experience. The section delved into the intricate task of measuring the development of TPACK among science teachers. The studies reviewed highlight the complexity of assessing TPACK due to its context-bound nature and the controversies surrounding its constructs. Various methods for measuring TPACK are described, including self-assessment surveys, classroom observations, and the use of tools such as interviews and video recordings. Overall, the section provides insights into the challenges and approaches to evaluating TPACK in science education. Having dissected relevant and recent TPACK literature, the following section provides a critical historical review of TPACK development to identify some crucial gaps that this study sought to fill.

2.13 TEACHERS' TPACK DEVELOPMENT: HISTORICAL REVIEW

The widespread integration of technologies in classrooms has transformed the teaching environment into a heavily technology-centric one, a shift not foreseen just a few years ago. This contemporary context is a departure from earlier conceptions of teacher knowledge, which primarily emphasised mastery of content and pedagogy as the key domains characterizing an expert teacher. The introduction of technologies into education has introduced an additional layer of complexity to the teaching process (Firdaus & Robandi, 2022; Niess & Gillow-Wiles, 2017; Malikova, 2019). As Gentles and Haynes-Brown (2021, p.6) observe, "Teaching with technology is an arduous and complex job given the multifaceted sources of knowledge which need to be contextualised and negotiated." This complexity of teaching with technology brings to the forefront a new type of teacher knowledge encompassing technology, pedagogy, and content. This has increased interest in measuring teachers' TPACK. For example, Setiawan et al. (2019) review of published research between 2011 and 2017 on current trends in TPACK research shows that the majority of the studies focussed on pre-service teachers (66%) and only one-third on in-service teachers (31%). This finding implies that when compared to pre-service teachers' TPACK, little is known about in-service teachers' TPACK development. Moreover, Setiawan et al.'s (2019) study indicates that fewer TPACK studies focus on specific subject fields such as Physics (6%), Biology (13%), and Chemistry (19%). Thus, the present study sought to contribute to the literature by studying in-service teachers' TPACK development within a specific Life Sciences subject.

Specifically, Valtonen et al.'s (2019) study in Finland measured 148 pre-service teachers' TPACK over a 3-year education course. The study found increased TPACK during the study duration. Bingimlas' (2018) quantitative research investigated 243 teachers' TPACK in Saudi Arabia. The findings showed a significant difference between teaching experience and TPACK. The study recommended that teachers transform their teaching strategies from conventional approaches to ones that use educational technologies. Furthermore, Khoza and Biyela's (2020, p.1) research in South Africa explored first-year Bachelor of Education pre-service teachers' technological pedagogical content knowledge. The researchers found that "TPACK was helpful when used as the learning framework, which generated curriculum concepts for the module to support the learner's knowledge of technology, pedagogy, and content."

In another literature review of 106 peer-reviewed papers on research trends in TPACK from the Springer database, Irwanto (2021) shows that when listed by country, the highest number of studies on TPACK was done in the United States of America, followed by Turkey, Australia, Singapore, and Taiwan. This also brings to the fore that few studies have so far been conducted on TPACK in the Global South compared to the Global North. Though some research has been conducted on teachers' TPACK in Africa, most studies have primarily looked at pre-service teachers. Thus, secondary school rural science teachers' TPACK development is little known, particularly in South Africa. Moreover, as Mohebi (2022) reported, contextual factors may affect teachers' teaching practices and technology integration. Little past research has looked at teachers' TPACK based on the requirements of specific teaching contexts. The contextual factors for teaching "vary from school to school and from one class to another" (Niess & Gillow-Wiles, 2017, p.78). Hence, this research examined how Life Sciences teachers develop

TPACK in rural secondary school contexts. The following Table 2 summarises studies on TPACK development from 2005 to 2023.

Table 2. A summary of the TPACK literature used to demonstrate technological pedagogical content knowledge development from 2005 to 2023.

RESEARCHER (S)	COUNTRY	POPULATION	MEASURING	METHODOLOGY & THEORETICAL FRAMEWORK
Koehler & Mishra (2005)	United States	13 Master's education learners	Group and individual TPACK proficiency	Quantitative (35-item survey), TPACK framework
Koehler, Yahya & Mishra (2007)	United States	24 Secondary school in-service teachers	TPACK Evolution	Quantitative and qualitative content analysis; Discourse analysis, TPACK framework
Schmidt et al. (2009)	Germany	Master's level in-service teachers in an educational technology course	Self-assessment TPACK	Quantitative (54-item survey; pre-test– post-test), TPACK framework
Angeli & Valanides (2009)	Cyprus	Primary pre-service teachers	TPACK evaluation	Quantitative (Self-assessment and expert evaluation)
Cox & Graham (2009)	United States	In-service science teachers	TPACK framework for integrating technology	Quantitative (Pre-test–post-test, paired, sample t-test; single-group), TPACK framework
Chai, Koh, & Tsai (2010)	Singapore	Pre-service teachers in Singapore	Perceptions of TPCK/TPACK	Quantitative (29-item survey), TPACK framework
Koh & Chai (2011)	Singapore	350 pre-service Singapore teachers	TPACK perceptions	Quantitative (30-item survey, Stepwise regression model), TPACK framework
Kohen & Kramarski (2012)	Israel	Pre-service secondary school teachers	TPACK scheme	Quantitative (Two mapping dimensions, one-way MANOVA, benchmarks, pre-test–post-test), TPACK framework
Jang & Tsai (2013)	Taiwan	1292 Science teachers from secondary schools	Integration of technology knowledge based on the TPACK model	Quantitative (Survey method, t-test, and ANOVA technique), TPACK framework

Kafyulilo et al. (2014)	Tanzania	12 in-service Science teachers	TPACK evaluation	Quantitative (Survey method, self-reported data), TPACK framework
Dong, Chai, Koh & Tsai (2015)	Singapore	390 pre-service teachers & 394 in-service teachers	Self-assessment TPACK	Quantitative (Pearson's product-moment correlation; 24-item survey), TPACK framework
Harris (2016)	United States	32 in-service teachers	TPACK development	Quantitative (27-item survey; exploratory factor analysis), TPACK framework
Durdu et al. (2017)	Turkey	71 pre-service teachers	TPACK development and conceptions	Mixed methods (A semi-structured interview, TPACK survey, and evaluation scores of pre-service teachers), TPACK framework
Bingimlas (2018)	Saudi Arabia	243 in-service teachers	TPACK framework for integrating technology	Quantitative (18-item Survey, 7-point Likert scale, Exploratory factor analysis), TPACK framework
Valtonen et al. (2019)	Finland	148 pre-service teachers	TPACK framework for development of technical skills	Quantitative (TPACK-21 questionnaire), TPACK framework
Hill & Uribe-Florez (2020)	United States	23 in-service maths teachers in a rural public school district	TPACK proficiency	Quantitative (22 close-ended questions), TPACK framework
Choi & Paik (2021)	South Korea	40 pre-service teachers	TPACK development	Quantitative (TPACK 5-level evaluation), TPACK framework
Kartal & Çınar (2022)	Turkey	33 pre-service mathematics teachers	Perceived development of pre-service teacher's TPACK and synthesis of such knowledge	Qualitative (TPACK development model proposed by Niess et al. (2007)), TPACK framework
Mensah, Poku & Quashigah (2022)	Ghana	113 secondary school Geography teachers	Technological integration proficiency	Quantitative (TPACK survey questionnaire), TPACK framework
Kapici, & Akcay (2023)	Turkey	38 pre-service teachers	TPACK self-efficacy	Mixed methods (Self-efficacy scale and lesson plans), TPACK framework
Aldemir Engin, Karakuş & Niess (2023).	Turkey	7 mathematics pre-service teachers	TPACK evaluation	Qualitative (Semi-structured interviews, lesson plans and lesson

				observations), TPACK framework
Karchmer-Klein & Konishi (2023)	United States	50 novice teachers	TPACK development and transfer	Mixed-methods (TPACK survey and interviews), TPACK framework
Galindo (2023)	Philippines	67 Teachers	TPACK evaluation	Quantitative (TPACK survey questionnaire using Chi-Square Statistics (X2)), TPACK framework
Luo et al. (2023)	China	1 192 pre-service teachers	TPACK description	Quantitative (29-item TPACK survey instrument), TPACK framework

2.14 LITERATURE GAPS

The literature synthesis above has unearthed some critical gaps in current TPACK research by prominent and authoritative scholars in the field. The identified gaps align with the present study's objectives as outlined in Section 1.6. These gaps encompass theoretical and population gaps and methodological gaps as follows.

2.14.1 Theoretical and Population Gaps

First, most TPACK studies were conducted in the Global North (Chai et al., 2010 [Singapore]; Durdu et al., 2017 [Turkey]; Galindo, 2023 [Philippines]; Koehler & Mishra, 2005 [USA]; Luo et al., 2023 [China]) while the representation from the Global South remains limited (Adedayo et al., 2022 [South Africa]; Mensah et al., 2022 [Ghana]; Tunjera & Chigona, 2020 [South Africa]) (see Table 3). Considering the context-dependent nature of TPACK emphasised by Kohler and Mishra (2007), the current knowledge within the TPACK domain primarily draws from the Global North, which might be distinct from the Global South context. Consequently, the understanding of TPACK development within Global South contexts remains scarce. This research gap underscores the significance of the current study, which seeks to bridge the gap by investigating TPACK within the Global South context.

Second, the body of knowledge on TPACK has so far been dominated by research on pre-service teachers (Angeli & Valanides, 2009; Durdu et al., 2017; Hill & Uribe-Florez, 2020; Luo et al., 2023). Thus, what is presently known on TPACK are perspectives from pre-service teachers and little about in-service teachers (Adedayo et al., 2022; Jang & Tsai, 2013; Mensah et al., 2022). Hence, the primary objective of the current study is to expand the knowledge frontiers of TPACK understanding by shedding light on its intricate nature and context-dependent development within a relatively unexplored research area - that of serving teachers. More precisely, this research aimed to pinpoint the practices, factors, and experiences that influence the growth of TPACK. These insights were sought from the vantage point of in-service Life Sciences teachers, providing valuable perspectives on the factors and methodologies that contribute to TPACK advancement.

Third, in the researcher's synthesis of TPACK studies spanning from 2005 to 2023 (see Table 3), it becomes evident that there is a notable scarcity of research that delves explicitly into the rural school context. Remarkably, only a solitary recent study conducted in the USA (Hill & Uribe-Florez, 2020) was conducted within the rural context. This conspicuous gap indicates that, on a global scale, the rural school contexts remain insufficiently explored throughout the evolutionary trajectory of research concerning teachers' TPACK. Given the unique challenges and opportunities in rural educational settings, including limited technological resources, different teaching dynamics, and distinct learner demographics, understanding how TPACK develops and functions in these contexts is paramount. Therefore, the present study intends to contribute to the TPACK literature by focusing on its growth within the rural context. This endeavour seeks to enrich the understanding of TPACK's adaptability across diverse educational landscapes and contribute insights to inform effective pedagogical practices and policies tailored to rural schools.

Furthermore, a prevailing limitation in much of the previous research has been the absence of contextual information, which subsequently posed challenges in extrapolating the implications of these studies to different settings. To bridge this gap, the current research takes a significant step forward by offering a detailed and comprehensive account of the rural secondary schooling context (see Sections 2.2 and 2.3). Additionally, the study extends this effort by presenting in-depth insights into the participating teachers' education levels and teaching experiences. This comprehensive contextualisation ensures that the findings are relevant and adaptable to a broader spectrum of educational landscapes.

2.14.2 Methodological gaps

The present study's literature review has uncovered a substantial methodological gap in past and present TPACK literature. As Table 3 above shows, most TPACK studies have predominantly followed quantitative and mixed methodologies (Kapici & Akcay, 2023;

Galindo, 2023; Koehler & Mishra, 2005; Mensah et al., 2022; Schmidt et al., 2009). Departing from this conventional trajectory, the current study embraced a qualitative approach to gather self-reported TPACK proficiency directly from teachers' voices, practices, and lived experiences. This approach recognises that the essential repository of TPACK knowledge is inherently embedded within the teachers themselves. Consequently, this distinctive methodological choice offers a novel contribution to TPACK research. Specifically, the intentional selection of a qualitative approach was guided by the understanding that delving into the intricate nuances of TPACK development, particularly within underrepresented rural schools, necessitated a holistic and in-depth exploration. Through this qualitative lens, the present study aspires to capture the intricate web of factors, experiences, and contextual intricacies that mould teachers' TPACK evolution. The researcher firmly believed that such an approach fosters a deeper comprehension of TPACK development and empowers teachers' voices to play a central role in shaping the research narrative.

Closely tied to the above methodological gap, a noteworthy observation made during the present study's literature review is that most prior TPACK studies exclusively relied on a single theoretical framework - most commonly the TPAPCK framework (see Table 3). Remarkably, this trend persists despite the cautionary note sounded by Koehler and Mishra (2006), who assert that the intricate realm of technology integration in teaching cannot be entirely explained within a sole theoretical framework. In alignment with this stance, Bagozzi (2007, p.244) teases that expecting a single theoretical model to comprehensively explain decisions, behaviours, and experiences across diverse technologies and decision-making contexts is unreasonable. Aligning with these viewpoints, the present study diverged from this prevalent practice of adopting a singular theoretical framework by drawing insights through a blend of two influential theories: SCT and TPACK. Through this harmonious amalgamation of SCT and TPACK frameworks, the present study introduces an innovative methodological contribution that can lay the groundwork for future scholars seeking to explore TPACK development within similar contexts, utilising the blended theoretical lenses established in the current research.

The synthesis of existing literature in the present study has unveiled inherent contradictions and controversies surrounding the measurement of TPACK and its constituents, primarily attributed to its situated and contextually bound nature (Cox & Graham, 2009; Niess, 2011; Chan & Hume, 2019). These contradictions have consequently prompted the proposal of diverse approaches for measuring teachers' TPACK. For example, in their paper titled *'How* *do we measure TPACK? Let me count the ways,'* Koehler et al. (2012) categorised a total of 141 instruments into four distinct types: assessment of lesson plans (Aldemir Engin, Karakuş & Niess, 2023; Bingimlas, 2018; Kapici, & Akcay (2023), classroom observations (Aldemir et al., 2023; Bingimlas, 2018; Choi & Paik, 2021), self-assessment surveys (Angeli & Valanides, 2009; Galindo, 2023; Kafyulilo et al., 2014; Kartal & Çınar, 2022), and a range of tools encompassing pre- and post-interviews, along with video recordings of teaching (Cox & Graham, 2009; Durdu et al., 2017; Kartal & Çınar, 2022). Within this diversity of TPACK measurement methodologies, the present study's literature synthesis (see Table 2) indicates a prevailing and exclusive reliance on the TPACK questionnaires. However, the TPACK questionnaire often fails to capture teachers' actual classroom practices and contextual intricacies, potentially limiting the comprehensive depth of exploration.

Distinguishing from this prevalent trend, the current research employs a range of instruments - TPACK questionnaires, semi-structured interviews, sharing circle discussions, and lesson observations. This methodological triangulation is deliberately incorporated to enhance the study's validity, broadening its findings' scope and robustness by cross-validating them through multiple data sources. Moreover, few studies have considered the seven-component architecture of TPACK (TK, CK, PK, PCK, TPK, and TPACK), which this study considered. In this study, the research extended its scope to identify the origin or source of each component within the framework of TPACK. This distinctive approach of the present research carries notable significance. By pinpointing the origins of each component within TPACK, this study sheds light on the intricate interplay between technological expertise, pedagogical strategies, and content comprehension. Such insight can illuminate the specific pathways teachers acquire and integrate these facets. This contributes to the advancement of educational research and offers valuable insights for teacher training programmes and curriculum development aimed at fostering a more nuanced and comprehensive approach to modern pedagogy.

2.15 CHAPTER SUMMARY

In Chapter 2 of this study, an extensive examination of pertinent literature laid the groundwork for the research's focal point on teachers' TPACK development. The chapter began by introducing the concept of 'rurality', providing a comprehensive depiction of the rural context within which this research was situated and highlighting the distinctive challenges and attributes associated with rural science teaching. This contextualisation served as a pivotal precursor to a deeper exploration of the specific challenges and opportunities confronted by teachers in rural secondary schools. Subsequently, the literature review narrowed its focus to science education in rural secondary schools, dissecting the complexities of teaching within such environments. The review progressed to scrutinise the dynamic nature of science education and the demand for pedagogical strategies capable of adapting to the evolving educational landscape.

Advancing further, the literature review investigated the role of technology in enhancing science teaching while thoughtfully considering the rural context. Subsequently, the review explored the broader literature on educational technologies in science education, offering an overview of how technology was integrated into science teaching. An essential facet of this chapter was the exploration of studies on teachers' TPACK development, underscoring the critical gaps in TPACK research and identifying areas that warranted further investigation to gain a more comprehensive understanding of how teachers could effectively acquire and apply TPACK within rural science education. This comprehensive exploration of literature provided a robust foundation for the present study while illuminating the gaps in existing knowledge that the current research aimed to address. The next section presents the study's theoretical frameworks.

CHAPTER THREE: THEORETICAL FRAMEWORK

> Theories are nets cast to catch what we call reality. We must cast many nets, and pull them in many different ways, for each reveals something. (James, 1890, p.8)

3.1 INTRODUCTION

A theoretical framework is foundational in research, providing a grounding point that shapes the research questions, methodology, and chosen approach (Rittel & Webber, 1973; Gao et al., 2022). It serves as an instrument for discourse amongst researchers and can situate micro-level research in the broader context and a more extensive body of knowledge (Hirose & Creswell, 2023). To Grant and Osanloo (2014, p.3), "researchers may draw on one or more theoretical frameworks appropriate to a study". This underscores the importance of diverse theoretical approaches in gaining comprehensive insights. In the epigraph above, James (1890), in his seminal works in philosophy and psychology, adeptly uses a fishing metaphor to advocate for employing multiple theoretical frameworks in research. He suggests that akin to using more nets to enhance the chances for a more abundant catch, employing multiple theories improves our understanding of reality's intricacies. Along the same line, Kohler and Mishra (2006) assert that in an intricate and versatile area such as technology integration in teaching, no single framework can address all the questions and that any theoretical framework, though indigent, is better than no framework at all.

The present study, consistent with the epigraph above, drew on components of two theories. These theories are the sociocultural theory's (Vygotsky, 1978) Social interaction and Mediated nature of human knowledge and the Technological Pedagogical Content Knowledge (Kohler & Mishra, 2006) as theoretical and analytical frameworks, respectively. In choosing these theoretical lenses, the researcher considered coherence among the study's objectives, research questions, and methodology. First, this chapter presents an overview of the foundations of the two theoretical frameworks adopted in this study. This is followed by a justification for choosing these frameworks, including acknowledging some limitations of the theory. To fully grasp the choice for this study's theoretical framework, one must first comprehend the foundations of the theories. Therefore, Sections 3.2 and 3.6 provide a synopsis of the origins of the Socio-cultural theory and Technological Pedagogical Content Knowledge, respectively.

3.2 THE FOUNDATIONS OF THE SOCIO-CULTURAL THEORY

Vygotsky's (1978) Socio-cultural theory (SCT) coheres with Piaget's (1981) Constructivist approach, which focuses on the individual construction of knowledge (Ajzen, 1991; Piaget, 1981). Constructivism posits that learning is an active process through which the experiences of an individual and their interaction with their environment allow them to build knowledge (Valente & Blikstein, 2019). In this study, it was the interaction of the teachers with various educational technologies that the researcher assumed offered them opportunities to develop technological pedagogical content knowledge. The following section provides an overview of constructivism as the foundational theory of the SCT used in this study.

3.2.1 Overview of Constructivism

Constructivism is a 'theory of knowing' and a theory about 'coming to know' (O'Connor, 2022) and how individuals construct knowledge through processes of discovery and exploration. This notion of 'coming to know' holds particular significance in this research because the intention was to seek to comprehend how Life Sciences teachers in rural secondary schools 'are coming to know' how to integrate technology into teaching. In other words, this is how Life Sciences teachers, who lack formal training in teaching with technology, develop technological pedagogical content knowledge as they appropriate technologies. There are various constructivism theories, each addressing different aspects. While some of these theories describe constructivism through the perspective of culture and social interaction, others focus on the individual, their learning activities, and their processes of knowledge construction. Through this lens, constructivism argues that learning is a dynamic process through which the experiences of the individual and their interaction with their environment allow them to build knowledge (Amineh & Asl, 2015).

Additionally, constructivism claims that learning is most successful when the tasks and contexts are real and meaningful to the learners (Clark, 2018; Quoc & Van, 2023). From a constructivist perspective, an individual's experiences represent spaces where many ideas and identities can converge and encourage individuals to participate in contributing content and shaping their contexts (Valente & Blikstein, 2019). The SCT used in this study draws on constructivism theory, which examines how Life Sciences teachers' experiences and interactions with educational technologies offer them opportunities to develop TPACK. Piaget (1981) argues that individuals can incorporate new information into their existing knowledge frameworks without changing them. This process, which he calls assimilation, happens when an individual's experiences or new information are aligned with the knowledge they already hold or how they currently see the world. Assimilating the new with the existing can construct new ways of knowing, understanding, and doing. Further, Piaget (1981) details assimilation in three forms: functional or reproductive assimilation, recognitive assimilation, and generalising assimilation, as discussed below.

3.2.1.1 Assimilation

Functional or reproductive assimilation describes the process that happens when action is repeated until the new practice assimilates into the existing (Piaget, 1981). For example, when secondary school Life Sciences in rural schools try new technologies in their teaching and repeat and use them, the new technologies become part of their practice. Having assimilated using the technologies from their experiences, the teachers become more experienced in assessing which technologies are most appropriate to represent certain content, leading to technological pedagogical content knowledge development. Similarly, Piaget (1981) describes recognitive assimilation as a process of appropriately assimilating components of a knowledge scheme. For example, as new technology tools become available, a Life Sciences teacher in a rural secondary school can successfully use them without disrupting their teaching. On the other hand, generalising assimilation describes how an individual can "extend the field of the scheme" (Piaget, 1981, p.70). The Life Sciences teacher can better determine which tools are most suitable to address various issues now that they have assimilated knowledge and ideas from their teaching experiences with technologies. For example, as Life Sciences teachers become more experienced with different technologies and develop TPACK, they are better equipped to select tools and strategies most appropriate to their teaching contexts.

3.2.1.2 Accommodation

Moreover, Piaget (2003) identifies what he termed accommodation as another crucial part of constructivism, which is relevant to this study. Through accommodation, failure leads to learning. Using new technology may not be successful initially, and failure becomes a learning experience that contributes to understanding and knowledge construction (Piaget, 2003). In this study, the rural Life Sciences teachers may discover that new technology does not work for them but still works well for others in their discipline. Learning to teach with that technology could lead to performing a previously thought impossible function, leading to the teacher modifying their earlier ideas and understanding to accommodate this new information

(Nicolopoulou, 1993). The knowledge that has been reframed to accept multiple perspectives makes the mind more open to possible alternatives.

From a constructivist perspective, knowledge is developed as individuals strive to arrange their experiences in terms of pre-existing schemes or ideas (O'Connor, 2022). Piaget (1981) argues that cognitive functions like organisation and adaptation remain constant throughout knowledge development, but qualitative and quantitative changes can happen in cognitive structures with new experiences (Amineh & Asl, 2015). This leads to what Piaget (2003) describes as equilibration. Equilibration is a process of internal self-regulation between assimilating and accommodating new information into existing ideas (O'Connor, 2022). Knowledge construction, or development, is a product of this process. Constructivism argues that disequilibration happens when individuals cannot assimilate their experiences with existing ideas. In these cases, individuals must modify their pre-existing ideas to assimilate the new information. This modification is the accommodation that restores equilibration (Clark, 2018).

Therefore, the interaction between assimilation and accommodation responds to how teachers combine new and old knowledge to form a new knowledge base (Shulman, 1986). In their exploration of teacher knowledge, Koehler and Mishra (2005) argue that there are distinctive bodies of knowledge for teaching. Technological pedagogical content knowledge blends content, pedagogy, and technology into unique understandings of how problems or topics are organised or adapted and presented to learners' diverse abilities and interests for teaching using technology (Koehler & Mishra, 2005). Therefore, TPACK is a blending of teachers' knowledge of the subject matter, their content knowledge (CK), with the understanding of various teaching methods, the technological knowledge and (TK) their pedagogical knowledge (PK) to present the content using technology. A Life Sciences teacher's specific understanding of technology, content and pedagogy and their combinations makes them better adapted to various teaching-learning contexts and learners' needs (Koehler & Mishra, 2014). Therefore, a hallmark of best teaching practice with technology and good teaching practice includes developing TPACK to respond to diverse learners, different teaching and learning contexts, and emerging technologies (Koehler & Mishra, 2007).

Vygotsky (1978) developed the socio-cultural theory (SCT) from the constructivist perspective. The SCT posits that learning and cognitive development are entrenched in social settings and individuals' interactions with others, objects, and events in a shared atmosphere. The components of the SCT include social interactions, the role of more knowledgeable others (MKOs), the zone of proximal development (ZPD), and the mediated nature of human knowledge. This researcher drew on the mediated nature of human knowledge, particularly the mediation of tools and social interaction.

3.2.2 Justification for Mediational Tools in this Study

The idea of mediation suggests that knowledge is mediated and developed mainly through the use of 'tools' (Vygotsky, 1978). The socio-cultural approach assumes that the use of these tools possibly promotes the meaning-making effort or activity. Vygotsky (1978) points out that the specific uses of such tools are critical to how knowledge is developed and the resultant and ongoing development and learning. Vygotsky (1978) recognises two kinds of tools: (i) human mediation tools and (ii) technical tools, i.e., physical objects or artefacts.

This study drew on the notion of the mediation of artefacts or tools, which are the educational technologies available to secondary school science teachers in rural schools in Eastern Cape province. These include computers, tablets, cell phones, the Internet, data projectors, printers, televisions, and school technology policies. Recent studies have shown that technology tools are powerful instruments that can prompt changes in technological knowledge levels (Bohn, 2009; Raschka et al., 2020; Säljö, 2002). For instance, studies on the mediation of artefacts suggest that novices, unlike experts, have a restricted way of expressing and representing content knowledge (Conole, 2009; Impedovo et al., 2017; Subero et al., 2018). Therefore, when novices are engrossed in a milieu that fosters the use of material tools, then novices can participate in patterns similar to experts (Subero et al., 2018). This idea is pertinent and fits with the goals of this study. The Life Sciences teachers in rural secondary schools in the study who, in the researcher's opinion, have a strong foundation in pedagogy from their initial teacher preparation but lack formal training on technology integration are immersed in technologically advanced teaching contexts.

Therefore, through interactions with technology tools, Life Sciences teachers in rural secondary schools would learn to align technology with the subject content and effective pedagogies (Mishra & Koehler, 2006). This would indicate the development of some technological pedagogical content knowledge. As Vygotsky (1978, p.55) observes, "tool mediation contributes to changing, broadening or development of human knowledge"; hence, this study focuses on developing TPACK. The present study employed the notion of mediation of tools as a lens to understand how the rural Life Sciences teachers' TPACK was negotiated and developed through access to and use of the available technology tools.

3.2.3 Justification for Social Interactions

In addition to the mediation of tools, this study argues that understanding Vygotsky's (1978) notion of social interactions serves as a foundation for the TPACK that Life Sciences teachers in rural secondary schools who lack formal training in teaching with technology are developing. The socio-cultural approach highlights the importance of social interactions in an individual's social context, including the physical settings. In this study, the researcher extended to the concept of interactions with objects such as technology tools. Research shows that to improve one's knowledge in a particular field, there need to be aspects between that field and what an individual experiences in their daily social life (Valente & Blikstein, 2019; Vygotsky, 1978). Technology tools are intricately entrenched within society's skills and ideas and abound in everyday life for most people, including banking and finance, religion, politics, and entertainment. Therefore, the notion of social interactions with technology tools in the rural secondary school science teachers' everyday lives is essential as this also bridges the gap between using technology to teach in their workplaces and daily lives. This may facilitate skills transfer between social life and the work context as they develop TPACK. As a result, the researcher used the idea of social interactions as a lens to understand whether and how rural secondary school Life Sciences teachers' access to and interactions with technology tools might contribute to how they describe the growth of their technological pedagogical content knowledge.

3.2.4 Shortcomings of the Socio-Cultural Theory in this Study

While strong literature evidence confirms the superiority of the SCT (O'Connor, 2022; Watkins et al., 2015), this theory, like any other theoretical framework, has shortcomings. The main weakness of the SCT in this research is its silence on teacher knowledge elements such as CK, PK, TK, TPK, and PCK. Yet, this study sought to interweave such knowledge elements to promote a comprehensive understanding of teachers' TPACK development. These forms of teacher knowledge are articulated in the TPACK framework. Hence, this research complemented the SCT with the TPACK framework.

3.3 THE FOUNDATIONS OF THE TPACK FRAMEWORK

The TPACK framework is grounded on Shulman's (1986) pedagogical content knowledge (PCK) framework. Shulman (1986) believes that content and pedagogy should not be separated. The framework argues that content knowledge, pedagogical knowledge, and their intersections, PCK, are all essential to effectively functioning as a teacher (see Figure 7).

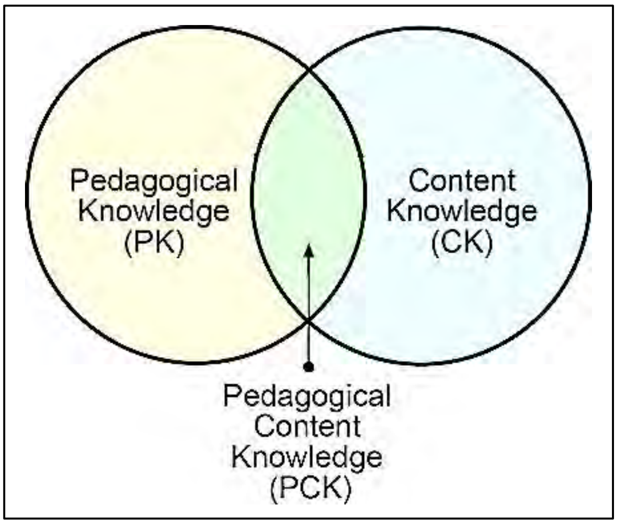


Figure 7: The PCK model and its knowledge components (Mishra & Koehler, 2006, p.4)

From the above illustration, Shulman (1987) then articulates seven knowledge classes to develop adequate teacher knowledge. The first three classes are content-related, while the other four are pedagogy-related. These classes are:

i. Content knowledge;
ii. Curriculum knowledge - with an understanding of the programs and materials that are the "tools of the trade" for teachers;
iii. Pedagogical content knowledge – the understanding of pedagogy and content and the interaction between the two;
iv. General pedagogical knowledge – understanding classroom organisation and management's broad strategies and principles;
v. Knowledge of the learners and their characteristics;
vi. Understanding of the teaching-learning contexts, e.g., from the classroom or group workings, financing, and governance of schools and their districts to the communities' demographics; and

vii. Knowledge of educational outcomes, purposes, values, and philosophical and historical foundations.

Since its initial introduction, the PCK framework has changed to enable its use in new scenarios (Abbitt, 2011; Shulman, 2015). As technology has become more widespread, people are paying more attention to the value of good technology integration in teaching. By adding technology knowledge as a new knowledge area that teachers must incorporate into their PCK, the current study's literature analysis uncovered various initiatives to advance Shulman's PCK model to accommodate these changes (Abell, 2008; Angeli & Valanides, 2014; Mishra & Koehler, 2006). These initiatives led to the PCK model being extended using various conceptualisations. For instance, Pierson (2001) discusses how technology, pedagogy, and content are related. Several researchers employed other describing systems. For example, Veal and Makinster (1999) use the phrase electronic PCK, Angeli and Valanides (2005) adopt the term information and communication (ICT)-related PCK, Niess (2005) describes it as technology-enhanced PCK, while Slough and Connell (2006) use the term technological content knowledge and, Margerum-Leys and Marx (2002) define the PCK of educational technology. To Koehler and Mishra (2005), the literature on the use of technology in education lacks a theoretical foundation. Without such a framework, Koehler and Mishra (2006, p.33) claim that "attempts to capture the big picture of technology implementation would be ineffective." Koehler and Mishra (2005) then coin the term technological pedagogical content knowledge (TPACK) to present a modification of PCK that included technology knowledge.

In a study, Koehler and Mishra (2007) investigated master's learners and teacher education faculty's collaborative design of online courses. According to the researchers, "the participants gained a deeper understanding of the complex web of relationships between pedagogy, content, and technology, as well as the contexts in which they function" (Koehler & Mishra, 2007, p.139). Following their findings, Koehler and Mishra proposed TPACK as a new theoretical framework for teachers to fully integrate technology into their teaching (Koehler & Mishra, 2007; Mishra & Koehler, 2005). In line with the preceding section, the TPACK framework offers numerous insights into how technologies should be integrated with other educational practices to succeed. The following section goes into detail about the TPACK framework employed in this study.

3.4 TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK) FRAMEWORK

The TPACK framework was introduced to describe a framework for teacher knowledge needed to teach with technology. It is a build-up of the earlier work of Shulman (1986;1987), in which he articulated the intersection of pedagogy and content knowledge (PCK). TPACK theorises the coming together of content, technology, and pedagogy. According to Firdaus and Robandi (2022, p.23), TPACK highlights how "new technological resources reshape pedagogical knowledge, content knowledge, and pedagogical content knowledge." They maintain that technology integration is not context-neutral, and proper teaching with technology entails being thoughtful of how technology connects with content and pedagogy not in isolation but in intricate, functional relationships that epitomise teaching practice (See TPACK diagram, Figure 8).

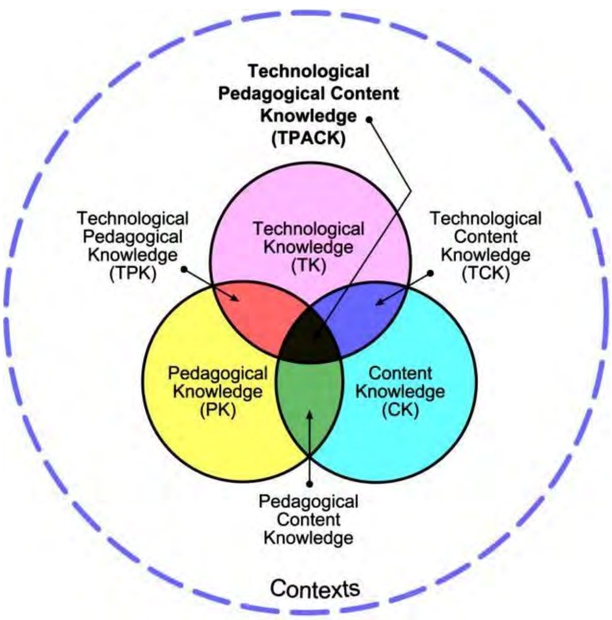


Figure 8. The TPACK framework adopted from http://www.tpack.org.

Table 3 below shows the resulting knowledge components of TPACK.

Table 3. The seven components in the TPACK framework (Koh, Chai & Tsai, 2010, p.564)

The Component	Abbreviation	Definitions
Content Knowledge	CK	Knowledge of the subject matter
Technological Knowledge	TK	Knowledge of various technologies
Pedagogical Knowledge	PK	Knowledge of the methods or processes of teaching
Technological Content Knowledge	TCK	Knowledge of subject matter representation with technology
Technological Pedagogical Knowledge	TPK	Knowledge of using technology to apply different teaching methods
Pedagogical Content Knowledge	PCK	Knowledge of teaching methods for different types of subject matter
Technological Pedagogical Content Knowledge	TPACK	Knowledge of using technology to implement teaching methods for different types of subject matter

The TPACK framework shows the presence of complexities and interconnectedness among the three key knowledge domains (content, pedagogy, and technology) (Koehler & Mishra, 2005; Warr & Mishra, 2023). The following few paragraphs provide details of the TPACK knowledge constructs.

3.4.1 Content Knowledge

CK refers to understanding the subject content being taught or learned, such as Life Sciences (Absari et al., 2020; Koehler et al., 2013). Therefore, a teacher must possess a solid foundation of content knowledge to be deemed competent in their subject field. One of the six TPACK subdomains, CK, is connected to PCK and TCK. Shulman (1986, p.8) notes the following:

> The teacher has special responsibilities concerning content knowledge, serving as the primary source of learner understanding of the subject matter. How that understanding is communicated conveys to learners what is essential about a subject and what is peripheral. In [the] face of learner diversity, the teacher must have a flexible and multifaceted comprehension adequate to impart alternative explanations of the same concepts or principles.

By utilising educational technologies, it is possible to connect with and support a wide range of learners in various learning contexts as they apply their knowledge to practical scenarios. In a school with limited resources, such as the selected rural schools in this study, a Life Sciences teacher, for instance, uses simulations or videos to aid learners in understanding the subject being covered with more real-world examples. This implies that a competent Life Sciences teacher is able to look for other resources to augment the school's offerings. Consequently, a Life Science teacher's inability to properly convey content due to a lack of resources is no longer an issue. Therefore, Life Sciences teachers in rural secondary schools must understand the disciplinary approaches to integrating technology to teach subject matter and develop strategies for seamlessly integrating the content and technology.

3.4.2 Pedagogical Knowledge

According to Koehler et al. (2013, p.397), PK refers to:

> Teachers' deep knowledge about the processes and practices of teaching and learning encompassing educational purposes, goals, values, strategies, and more. PK is a generic form of knowledge that applies to learner learning, classroom management, teaching planning and implementation, and learner assessment. It includes knowledge about techniques or methods used in the classroom, the nature of the learners' needs and preferences, and strategies for assessing learner understanding.

Based on this notion, Life Sciences teachers in rural secondary schools must be adaptable to teach in various settings, including schools with diverse socioeconomic circumstances, including those that are poorly resourced, have poor discipline, or are well-resourced and well-managed. For instance, as part of the school's discipline policy, a Life Sciences teacher could forbid learners from using mobile devices in class but allow them to use them while teaching a topic that learners cannot easily access, such as a video showing the dissection of an internal organ. The video content could then be shared with other schools that may not have these resources. As outlined in national guidelines like Curriculum Assessment and Policy Statement (CAPS), a competent Life Sciences teacher in a rural secondary school would, thus, be able to apply various discipline management techniques and several teaching strategies to promote teaching-learning in any context.

3.4.3 Technological Knowledge

TK was incorporated into Shulman's (1986) PCK model to form the TPACK framework. Many academics contend that it is challenging to define TK because it is so quickly outmoded, making it elusive (Absari et al., 2020; Koehler et al., 2013). Koehler et al. (2013, p.23) maintain that "certain ways of thinking about, and working with, technology can apply to all technology tools and resources." Thus, this definition is consistent with the intent of technology, which also embraces knowledge of how to utilise various technology tools for instruction and learning, including the online platform, multimedia, and other computer-related devices. To be competent in teaching with technology, Life Sciences teachers in rural secondary schools must possess the TK of how to use technologies and the ability to put that knowledge into practice.

Additionally, TK includes fundamental abilities like using technology to prepare lessons, using PowerPoint presentations to present the lessons and emailing other teachers. It is not unrealistic to assume that Life Sciences teachers in rural secondary schools who are more proficient with TK will also probably be self-reliant to learn numerous different technologies by themselves and stay current with the swift technological developments. The individual Life Sciences teacher must determine which technologies to use and how to use them in the classroom. The potential for thorough TK will be present if the Life Sciences teachers in rural secondary schools interact with technologies. At the same time, teaching would also result in more competent Life Sciences teachers in rural secondary schools. For instance, a creative Life Sciences teacher in a rural secondary school with access to new technologies could quickly learn how to operate the tools independently. As a result, TK offers Life Sciences teachers in rural secondary schools the opportunity to utilise technologies, develop their TK, and become self-reliant, proficient teachers.

3.4.4 Pedagogical Content Knowledge

The term pedagogical content knowledge (PCK) refers to the explanations that Life Sciences teachers provide as they apply pedagogical principles to the subject matter to improve learning or combine content and pedagogy to streamline the learning process (Shulman,1986). In this study, teaching in rural secondary schools gives Life Sciences teachers the opportunity to interact with diverse learners, unique teaching situations, and content that requires them to modify the curriculum to accommodate every learner's needs. Therefore, PCK is inevitably included in the planning and executing technology-based teaching and is crucial to making knowledge accessible to all learners (Shulman, 2015). To be competent in teaching content, Life Sciences teachers in rural secondary schools should develop various skills, including teaching using technology. For instance, allowing learners to watch a video repeatedly at their tempo and schedule can reinforce previously taught material.

3.4.5 Technological Content Knowledge

Technological content knowledge (TCK) is the knowledge concerning how technology can impact and present new opportunities in teaching new content and how Life Sciences teachers can appropriate a particular technology to alter how learners acquire and comprehend the subject's concepts (Koehler et al., 2013; Simuja,2017). In addition to being knowledgeable in their field, Life Sciences teachers in rural secondary schools must also be well-versed in the various methods used to impart that knowledge, mainly when utilising technology in teaching. This implies that Life Sciences teachers already adept at using technology select the correct tools to enrich lesson presentation and learning. For instance, software like augmented reality (AR) to demonstrate a heart's function can aid learners in understanding some of the processes involved. In addition to subject matter expertise, which is more crucial in delivering a lesson, the ability to use educational technologies can enhance the teaching-learning quality. This, therefore, becomes the key to the growth of the teachers' TPACK, the integration of technology tools and the appropriate teaching of content. Life Sciences teachers in rural secondary schools must be knowledgeable in their subject and have experience using various technologies to convey that knowledge to their learners.

3.4.6 Technological Pedagogical Knowledge

TPK refers to applying technologies in various ways to adapt to evolving teaching-learning situations (Koehler et al., 2013). Life Sciences teachers can acquire TPK through their classroom instruction. In other words, TPK can develop when teachers interact with technology in various teaching contexts. When planning lessons for diverse learners, Life Sciences teachers in rural secondary schools should comprehend the affordances and setbacks of using technologies. This implies that a proficient Life Sciences teacher in rural secondary schools would be able to judge the merits of utilising technology to teach a specific area of Life Sciences or select one tool over another.

3.4.7 Technological Pedagogical Content Knowledge

The interactions of the above knowledge components will result in understanding the subject matter to be taught using the proper pedagogical techniques and technological tools. The

TPACK component, the intersection of all content, pedagogy, and technology domains, forms the model's core. In their work, Koehler and Mishra (2005, 2007) underscored how the TPACK construct differs from all the other three knowledge components (CK, PK, and TK) individually and instead emphasised these concepts' intersection and interaction. As a result, TPACK becomes:

> The basis of effective teaching with technology requires 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 learners face; knowledge of learners' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge to develop new epistemologies or strengthen old ones. (Koehler & Mishra, 2009, p. 66)

In this research, the TPACK framework was employed to characterise the intricacy of the knowledge set Life Sciences teachers in rural secondary schools required to use technology in their classrooms. Moreover, the TPACK framework served to describe the relationships and interactions among CK (what to teach), PK (how to teach), TK (how to do so using technologies), and the conversion that occurs when blending these domains. A justification for using the TPACK framework in this research is given in the following section.

3.5 RATIONALE FOR TPACK FRAMEWORK ADOPTION AND ITS SHORTCOMINGS

This section explores both the reasons for adopting the TPACK framework and its associated limitations. Understanding the rationale behind the TPACK framework's choice is crucial to grasp the framework's applicability and relevance in the current research.

3.5.1 Justification for the adoption of the TPACK framework

Although TPACK is relatively recent, numerous empirical studies grounded on the TPACK framework have reported its usefulness. For example, Tseng et al. (2020, p.76), in their systematic review involving 107 empirical studies regarding the TPACK framework, concluded that "TPACK presents a dynamic framework for examining teachers' knowledge required for instruction with technology." To help the researcher make sense of this study's results, he foregrounded the TPACK framework as the analytical lens to explore Life Sciences teachers' TPACK development in a rural schooling context. This was necessitated by the literature review in the preceding chapter two, revealing a dearth of research on TPACK development in teachers working in rural secondary schools. More so, the following remained unclear in the TPACK research so far:

- How technologies could offer rural science teachers the opportunities to develop TPACK, and the factors that guide the development of this expert knowledge.
- How and when the Life Sciences teachers construct TPACK in teaching.
- Which knowledge domains are prominent in the Life Sciences teachers' TPACK, and if they exist in practice?

Thus, the researcher relied on the TPACK framework's ability to help address the above concerns. Moreover, the researcher was aware that TPACK scholars have made it apparent how context plays a fundamental role in TPACK because every form of teacher knowledge is context-bound and situated (Koehler & Mishra, 2009; Harris & Wildman, 2020). In the same line, Cox and Graham (2009, p.47) go as far as to claim that "…the effect of different contexts is that the nature of TPACK is unique, temporary, situated, idiosyncratic, adaptive, and specific and will be different for each teacher in each situation." Hence, this study embraced the TPACK framework, acknowledging the significant role of context in developing TPACK. This approach enabled the researcher to account for various contextual influences, such as the availability of technology infrastructure, support from School Management Teams (SMTs), and school technology policies. The subsequent section delineates certain shortcomings of the TPACK framework as applied in this study.

3.5.2 Shortcomings of the TPACK Framework

While TPACK is broadly considered a leading framework to articulate teacher knowledge for technology integration, the researcher acknowledged some shortcomings of this framework in the present study. First, this framework was initially conceptualised from a study involving pre-service teachers working with lecturers in a university context. In contrast, this study involves in-service teachers in rural secondary school contexts. From this viewpoint, the researcher assumed that the TPACK framework might not articulate some issues related to the teachers in secondary school settings. On the other hand, while the TPACK framework was revised and tested in various settings in numerous studies, most of these were done in the Global North. The researcher further assumed that the TPACK framework in its current form might not articulate how teachers in the Global South, particularly in rural secondary schools, develop TPACK. To further define the opportunities that the framework offers, additional discussions, viewpoints from various paradigms, and targeted research studies are needed, such as this study in rural contexts.

Furthermore, Niess and Gillow-Wiles (2017) argue that the TPACK framework is static and ineffective in areas where conventional resources such as chalkboards and paper are still the primary teaching aids. This is the context of many rural schools where this research was conducted. Moreover, some rural secondary schools selected in this study still teach without much reliance on educational technologies because of, for instance, inadequate technology infrastructure. In such cases, it has been argued that the TK element of TPACK is irrelevant for teachers in such settings. In addition, several authors (e.g., Cox & Graham, 2009; Spangenberg & De Freitas, 2019) posit that the TPACK framework falls short in adequately articulating the context, excludes the relationships between teachers and learners, and fails to consider classroom actualities such as overcrowding. This was the reality in most secondary schools where this study was conducted.

Although the TPACK framework has received criticism, teachers and researchers still believe it is helpful in their efforts to implement technology effectively (Angeli & Valanides, 2009; Firdaus & Robandi, 2022). Many have called for more research to "shore up weaknesses in the clarity of TPACK construct definitions and in articulating ways that the constructs are related to each other" (Tseng et al., 2020, p.19). This work results in this study contributing to the remodelling of the TPACK framework to fit the needs of the developing world, especially the rural teaching context. The necessity of combining the SCT and TPACK frameworks in this research is explained in the ensuing section.

3.6 COMBINING SOCIO-CULTURAL AND TPACK PRINCIPLES

Akayoğlu's (2019, p.11) meta-analysis of 114 empirical studies on technology integration published between 1997 and 2018, encompassing over 34000 teachers, showed that the socio-cultural theory was the prominent theoretical framework used in most studies. The researcher even claimed that "the socio-cultural theory will continue to be adopted by researchers regardless of what new tools and platforms emerge for educational purposes." However, the meta-analysis also brings to the fore critical limitations to current research using only the sociocultural theory. For instance, Glăveanu et al. (2019) and Whipp et al. (2015) suggest that

SCT falls short in describing the teacher knowledge vital for effective technology integration in the classroom. These knowledge components are articulated in the TPACK framework. Consequently, studies combining the SCT and the TPACK framework are rising; for example, Bostancıoğlu and Handley's (2018) quantitative research in the UK, Purwati's (2022) mixed methods study in Indonesia, and Olofson et al. (2016) qualitative exploration in the USA. Thus, in the present study, the researcher argues that combining the SCT and TPACK principles offered a more rounded grasp of the Life Sciences teachers' TPACK in rural secondary school contexts. In this study, the TPACK framework provided the analytical framework to examine teacher knowledge to integrate technology in the classroom. On the other hand, the researcher used the SCT to explore how rural Life Sciences teachers' interaction with technology tools mediates (or not) their self-reported TPACK development. The framework for combining the SCT and TPACK principles is outlined below in Figure 9.

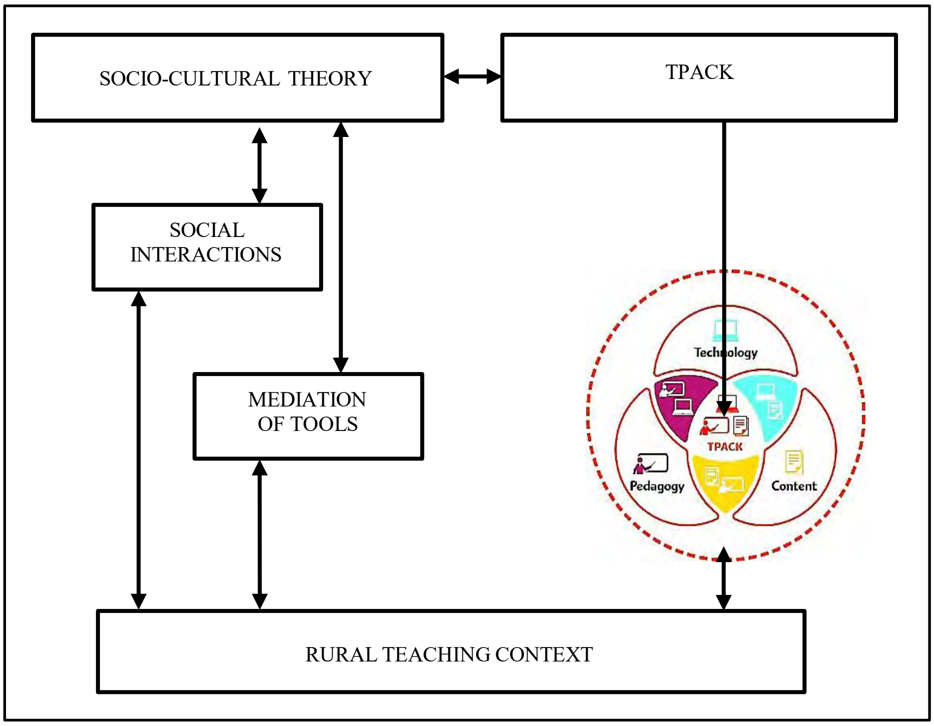


Figure 9. SCT and TPACK conceptual framework (drawn by the researcher)

Lastly, the SCT and TPACK complemented each other in this study as they both recognise that human knowledge construction, such as the development of TPACK, is context-dependent. This allowed the researcher to consider all the contextual factors such as the grade, subject, learner's socio-cultural background, types of available technologies, and individual teacher attributes such as their philosophy, teaching style, and experience.

3.7 CHAPTER SUMMARY

Chapter 3 delved into this study's theoretical underpinnings, emphasising the adoption of Socio-cultural theory (SCT) and the Technological Pedagogical Content Knowledge (TPACK) framework to explore the development of TPACK among Life Sciences teachers in rural secondary schools. The chapter began by establishing common ground between SCT and the constructivist approach, focusing on active learning through experiential interactions with the environment. SCT was highlighted as the current study's foundational theory, known for emphasising social interaction and the mediation of tools, particularly emphasising the significance of authentic and meaningful learning experiences. The TPACK framework, built on Shulman's (1986) PCK model, was then introduced, and its core components were elucidated, illustrating how content, pedagogy, and technology domains intersected to form TPACK. Furthermore, the chapter rationalised incorporating the TPACK framework, as it offered a more comprehensive understanding of TPACK development by unpacking the elements of teacher knowledge essential for technology integration, thereby bridging a gap in SCT's coverage. Acknowledging the shortcomings of the TPACK framework, Chapter 3 justified its adoption by citing its dynamic and context-dependent nature, particularly suited for studying technology integration in rural school settings. Chapter 4, presented next, outlines the study's methodology.

CHAPTER FOUR: RESEARCH METHODOLOGY

> The methodology is the glue that holds the research together. It is the foundation on which the research is built, the lens through which it is viewed, and the tool the researcher uses to collect and analyse data. The methodology also ensures the trustworthiness and credibility of the research findings, and it is the way that the researcher communicates the research findings to others. (Hirose & Creswell, 2023, p.11)

4.1 INTRODUCTION

The preceding chapter delved into the theoretical framework adopted in this study: SCT and TPACK. The current chapter is dedicated to delineating the methodology employed in this research. Hirose and Creswell (2023, p.53) define research methodology as "a broad term that refers to the research design, methods, procedures, and approaches used in a carefully planned investigation to address a research problem." Also, Pandey and Pandey (2021, p.13) view research methodology as "a set of advance decisions that make up the master plan specifying the methods and procedures for collecting and analysing the needed information." When deciding on this study's methodology, the researcher considered the coherence of the research questions, the theoretical lens, and the type of data to be generated.

Based on these considerations, this investigation adopted an exploratory, investigative case study method to examine rural secondary school Life Sciences teachers' technological pedagogical content knowledge development using the qualitative approach within the interpretivist paradigm. This chapter includes a thorough insight into the paradigm, research approach, methodology, participants' sampling techniques, research instruments, and data generation and analysis procedures used in this research. The chapter also clarifies crucial issues relating to research trustworthiness and aspects of triangulation and pilot studies. An explanation of how the research's ethical concerns were addressed is provided as the chapter closes. A summary of this study's methodology is provided in Table 4 below. This is followed by a discussion of the paradigmatic disposition within which this research is located.

Table 4. A summary of the research methodology for this study

Research title	Technological Pedagogical Content Knowledge: An examination of rural secondary school science teachers' integration of technology in Eastern Cape Province
Research questions	1. How do rural secondary school Life Sciences teachers describe their ways of integrating technology? 2. How do rural secondary school Life Sciences teachers describe their pedagogical technological content knowledge? 3. What sources of pedagogical technological content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?
Paradigm	Interpretive
Approach	Qualitative
Method	Phase 1: Exploratory case study Phase 2: Interventionist case study
Population	Secondary school Life Sciences teachers in rural schools in Joe Gabi District • Seven teachers: Questionnaire respondents • Seven teachers: Semi-structured interviews. • Seven teachers: Sharing circle discussions. • Two teachers: Lesson observations
Sampling techniques	Convenient and Purposive sampling
Research tools and data collection	• TPACK questionnaires • Semi-structured interviews • Lesson observations • Sharing circle discussions • Document analysis
Reliability and validity	Strategies that enhanced reliability and validity • Instruments validation • Pilot testing of instruments • Theory triangulation • Data triangulation • Exposure of participants to the same research instruments

Data analysis	• Survey data were analysed using a count, percentage, and frequency table. • Qualitative data were thematically analysed.
Ethical considerations	Ethics clearance and approval were sought from relevant authorities. The research process safeguarded the participants' rights to informed consent, voluntary participation, withdrawal at any stage, confidentiality, anonymity, and privacy.

4.2 RESEARCH PARADIGM

This section outlines the research paradigm underpinning this research and the rationale behind the choice. Ryan (2018, p.36) explains that a paradigm is "a shared understanding of reality and that each paradigm carries a set of assumptions about the nature of Social Science and the nature of society." This research was located within the interpretivist paradigm, where individual experiences, views, meanings, beliefs, and contexts are the basis for an inquiry (Cohen et al., 2018). Thus, this study employed the interpretivist paradigm to comprehend the rural Life Sciences teachers' beliefs, views, and self-reported experiences of TPACK development. In addition, the interpretivist paradigm coheres with this study's theoretical frameworks, SCT and TPACK, which all recognise the participants' contexts and reported experiences from rural secondary schools as integral parts of an inquiry.

The researcher assumed the teacher participants would expressly share their views, meanings, and interpretations of TPACK development. Access to the in-depth comprehension of the rural secondary school science teachers' TPACK was solicited through questionnaires, interviews, lesson observations, and sharing circles, per the interpretivist paradigm traditions (Cohen et al., 2018), and these might lead to validation of the findings through data triangulation. The interpretivist paradigm has some drawbacks that were observed in this study. The realities of TPACK development were interpreted differently by each participant, which is one of the interpretative paradigm's shortcomings. As a result, the researcher scrupulously followed ethical responsibility throughout the study to keep any potential subjectivity under check and lessen the impact of this limitation. The next section explains the research approach adopted in the study.

4.3 RESEARCH APPROACH

This section presents the research approach and highlights its rationale. Hirose and Creswell (2023) underscore the significance of choosing an appropriate research approach that aligns with the type of data to be gathered, the methods for data collection, and the sampling procedures. This study aimed to explore the reported experiences of Life Sciences teachers in rural secondary schools regarding their technological pedagogical content knowledge development. Hence, a qualitative approach was deemed most fitting. The rationale behind this choice was its capacity to yield rich and thick data from participants about the pivotal practices and processes involved in acquiring technological pedagogical content knowledge. Qualitative research, especially adept at examining visual, non-numerical, and narrative data, proves advantageous when seeking insights into the investigated issues (Hirose & Creswell, 2023).

Furthermore, as indicated by Wa-Mbaleka (2020) and Wilkinson and Dokter (2023), the researcher serves as the primary research instrument in qualitative research, and the natural environment is the definitive data source. In qualitative research, it is generally accepted that for the findings to have real-world relevance, the study should occur within an authentic, real-world setting (Silverman, 2020). Consequently, since the emphasis is on investigating the study's specific context, researchers employing a qualitative approach should immerse themselves in the particular environment under investigation. Qualitative researchers assert that events are better comprehended when observed in natural settings where they naturally unfold (McNaught & Lam, 2010; Patton, 2014; Prosek & Gibson, 2021). Most significantly, the qualitative research method uses "processes, assumptions, and skills that the researcher moves from the paradigm to the empirical world" (Denzin & Lincoln, 2021, p.32). For this study, the researcher needed to consider contextual factors, such as the classroom integration of technology, teachers' experiences with technology integration, and the kinds of technology tools available to the teachers. This was crucial to fully comprehend the complex ways technologies offer opportunities for the Life Sciences teachers in rural secondary schools to develop the situated and context-bound TPACK.

In addition, Denzin and Lincoln (2021, p.26) describe the process of qualitative data collection and analysis as follows: "…the researcher does not just leave the field with mountains of data of empirical materials and then easily write up his or her findings." Although the researcher used computer software for coding and analysis in this study, he remained the primary qualitative 'software' and research 'tool'. The researcher in the current research immersed himself in the research context throughout the research process by visiting classrooms, conducting sharing circles, and conducting interviews.

Further, qualitative research highlights the interconnectedness of the human mind with the social world or reality and the fact that the social world is a product of human creation. This implies that people assign meanings to situations, events, and objects. Therefore, no two people view the world the same way, and Pathak et al. (2013, p.45) argue that "there are as many constructions and intangible realities as the people making them." Thus, a study gains validity in the qualitative approach when it acknowledges and surfaces these 'multiple realities.' As a result, a person's background, creed, race, religion, interests, and needs primarily shape and influence their worldview. This results in "multiple individualised truths and multiple social worlds" (Pathak et al., 2013, p.47).

Moreover, the qualitative method dispels the idea of an objective, unbiased researcher and embraces the notion that both the worldview and authentic research are subjective. According to qualitative research, it is best to understand people's actions when the researcher is familiar with their point of view. In other words, understanding people's worldviews from the inside out rather than from the outside is crucial. Hence, qualitative research assumes that the researcher and the participant are inseparable and continually interact to influence each other. The qualitative researchers acknowledge that their presence in the research context may influence the participants' behaviour and interactions with the researchers. According to Patton and Broward (2023, p.81), qualitative researchers try to avert the "observer effect" by relating with their participants in an unobtrusive, non-threatening, and natural way.

The qualitative approach aims to holistically investigate and understand human experiences, contexts, or situations. In addition, qualitative research appreciates diverse realities and views research as valid when it examines a social world in its entirety rather than just an amalgamation of its components and then provides a merged outlook of the complete setting. The fundamental contention is that human nature is intricate and cannot be fragmented into constituent variables or parts. Studying a particular context in its totality is vital to generating meaningful insights and understandings. In support, Pathak et al. (2013) point out that a qualitative researcher's holistic approach is paramount to understanding the various aspects related to the complex nature of human behaviour.

Hence, given the above, for the present research, the qualitative approach was chosen due to its merit of being a holistic approach that explores participants' views, experiences, emotions, and behaviour (Cohen et al., 2018). Moreover, in qualitative research, "knowledge is constructed not only by the observable phenomenon but also by descriptions of people's intentions, beliefs, and self-understandings" (Prosek & Gibson, 2021, p.172). Thus, this study assumed that through the qualitative approach, the beliefs and reported experiences of the teacher participants' TPACK development would be uncovered and the meanings constructed (Patton, 2014; Patton & Broward, 2023). Further, as mentioned earlier, qualitative research is premised on the collection and analyses of linguistic rather than numeric data (Prosek & Gibson, 2021), such as questionnaires, interviews, observations, and sharing circles, which this study employed, and focused on the context within which the research occurred.

Additionally, the present research exhibited several crucial aspects of qualitative research. For instance, qualitative research involves social interaction between participants and researchers. This offered in-depth interpretations of the reported experiences of the Life Sciences teachers in developing TPACK. In addition, qualitative research constructs knowledge in specific contexts (Prosek & Gibson, 2021). In this research, the rural secondary school contexts provided opportunities to learn more about the lived experiences and self-reported perspectives of Life Sciences teachers in rural secondary schools as they build TPACK. The following section discusses this study's research method.

4.4 RESEARCH METHOD

The current research consisted of two distinct phases: Phase 1, which was exploratory and investigative, and Phase 2, where an interventionist case study occurred. The intervention applied a methodological approach, as obtaining information from participants in rural and culturally sensitive contexts often presents certain challenges. For example, rural and culturally sensitive contexts may have different cultural norms and values than the context from which the researcher hails. This can make building trust with participants and understanding their perspectives difficult. In this context, incorporating sharing circles, inspired by indigenous methods, was seen as a valuable methodological intervention to enhance data collection within the rural setting. The present study adopted a case study method. Harrison et al. (2017, p.22) view a case study as a "study of the particularity and complexity of a single case, coming to understand its activity within important circumstances."

Furthermore, Prosek and Gibson (2021) point out that case study research approaches could be divided into exploratory, investigative, descriptive, and explanatory approaches to address the "who," "what," "where," "how," and "why" research questions. Thus, an exploratory and interventionist case study was regarded as suitable for this research as it sought responses to the "how" and "what" questions from rural Life Sciences teachers regarding their TPACK development. A case study was appropriate because the researcher needed to investigate how life science teachers in rural secondary schools did or did not develop technological pedagogical content knowledge in their natural setting. Thus, the data would be contextual, situated, and intrinsically tied to the inquiry itself (Denzin & Lincoln, 2021).

Moreover, the case study goal is "particularisation, to present a rich portrayal of a single case to inform practice, establish the value of the case and add to the knowledge of a specific topic" (Harrison et al., 2017, p.24). This study's case was the Life Sciences teachers in rural secondary schools. Therefore, the unit of analysis was the teachers' TPACK. In choosing a case study method, the researcher considered some shortcomings of this approach. The chief weakness of the case study method is that findings cannot be generalised (Cohen et al., 2018; Patton & Broward, 2023). However, this study had no intention of generalising its results to a larger population. The findings are only limited and applicable to the schools and teachers who participated in the research. The following section describes the research sites and the participants.

4.5 RESEARCH SITES AND PARTICIPANTS

The sub-sections below detail the research sites and the participants. In addition, the sub-sections explain the sampling techniques and criteria for inclusion in this study, including the sample size.

4.5.1 Selection of sites

Aspers and Corte (2021, p.4) suggest that as a researcher:

> A case study ought to set parameters, conduct a thorough analysis of your case(s) that you can research within the constraints of your time and resources, that are directly related to your research questions, and that likely comprise illustrations of what you want to investigate.

For this investigation, the sites were chosen based on the following inclusion criteria: (1) secondary schools located in a rural area and offering Life Sciences subject; (2) teachers have access to and received technology devices from the ECDoE, the schools installed some technology devices. The study selected schools (sites) from two Education Circuit Management Centres (CMCs), i.e., Ugie-Maclear and Mt Fletcher, in the Joe Gqabi District in the Eastern Cape Province of South Africa. Although many schools in the district meet the inclusion criteria, the researcher employed convenience sampling based on accessibility and proximity to the researcher (Obilor, 2023). In selecting the sites, considerations relating to specific contexts of the schools also served as a guide. The chosen schools' contextual information was readily obtainable to the researcher as he is a District official who works with science teachers in the schools.

4.5.2 Selection of participants

The participants were drawn from a population of rural secondary school Life Sciences teachers in the Joe Gqabi district. The study assumed that the teachers had varying experiences of technology integration in their classrooms, had various technology tools at their disposal, and their schools received technologies from the government and non-government organisations. The participants were selected through what Suri (2016, p.68) calls "purposive and convenient sampling." A "purposive sampling" (Pandey & Pandey, 2021, p.43) or a "purposeful sampling" (Patton, 2014, p.232) is used by researchers to access "knowledgeable people" (Cohen et al., 2018, p.75) who have knowledge about specific issues. Purposive sampling enabled the researcher to draw from individuals with specific traits to offer the wealthiest contribution to answering the research questions. To take part in the research, the teachers ought to meet the following selection criteria: (a) qualified Life Sciences teachers in rural secondary schools, (b) have more than five years of teaching experience, and (c) have access to educational technologies at school. Ethnicity, health, race, marital status, gender, religion, income, sexual orientation, disability status, family size, or age were not part of the selection criteria.

In the initial step, the researcher purposefully selected all Life Sciences teachers in the district who actively responded to the questionnaire. This selection method can be described as purposive sampling because it specifically targeted Life Sciences teachers rather than teachers of other science subjects. Furthermore, at the end of the questionnaire, respondents were allowed to express their willingness to engage in subsequent activities, such as semi-structured interviews, lesson observations, and participation in sharing circles. Subsequently, the researcher employed purposive sampling again, this time selecting seven participants for the semi-structured interviews and sharing circle discussions, while two participants were chosen for the lesson observations. The following section delves into the research instruments utilised in this study and the processes by which data were generated.

4.6 RESEARCH INSTRUMENTS AND DATA GENERATION

In this section, the researcher introduces the research instruments used in the study and justifies their selection. The section also explains how data were generated. To ensure a comprehensive response to the research questions, the researcher chose specific instruments, including the survey questionnaire, a semi-structured interview protocol, lesson observations, sharing circle discussions, and conducted document analysis. It is important to note that document analysis, while not employed as a primary data-generation tool, significantly contributed to enhancing the understanding of the study's context. The researcher was aware that the number of data-generating instruments in this study might be considered to be somehow too many, potentially overwhelming the participants. However, the researcher put it up front that the amount of data generated was meant to deepen the search for the kind of knowledge being sourced.

4.6.1 Structured questionnaire

Dalati and Marx Gómez (2018, p.68) define a questionnaire as "a series of written questions given to a selected group of respondents to record their answers." Similarly, Taherdoost (2016, p.228) views a questionnaire instrument as "a set of questions which are to be responded to by different respondents in writing and are usually handed or e-mailed to the respondents." There are three types of questionnaires: structured, semi-structured, and unstructured. Roopa and Rani (2012, p.274) explain that "unstructured questionnaires ask the respondents to respond in their own words, whereas structured questionnaires require respondents to choose responses from a given set of choices." This study's questionnaire, which had two parts/segments, comprised structured questions (see Appendix F). The first part focused on the respondents' biographical information, such as age, gender, teaching experience, educational qualifications, and some contextual factors related to their institutional features. The second section employed the Likert scale using questions based on the SCT and TPACK survey.

It is crucial to indicate upfront that although this research employed a questionnaire instrument and that questionnaire results were reported using percentages, means, standard deviations, tables and figures, the present research is by no means a mixed methods study but a qualitative investigation.

The current study's questionnaire was designed based on a five-point Likert scale (strongly disagree to strongly agree), which is understood to have equal theoretical intervals amongst responses. The five-point scale allows the respondents to indicate their choice from 1 (strongly disagree) to 5 (strongly agree). Choosing a five-point scale in this research was informed by Taherdoost (2019), who emphasises that it is the standard norm for Likert scales to be made of an odd number of points on response scales. The five-point Likert scale was chosen since data from Likert items tend to become less accurate when the number of scales goes above seven points and drops below five (Taherdoost, 2019).

Moreover, a neutral mid-point was included in the Likert scale to allow the respondents to show their neutrality to the question statements. Thus, the neutral mid-point would illustrate neither agreement nor disagreement or indecision on the respondents' part concerning the presented Likert question. In the same line, South et al. (2022) caution that adopting a method that forces respondents to agree or disagree with the Likert statements by excluding a neutral point is prejudicial. Including a neutral point, therefore, becomes crucial because some respondents might not have an opinion about a particular question item. This is similar to how Simms et al. (2019, p. 550) put it: "The purpose of a neutral mid-point option is evidently to avoid forcing respondents to express agreement or disagreement when they may lack such a clear opinion." This could risk the quality of the data in addition to annoying the respondents. To prevent what might just be a random selection of disagreement or agreement, it was crucial to use the mid-point. In addition, Taherdoost (2019) encourages using Likert scales because they enable gathering adaptable and genuine responses motivated by the desire to find frequencies, correlations, and other statistical evaluation forms.

Specifically, the questionnaires utilised in this research incorporated the TPACK survey, adapted from Schmidt et al. (2009a). It is noteworthy that, except for minor wording adjustments tailored to Lie Sciences, no modifications were made to the user acceptance scale. These questionnaires were administered to Life Sciences teachers in rural secondary schools to elicit information regarding their TPACK development. The questions within the questionnaire were formulated based on both Social Cognitive Theory (SCT) and TPACK principles, ensuring alignment and internal coherence between the research instruments and the theoretical framework. Furthermore, the main and sub-research questions (see Section 1.7) served as the foundation for these question items. The questionnaire validated the findings through triangulation with the other research instruments. It comprised 56 items, as detailed in Appendix F, which were categorised into four distinct sections. Section A consisted of seven questions that asked for participants' biographical data, such as gender, age, qualifications, and teaching experience. Then, section B focussed on the respondents' technology access and use (8-11). Furthermore, section C focussed on the respondents' understanding of TPACK (12-15). Lastly, section D questions were based on six TPACK constructs: TK= 6 items (16-21), CK = 6 items (31-36), PK= 8 items (37-44), PCK = 2 items (45-46), TPK = 7 items (47-53), and TPACK = 3 items (54-56). The questionnaire also contained questions that asked respondents to report on their technical skills in using specific technology tools for teaching (22-30). All section D questions of the TPACK questionnaire used a five-point Likert scale (scored from 1 to 5) with the following options: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree. The subsequent subsection discusses the reliability and validity aspects of the questionnaire.

5.2.3 Reliability and validity of the instrument

The TPACK questionnaire is widely recognised as a valid and reliable instrument, as evidenced by numerous studies (see Section 2.13). Leech et al. (2015) argue that utilising previously validated measures enhances the reliability of new data. The questionnaire demonstrated a construct validity score of 7.88 (Schmidt et al. 2009b) and Cronbach's alpha reliability coefficients ranging from 0.75 to 0.93 for five out of the seven constructs of the TPACK framework (Schmidt et al. 2009a). Cohen et al. (2011, p. 639-640) emphasize the importance of assessing instrument reliability in research.

> Cronbach's alpha is a measure of the internal consistency and calculates a coefficient of reliability that can lie between 0 and 1 with the guidelines of >0.90 considered to be a very highly reliable score; 0.80-0.90 as highly reliable; 0.70-0.79 reliable; 0.60-0.69 minimally reliable and <0.60 should be considered unacceptable.

The reliability measures of the six domain scores in this study yielded a median alpha of α=0.79, demonstrating the questionnaire's high reliability. Given the successful adaptation of the TPACK survey by previous researchers for various populations and the study's design requirement to collect questionnaire data, the researcher modified the survey for Life Sciences teachers in rural schools. Table 5 displays the Cronbach's alpha reliability coefficients utilised in this study.

Table 5. Reliability of the TPACK questionnaire

Domains	No. of items/variables	Cronbach alpha coefficient
TK	6	0.78
CK	6	0.82
PK	8	0.82
PCK	2	0.74
TPK	3	0.83
TPACK	3	0.75
Total scale scores	**28**	**0.79**

Furthermore, the researcher employed Fisher and Marshall's (2009) classification to interpret the five-point Likert scale's mean scores and explain the teachers' TPACK development. Table 6 below illustrates the classification of mean scores. By applying this classification, the researcher could analyse and interpret the teachers' responses and gain insights into their TPACK development.

Table 6. Mean Score Classification

Mean score	Classification	Interpretation
4.5 - 5.0	Very high	Strongly Agree
3.5 - 4.49	High	Agree
2.5 - 3.49	Medium	Neutral
1.5 - 2.49	Low	Disagree
0.0 - 1.49	Very low	Strongly Disagree

The researcher distributed the structured questionnaire (see Appendix F) to all the Life Sciences teachers during a subject meeting at the district offices (see Figure 10) below. A total of 50 questionnaires were distributed, surpassing the required number of seven participants. These seven were marked and provided to the known participants to distinguish the specific questionnaires intended for the study. As previously mentioned, the researcher intended to gather an extensive dataset in pursuit of publication in journal articles.

Figure 10: Researcher administering the TPACK questionnaire

In addition, the researcher also distributed the questionnaire via email to those respondents who chose to use email. The researcher allowed the respondents four weeks to complete the questionnaire. After completing the questionnaires, the respondents returned them to the next meeting at the district offices. To boost the number of responses, the researcher sent a reminder e-mail before closing the four-week survey period to remind the respondents of the date due. The questionnaire was intended to help answer research questions one and two.

Notably, consistent with Aspers and Corte (2021) that no data collection instrument is flawless, the researcher was aware of the major flaw of the questionnaires. First, it was most likely that respondents to a questionnaire would misunderstand some questions. Since there might not be any clarification on ambiguous questions, respondents might provide false answers, while others might decide not to respond to specific questions. However, questionnaires responded to by literate respondents may not need extra clarification. Since all the respondents were acceptably educated and literate teachers, this study assumed that the respondents would be able to comprehend the questions. However, the questionnaire and all other instruments were piloted to ensure that the questions' ambiguity was reduced to the absolute minimum. Second, given that it required their valuable time, some respondents might find completing questionnaires a hassle (Cohen et al., 2018). Third, if the questionnaire is too lengthy, some respondents might rush through their responses and not complete them all (Dalati & Marx

Gómez, 2018). To address these issues, the researcher stressed to the respondents the value of fully completing and returning all questionnaires.

Furthermore, it is crucial to note that the employment of TPACK survey scales has gained widespread recognition and proven beneficial in numerous studies (Krosnick, 1999; Ndlovu & Meyer, 2023; Phillips, 2017). However, as already indicated, it is essential to acknowledge that these scales are not without their limitations, as noted in this study. A primary concern was that the data depended on self-reporting, which raises questions about the potential threat to validity posed by self-assessment. Some participants overestimated, while others underestimated, their technological, pedagogical and content knowledge, which could affect the accuracy and reliability of the results.

A noteworthy aspect that emerges from the literature is the discrepancy between teachers' self-reported knowledge and their actual classroom practices. Several studies have revealed incongruities when comparing teachers' perceived knowledge, as assessed through the TPACK scales, with their demonstrated competence in integrating technology in the classroom (Jita, 2016; Kartal & Dilek, 2021; Luo et al., 2023). Mensah et al. (2022) attribute this phenomenon to the possible disparity between teachers' confidence in their technology integration abilities and their practical implementation in the classroom setting. Although this misalignment is not uncommon in research, it underscores the need for careful consideration and interpretation of the findings.

Another critical issue of concern raised by researchers is the varying interpretation of the TPACK domains, particularly evident in the phrasing of survey items. The use of different expressions, such as 'I know how to teach science,' 'I am able to teach science,' or 'I feel comfortable teaching science,' has engendered debates about whether these items genuinely assess teachers' knowledge or are, in fact, capturing their confidence and self-efficacy (Brantley-Dias & Ertmer, 2013; Voogt & Roblin, 2012). Lyublinskaya and Kaplon-Schilis (2022) and von Kotzebue (2023) argue that specific survey scales may unintentionally measure teachers' self-efficacy and confidence rather than their actual content knowledge and pedagogical skills related to technology integration.

From the above observations, it becomes clear that developing reliable and valid measures for assessing TPACK knowledge is indeed a challenging endeavour (Lyublinskaya & Kaplon-

Schilis, 2022). Researchers have encountered the intricacies of operationalising and capturing the multifaceted nature of TPACK, which encompasses technological expertise, pedagogical competence, and subject matter knowledge, all intertwined in the educational context. Nevertheless, scholars have been given the autonomy to select suitable assessment methods in line with their research objectives and transparently report their chosen approaches. This pluralistic approach has contributed to the growth of knowledge and a more comprehensive understanding of the TPACK framework (Schmidt-Crawford et al., 2016).

Despite the critical discussions and limitations surrounding using TPACK survey scales, it is crucial to underscore their significance in evaluating teachers' technology integration knowledge in education (Lyublinskaya & Kaplon-Schilis, 2022). Rather than advocating for the outright rejection of these scales, the emphasis lies in complementing them with triangulation methods (von Kotzebue, 2023). Indeed, teachers' knowledge is not always directly observable, necessitating a comprehensive approach that considers their actions, declarative statements, and professional artefacts to ensure the reliability and validity of assessments (Roulston & Choi, 2018). Thus, the current research employed a variety of data generation tools to ensure cross-validation of the findings. At the end of the questionnaire, participants were allowed to express their willingness to participate in semi-structured interviews, sharing circle discussions, and lesson observations. From the pool of 37 interested participants, a purposive sampling approach was used to select seven individuals (n = 7) for further data generation. By generating data through multiple research instruments, the researcher sought to achieve data triangulation to enhance the validity of the findings.

4.6.2 Semi-structured interviews

Cohen et al. (2018) define an interview as a social interaction between the interviewer and the interviewee(s) to exchange opinions and generate new knowledge. To Turner and Hagstrom-Schmidt (2022), we interview to know and understand what we do not and cannot know otherwise. Similarly, Denzin and Lincoln (2021) assert that an interview aims to elicit knowledge that can be conveyed as answers and become interpretable. As a data-generating tool, interviews facilitate the exploration of aspects that might be challenging to perceive directly, such as an interviewee's motivations and rationale behind specific emotions, behaviours, and experiences. Therefore, interviews represent active social interactions involving two or more individuals, leading to nuanced findings shaped by the context in which they occur (Flick, 2022).

There are three main categories of interviews: structured, semi-structured, and unstructured (Magaldi & Berler, 2020). The structured interviews are constrained by rigid, pre-determined questions. The interviewer cannot veer off course by asking more questions or tapping the interviewee further on their responses (Roulston & Choi, 2018). Given the topic being studied and the researcher's understanding from the literature that it can be difficult to express one's feelings and experiences, the researcher decided that a structured interview was unsuitable for this investigation. Moreover, the researcher foresaw the necessity of following up with the interviewees and encouraging them to express their experiences and thoughts. The unstructured interview method necessitates a highly skilled interviewer to focus on the research objectives (Gibbs, 2014). Because the researcher was highly likely to miss the interview's purpose, waste time and therefore be unable to generate useful information, he was sceptical about using unstructured interviews. Consequently, the researcher opted for semi-structured interviews. Roberts (2020, p.74) defines semi-structured interviews as "qualitative tools for gathering verbal data from planned questions, where interesting and unexpected answers may be used to construct probing questions to understand people's reported experiences in depth."

This study investigated rural secondary school Life Sciences teachers' TPACK development. Hence, semi-structured interviews were the most suitable to generate data on peoples' beliefs, perspectives, and personal experiences that are impossible to gather using ways like direct observation (Aspers & Corte, 2021). Seven participants, purposively sampled, participated in the semi-structured interviews. Each teacher was interviewed once to examine their TPACK development. These interviews, as previously mentioned, were semi-structured. In other words, some questions were designated in advance, and others were incorporated based on each participant's responses. Each interview lasted roughly 30 minutes, was recorded on a digital audio recorder, and was wholly transcribed. The interviews were done at venues, times, and dates chosen by the participants.

The researcher visited the participants' schools before the scheduled interview date to issue consent letters to sign, which they did (see Appendices C & D). The seven participants were not coerced into participating. Participation was voluntary and free. The interviews were arranged at locations and times that accommodated the participants' convenience. For Xaba, the interview was arranged at his preferred location, his home in the kraal (see Figure 11 below). Xaba specifically requested the inclusion of his wife in the interview, a request that the researcher accommodated. Nevertheless, it is crucial to clarify that Xaba's wife did not participate in the current study.

Figure 11: The researcher interviewed a participant at their kraal

The researcher's flexibility in accommodating Xaba's preference for interviewing at his home, specifically at his kraal, and including his wife in the interview raises several important methodological points. Firstly, it reflects the researcher's cultural sensitivity, which is consistent with the socio-cultural theory employed in this research and understanding of the significance of cultural practices and traditions when conducting research. By conducting the interview in Xaba's familiar environment and respecting his cultural context, the researcher enabled him to feel at ease, facilitating a deeper understanding of his perspectives and experiences. Secondly, the researcher's willingness to adapt to Xaba's request fostered a sense of trust and rapport between the researcher and the participant. The acknowledgement of participants' family dynamics, evident in including Xaba's wife in the interview, further strengthened the rapport, leading to a more open and candid exchange of information. In addition, Xaba might have felt supported and comfortable sharing his experiences with his wife present, contributing to the authenticity of the data collected. Thirdly, the decision to interview in Xaba's home environment, the kraal, offers a unique contextual setting that could enable a deeper exploration of the research topic and provide valuable insights into his perspectives and experiences.

During the interview session, the researcher first introduced himself. The researcher clarified to the participants the goals and procedures of the interview, such as that he would take notes if necessary and that they should not be distracted by them. The researcher once more requested their permission before recording the conversations so he could transcribe them later. Similarly to Mutanho (2021), the researcher protected the participants’ real names by using their clan names (with the participants’ permission). Clan names are deeply rooted in a person’s familial and community ties, heritage, and the cultural fabric of many indigenous communities, such as the one in which the current study was conducted. It was apparent that using the participants’ clan names gave them a sense of pride and being honoured and respected. For example, Xaba exuded a profound sense of pride, expressing his deep connection to his roots through a heartfelt voice recording sent to the researcher. In the narration, he eloquently praised his clan, sharing the rich heritage and traditions that define his identity. Xaba’s pride in his clan name was unmistakably evident as he painted in his voice a vivid picture of the reverence and honour he held for his ancestral lineage. He narrated in his native language (IsiXhosa), and the researcher requested for his translation to English as follows:

Ndingu Xaba, *Nonkosi!* *Mashwabada* *Washwabadelinkomo nezimpondo* *Ukhabane* *Owakhaba udaka kwavela amanzi* *uNonxasikhathali* *AmaXaba angavali nemivalo,* *Avala ngamakhanda amadoda* *Amalinda Amahle* (Xaba)	*I am Xaba,* *The great one!* *The cattle breeder* *The one who tamed the wild beasts* *The one who kicks,* *Who kicked the earth and water surfaced* *The one who never gets bothered* *The Xaba who don’t use doors to close,* *But use the heads of men to close* *The beautiful waiters*

By incorporating the participants’ clan names into the study, the researcher successfully cultivated a sense of trust with them. This trust became particularly evident as participants like Xaba willingly opened their kraals (sacred spaces among African communities where discussions surrounding cultural ceremonies and rituals occur) for the interviews. Establishing this trust not only facilitated the research process but also underscored the significance of acknowledging and respecting the participants’ cultural identities.

The semi-structured interviews were conducted to solicit answers to research questions one, two, and three. The researcher audio-recorded all the interviews while observing each interviewee’s gestures and body language and taking notes by hand to support the recordings. To ensure alignment of the interview protocols with the study’s theoretical frameworks, the researcher formulated the interview questions from the dimensions of the SCT and the TPACK tenets to access and understand the teachers’ TPACK development (see Appendix G). In addition, Prosek and Gibson (2021, p.172) maintain that interviews have the advantage that "they have a high return rate, fewer incomplete answers, and controlled answering order." Although participants in this study had the choice of not answering any questions, they all showed a willingness to answer all questions. Thus, there were no incomplete answers.

Additionally, the semi-structured interviews allowed the researcher to delve deeper and follow up on specific responses to discover more. The researcher was also able to steer and control the conversations, ensuring that the interviewees remained within the parameters of what he needed to learn from them. Conversely, in opting for semi-structured interviews, the researcher was cognisant of the shortcomings of this research instrument. For example, semi-structured interviews can take much time, cannot always guarantee anonymity, and are subject to subjectivity from participants and researchers (Roberts, 2020). This was undoubtedly salient in this study because the researcher had to meet personally with all seven participants. In the current study, it is imperative to highlight the challenges encountered during the interview phase, specifically about some participants' non-participation. Notably, individuals such as Faku and Mkoena failed to attend the scheduled interviews, and despite diligent efforts to establish contact, these attempts proved unproductive. Nevertheless, through a persistent process of rescheduling, the researcher eventually managed to conduct the interviews. This situation demanded a considerable amount of patience on the part of the researcher, underscoring the resilience and adaptability required in navigating unforeseen obstacles during the research process.

4.6.3 Non-participatory observation

Speed (2019, p.13) defines observation as "the systematic description of events, behaviours, and artefacts in the social setting chosen for study". It is the method of obtaining first-hand and open-ended data by observing people and contexts at a study location using a look-and-see approach (Hirose & Creswell, 2023). According to the two definitions, observation entails watching people go about their everyday routines, focusing on insight, and capturing the natural setting as it is experienced by the people involved without changing or modifying it. Prosek and Gibson (2021) observe that there are two kinds of observation: participant and non-participant. In this investigation, the researcher chose the former. In non-participant observation, the researchers do not directly immerse themselves in the observed events. In other words, "the researcher observes and records behaviours but does not interact or participate in the life of the setting under study" (Roberts, 2020, p.382). To meticulously observe and

document the subject of the investigation, the researcher was largely an outsider who sat in a convenient location.
The researcher purposively sampled two teachers for observation from the seven who would participate in the sharing circle discussions. The researcher observed each teacher twice while teaching in their classroom and used technology in teaching. The researcher conducted four observations over four months. Forty-five minutes were allotted for each lesson that was observed. The researcher stayed present for the entirety of each lesson. The researcher developed an observational protocol to document specific technology integration and TPACK development issues that the research intended to surface over the observation cycle. The issues that were to be the core of the observations were made clear in the observation schedule that the researcher employed to direct himself when conducting observations. These issues included the types of technology tools present in the classroom, the lesson structure and content (CK), the use of technology to enhance content presentation (TCK), and the application of technology in pedagogy and content (TPACK) (See Appendix H).

The rationale for observational protocols was that they offer a common framework that facilitates establishing and classifying data across various sets of notes (Prosek & Gibson, 2021). As an observer, the researcher included reflective and descriptive information in his field notes when recording observational information. According to Turner and Hagstrom-Schmidt (2022, p.271), "descriptive fieldnotes record a description of the events, activities, and people (what happened)." On the other hand, "reflective fieldnotes record personal thoughts that researchers have that relate to their insights, hunches, or broad ideas or themes that emerge during the observation (what sense you made of the site, people and situation)." The researcher documented the field notes for precision and depth while in the field. The researcher used the observation method as a data generation tool because it gave the researcher several advantages. One advantage was that it did not involve the researcher asking the participants questions, thus protecting against the biases caused by intrusive questions (Rolfe, 2020).

Furthermore, the researcher's presence in the scenario must not intimidate the participants. This allows people to not explicitly adjust their behaviours and actions to the image they think would please the researcher. Moreover, observations generate data in real-time rather than retrospectively and on actual experiences rather than self-reported actions or experiences. Hence, according to Cohen et al. (2018), the key advantage of the observation method for gathering data is that it allows for capturing circumstances and 'live' data as they develop naturally. This permitted the researcher to observe what is 'in situ' instead of relying on respondents' accounts. Furthermore, since what people assert to do might not match the reality on the ground, the observation technique provides a mechanism for reality-checking.

Therefore, it was hoped that by employing the observation method, this investigation would be able to determine whether the claims made by the respondents during interviews were consistent with the situation on the ground. Thus, the lesson observations offered the researcher opportunities to examine the teacher participants' experiences in complex circumstances, such as technology integration in the classrooms (Marietto, 2018). Notably, the observations allowed the researcher to investigate aspects related to the teachers' TPACK development in their natural settings. Some of these could be aspects that the participants might not express in the questionnaires or interviews or that might be concealed (Cohen et al., 2018; Patton & Broward, 2023; Patton, 2014).

Moreover, the decision to use the observation method also stemmed from the fact that this method is more personal and supported by sociocultural perspectives. The socio-cultural perspective views truth and knowledge as created by individual interactions in a social group (Johnson et al., 2020). This implies that a researcher can observe the participants interact in their natural settings using the observation method. Therefore, considering contextual factors was consistent with this study's theoretical framework (SCT and TPACK). The frameworks recognise that teachers' TPACK development is situated and context-bound, like any teacher knowledge.

Despite its advantages, observational data generation does have some drawbacks. The researcher observed some constraints of reality that limit observations in the study, which are never explicit in advance. The observation method restricted the researcher to the locations and contexts where he would most likely be granted access. In addition, the researcher finds it challenging to build a positive rapport with some participants in the school he was given access to. Even more, this data collection tool continues to be subject to bias (Marietto, 2018). The bias emanates from a researcher serving as the main instrument and the observer, who occasionally brings his array of blinders to the activity. To mitigate this, the researcher made a valiant effort to lessen the observer's influence by using an observation guide. The researcher anticipated that observations might gather data to help answer all the research questions.

4.6.4 Sharing circle discussions

Sharing circle discussions are an example of a focus group method derived from indigenous worldviews, where researchers gather information through group discussions (Afonso-Nhelevilo, 2013; Chilisa, 2012; Hanson & Danyluk, 2022; Lavallée, 2009). People frequently gather in a circle in African contexts and among indigenous peoples, particularly in rural communities. It might happen when children gather in circles to play games or when people gather to sing in circles during celebrations or around the fireplace. Sharing circles are used to ensure collective knowledge construction by soliciting and capturing people's experiences, views, ideas, and perspectives of a particular group of individuals.

The sharing circle represents and promotes cooperation, respect for one another's viewpoints, harmony, and reciprocity among its group members. During the discussions, the group remains silent and non-judgmental throughout each member's speech, which is heard in its entirety. In qualitative research, sharing circles serve as a research tool that gathers various participants to discuss particular topics under the guidance of a facilitator or moderator. This entails generating data by interviewing and soliciting a specific group of individuals' views, ideas, and experiences (Aspers & Corte, 2021;Simuja,2024). Thus, at its core, this method seeks to generate a group perspective. This approach especially fits with the customs and practices of the rural setting where this study was conducted. Most teachers who grew up in rural areas were brought up participating in sharing circles. This is indicated by the fact that during break times at school, most teachers frequently stand or sit in a circle and discuss various topics.

In research, a sharing circle sample size may range between two to twelve people (Tachine et al., 2016). In this study, seven participants took part in the sharing circle discussions. The circles constituted the intervention phase and were conducted after every lesson observation. Like Nhase (2019), the circles offered reflective spaces in which teachers came together and shared experiences and best practices on teaching with technologies as they developed TPACK. The circles, scheduled at times, dates, and venues convenient to the researcher and participants (see Appendix I), were conducted over four months. The rationale behind sharing circles was that they could provide optimal information, especially if the participants shared a lot of similar characteristics. This study's participants were all Life Sciences teachers working in rural secondary schools. Since the participants were colleagues who frequently gathered for meetings, the researcher assumed they would feel more comfortable voicing their thoughts and ideas in each other's presence than on their own with the researcher. Further, Hanson and

Danyluk (2022) note that using sharing circles yields enormous amounts of data relatively quickly and is thus cost-effective.

Another consideration that influenced the decision to use sharing circles in this study was the view that they could encourage participants to converse more openly and build on others' responses. Furthermore, unlike in a one-to-one scenario, sharing circles capture more than one individual's perspectives. As a result, by allowing the respondents to agree or disagree and ultimately consider each other's views, the sharing circles encourage the formation of a group perspective. Sharing circles, thus, create a space for dissenting views. With sharing circles, "participants tend to provide checks and balances on each other, which weeds out false or extreme views" (Lavallée, 2009, p.35). More so, the circles enable participants to express themselves in their own words, encourage a collective of ideas instead of individual opinions, concerns, and views, and cover more issues than surveys.

The sharing circles cohered perfectly with the constructivist and socio-cultural theory underpinning this research. More specifically, Vygotsky's (1978) SCT posits that knowledge construction and cognitive development are entrenched within social settings and happen when people interact with each other, objects, and events in a cooperative environment. The SCT promotes using more personal, collaborative data generation methods, such as sharing circle discussions. Its fundamental premise is that knowledge is constructed through social interactions and results from social processes and diversity within a group. According to constructivists, individuals construct knowledge as they interact in gatherings. Therefore, as the Life Sciences teachers in rural secondary schools gathered and shared their experiences, this was beneficial in two ways. First, the researcher was able to generate a group perspective regarding the teachers' TPACK development. Second, science education research shows that it is beneficial for teachers to observe model teachers who have developed effective teaching methods (Afgan, 2015; Firdaus & Robandi, 2022; Hofstein & Lunetta, 2004). However, teachers rarely observe effective teaching in other classrooms, most often because they are too busy with their own (Nelson et al., 2019; Conger et al.,2015).

Therefore, as discussed earlier, bringing the Life Sciences teachers together in the sharing circles was an intervention that would offer the teachers a reflective space. This space enhanced collaboration and teamwork among the teachers as they reflected and shared best practices and experiences on how teaching with technologies offered them opportunities to develop TPACK.

Eventually, the researcher assumed that the teachers' collaboration would improve the quality of teaching. As a result, given the strengths of this qualitative data-generating method and how it permits the participants to describe their TPACK in groups as propounded by constructivists, the researcher adopted the sharing circles for this study. Figure 12 below shows the researcher and participants sharing circle discussions.

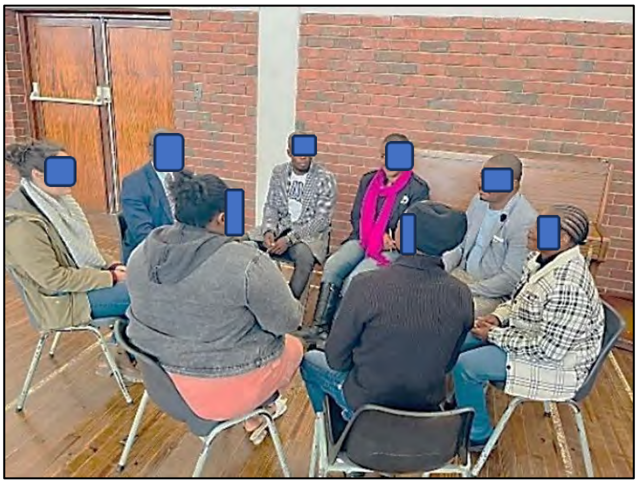


Figure 12: Researcher conducting sharing circle discussions with participants

Nevertheless, it is essential to acknowledge that sharing circles as a data generation tool have notable limitations. Tachine et al. (2016) point out that the facilitator may encounter challenges in guiding the ensuing discussions and maintaining control over the discourse. Hanson and Danyluk (2022) share a similar view, emphasising that managing discussions within sharing circles can be a formidable task for a facilitator lacking authority over group interactions. This is due to the potential risk of sharing circles devolving into a state of disorder if the moderator lacks the requisite skills to manage the group dynamics. It is worth underscoring that the researcher did not encounter any difficulties in facilitating the sharing circle discussions. This can be attributed to the researcher's extensive experience as a Subject Advisor, which often involves leading group discussions in various teacher meetings. Consequently, the researcher possessed the essential skills and expertise to facilitate the sharing circle activities effectively.

Moreover, both Lavallée (2009) and Chilisa (2012) concur that capturing and analysing the data arising from sharing circle discussions presents inherent challenges. When multiple participants speak simultaneously, taking accurate notes becomes impractical. Similarly, distinguishing between different voices within audio recordings of these discussions poses difficulties for subsequent analysis. To mitigate these issues, the researcher implemented specific guidelines during the sessions. The directive ensured that only one person spoke at a time and that all contributions occurred through the chair, aiding in organising the discourse. Specifically, two strategies were employed to accurately identify individual speakers within the group.

Firstly, the researcher prompted participants to speak using their clan names, enabling clear identification during transcription. Secondly, all audio-recorded data was promptly decoded after the sharing circle discussions while the facilitator's recollection remained fresh. This approach aimed to ensure an accurate representation of individual contributions. Encouraging all participants to voice their concerns and opinions during the discussions was imperative to derive substantial and meaningful outcomes. However, in the dynamics of sharing circle discussions, an uneven participation pattern often emerges, with a few individuals dominating the conversation while others might tend to be reticent.

In contrast, others may affirm their dominant position during the discussions to influence its result or possibly lead to bias (Tachine et al., 2016). The same school of thought is emphasised by Hanson and Danyluk (2022), who contend that sharing circles are characterised by the difficulty of hearing the same voice repeatedly, mainly when there is a dominant individual in the group. The influence of group dynamics occasionally muzzles dissenting voices on contentious issues. This implies that "inarticulate members may be denied a voice and that the data may lack overall reliability" (Hunt & Young, 2021, p.437). Therefore, it could be argued that sharing circle discussions sometimes fails to adequately address trustworthiness and credibility concerns. The researcher tried to address this flaw by ensuring that all participants had a chance to voice their opinions. This was accomplished by establishing a ground rule that required each respondent to refrain from speaking for over five minutes without allowing someone else to speak.

Overall, the sharing circles operated seamlessly, allowing participants to express themselves without interruption. Throughout these sessions, the participants maintained a non-intrusive environment. The researcher carefully observed the participants' body language, where they mostly nodded in acknowledgement while refraining from interjecting during the speakers' discourse. This approach fostered a smooth and conducive environment for open communication within the sharing circles. Nevertheless, despite the limitations of sharing circles that have been discussed, the researcher believed that this method's advantages outweighed its drawbacks. As a result, the researcher adopted the sharing circles to address all the research questions.

4.6.5 Document analysis

Bowen (2009, p.3) describes document analysis (DA) as the "systematic procedure for reviewing or evaluating documents." He continues that document analysis is done in qualitative research to "elicit meaning, gain understanding, and develop empirical knowledge from relevant documents." Fundamentally, research findings must relate to the study's context to ensure the recommendation of contextualised practices. Therefore, lesson plans and educational policies, such as selected schools' technology integration policies, the Curriculum and Assessment Policy Statement (CAPS), and Department of Education policies on ICT-Education and reports in South Africa were reviewed to understand the research context. For this investigation, the researcher chose pertinent documents using purposive sampling as his guide, which was informed by the research questions. It is crucial to note that the researcher did not use document analysis as a tool for research or data collection but rather to comprehend the policy framework for school technology integration.

Mainly, DA involves looking through written records, including files, diaries, field notes, and books (Davie & Wyatt, 2021;Conger et al.,2016). After interviewing and observing teachers, the researcher examined their lesson plans to comprehend what they would have taught and document it on the observational template. Furthermore, after class, the researcher requested the participants' permission to make photocopies of their lesson plans, demonstrating a pedagogical intent to integrate technology. It is crucial to note that in including lesson plans in document analysis, the researcher was cognisant that some scholars prefer documents prepared outside the requirements of current research (Altheide et al., 2008; Davie & Wyatt, 2021; Rapley, 2018). Therefore, they do not consider lesson plans of observed lessons prepared for the study as documents for DA.

However, like Gardin (1973), Karppinen and Moe (2012) and Quintão et al. (2020), the researcher included lesson plans in document analysis. This is because lesson plans could offer opportunities to see if there is a pedagogical intent to integrate technology into the lesson (Koehler & Mishra, 2008). Thus, incorporating lesson plans in document analysis could provide insight into the teachers' TPACK development. Discussing the benefits of document analysis as an approach, Wood et al. (2020, p. 460) state that "it is an enabler for obtaining the language and words of participants, and an unobtrusive source of information," which, as representing the participants' written information, can be taken to be trustworthy and genuine.

Therefore, documents are written evidence that can be consulted and reviewed because they are readily available in the physical world. It was necessary to analyse the participants' lesson plans to strengthen the validity of this research and determine whether teachers successfully integrated technology. The researcher wanted to check whether the teachers' daily documentation reflected what they had promised to do. The study's analysis was driven by the predetermined research objectives and questions, for instance, verifying teachers' questionnaires and interview responses by looking at actual lessons. Consistent with Davie and Wyatt (2021) that teacher knowledge in practice is understood through class observations, the researcher observed and evaluated the four participants' lesson plans. The Life Sciences teachers' TPACK was validated through document analysis per their survey and interview responses. The following section articulates how the researcher navigated his position in this research.

4.7 POSITIONALITY AND REFLEXIVITY

In research, the researcher needs to be cognizant of personal biases that may affect the results and put into place measures to mitigate the influence of these biases. In addition, the researcher must acknowledge that there might be power dynamics between the researcher and the participants (Cohen et al., 2018; Holmes, 2020; Patton & Broward, 2023). Further, the researcher needs to define their role clearly, and according to Holmes (2020), the researcher's first role is as a researcher, and the second is as a learner. With all these considerations in mind, I acknowledged that I am a District Education official (Subject Advisor for Life Sciences), which made me an insider in the study that involved Life Sciences subject. Moreover, I was aware that as a supervisor of the teacher participants, this might impact how they would relate to me in the study. To counter these power dynamics, I placed myself as a learner (Ngcoza & Southwood, 2015) and did not misuse my position as a District official to influence the participants. Instead, I conducted this research in agreement with research principles.

Further, I anticipated that my professional relationship with my participants would facilitate their 'buy-in' to this study without feeling compelled as I am their supervisor. I have been a teacher and colleague with the teacher participants and have built professional relationships for ten years. I anticipated my interaction with the participants would continue our professional relationship. Moreover, I was also mindful of the need to reflect on my culture, personal background, and experiences that might shape my interpretation of the findings (reflexivity). As Mason-Bish (2019) explains, reflexivity requires that the inquirer reflects on their role in an inquiry. Their experiences, background, and culture can shape their interpretation, including the meaning they ascribe to the data and the themes they advance. I have been a Life Sciences teacher in a rural secondary school, and I am currently an advocate of technology integration in teaching, which further made me an insider in this study.

I took precautions to minimise any of my subjectivities throughout the research steps to counteract the effects of my background on the research processes. For example, I used research instruments designed and reviewed by experts to lessen possible bias. Moreover, I was reflective on my probing questions during interviews and sharing circles to minimise my influence on the data gathering. During data analysis and interpretation, the potential remained for the researcher's lens to impact the interpretation of the findings. I used thematic analysis and specific examples from interview transcripts to reduce this influence. In other words, I allowed the data to speak for itself.

Furthermore, consistent with socio-cultural theory (Vygotsky, 1978), I acknowledged the role of culture in this research. My cultural background is different from that of my participants. I admitted that I would deal with participants' practices and lived experiences from a culture different from mine. For instance, although I am Zimbabwean (Shona speaker), similarly to Mutanho (2021), I learned to speak isiXhosa to understand and respect their culture, and hence I shifted from being an outsider to an insider. In addition to learning the Xhosa language, customs, and ceremonies, I also immersed myself in the Sotho traditions because some of my participants were Sotho speakers. The following pictures in Figure 13 show me sharing my pride in the local cultures through their dressing.

Figure 13: Researcher demonstrating learning of the local cultures

In addition to learning the languages, I remained mindful that age, customs, race, gender, and marital status might impact the study. As a result, I set aside all my prior research assumptions and learned from the participants. The following section explains how the generated data were analysed.

4.8 DATA ANALYSIS

Data analysis entails breaking the data into bits and then 'beating' the bits together, much like when making an omelette, an assimilation activity where the central process is breaking and beating eggs (Bazeley, 2013; Bingham, 2023; Conger et al.,2015). In this study, the researcher gathered qualitative and non-numerical data using a questionnaire, semi-structured interview, lesson observation, and sharing circle discussion methods. The researcher analysed the qualitative data using qualitative procedures. Miles et al. (2018) reiterate that qualitative data analysis techniques are most suitable when an in-depth subject investigation is required. Advocates of qualitative data analysis methods argue that the perspective is inductive in its approach.

Themes, patterns, and concepts are deduced using accurate readings of primary data. This makes constructing an appropriate coding scheme, which is, at this approach's core, complicated and time-consuming. For instance, the researcher had a tonne of data for this study due to the accumulated collections of questionnaire responses, interview and sharing circle discussion transcripts, lesson observation notes, and field notes. As can be seen, there were seven questionnaire responses, seven transcripts from interviews with seven teachers, four sets of lesson observations from two participants, and two transcripts from sharing circle discussions. The TPACK questionnaire consisted of closed-ended Likert-type questions. The researcher used the criteria set forth by Schmidt et al. (2009) to analyse the questionnaire responses. The researcher gave each response to the questionnaire a score, ranging from 1 for strongly disagree to 5 for strongly agree. To display the average scores of the teachers on each TPACK component, the researcher calculated the mean scores and standard deviation values for each of the TK, CK, PK, PCK, TPK, and TPACK components. The researcher did this to determine which TPACK elements were prominent in the teachers' TPACK.

Upon receiving the questionnaire responses, the researcher coded the data and entered it into a Microsoft Excel spreadsheet. Before data analysis, the researcher performed a preliminary screening to identify missing values and outliers. Missing values occur when respondents fail to provide specific values. It was crucial to scout for missing values for several reasons, as they are a significant statistical concern in questionnaire research. First, missing values can compromise the validity of the findings by affecting the performance of confidence intervals and introducing bias in parameter estimates (Acock, 2005; Baraldi & Enders, 2010; Kyriazos & Poga, 2023). Second, missing values reduce information, resulting in inaccurate and invalid conclusions (Pallant, 2020; Pesigan & Cheung, 2023;Nyirenda & Simuja,2023).

In the present research, there were no missing values, and this could be due to the awareness the researcher raised with the participants on the importance of completing all the questions. After inspecting for missing values, the researcher examined the database for outliers. Outliers are values that deviate significantly from most responses (Kwak & Kim, 2017; Kyriazos & Poga, 2023). Like missing values, outliers can substantially impact statistical analyses by distorting measures of central tendency such as standard deviation and mean (Hair et al., 2010). However, in this study, the response options were constrained between 0 and 5, making the presence of outliers impossible. Once the data was 'cleaned', the researcher used Microsoft Excel for data analysis. Like Nomlomo (2007), Finucane (2021), and Lauer (2022), the presentation of questionnaire findings primarily utilised frequencies and percentages. Additionally, means and standard deviations were sparingly employed in the reporting, albeit in limited instances.

The current researcher's use of means, standard deviations, and percentages is a notable aspect to highlight. It is essential to clarify that despite employing these quantitative measures, the current research maintains its pure qualitative nature and is devoid of mixed methods. This acknowledgement arises due to the common association of means and standard deviation with quantitative and mixed methods research. While it is not the norm, several qualitative researchers such as Nomlomo (2007), Finucane (2021), and Lauer (2022) have incorporated limited quantitative elements into qualitative studies for specific purposes. This involved summarising numeric data in conjunction with qualitative information. Specifically, Sandelowski's (2001) work delves into a nuanced discussion about employing numeric data, including means and standard deviations, within qualitative research contexts. By doing so, Sandelowski (2001, p.1) challenges what he referred to as the anti-number myths in qualitative research as follows:

> Two myths about qualitative research are that real qualitative researchers do not count and cannot count. These anti-number myths have led to the underutilisation of numbers in qualitative research and the simplistic view of qualitative research as non- or anti-number. Yet numbers are integral to qualitative research, as meaning depends, in part, on numbers. As in quantitative research, numbers are used in qualitative research to establish the significance of a research project, to document what is known about a problem, and to describe a sample.

Similarly, Miles and Huberman (1994) and Goldberg and Allen (2015) also cite instances where quantitative elements like means can potentially support communicating qualitative findings. Furthermore, McBeath and Bager-Charleson (2020) provide comprehensive insights into designing qualitative research, including discussions on integrating quantitative elements like means and standard deviations into qualitative studies. However, it is essential to acknowledge that statistical measures are not conventional within pure qualitative research. The application of quantitative measures in the current study was cautious and deliberate, intended to enhance the qualitative analysis through specific numeric summaries. Notably, in the present research, means and standard deviations were used sparingly to compare the differences in the dominance of the different TPACK components.

Furthermore, Cohen et al. (2018, p.475) explain that reducing enormous volumes of data is "one of the most enduring problems of qualitative analysis." On the other hand, Braun and Clarke (2012, p.78) pronounce thematic analysis as a "foundational method for qualitative analysis" for surfacing a "rich and detailed yet complex account of data that can eschew the anything goes critique of qualitative research." In light of this, the researcher chose the thematic analysis approach for analysing the qualitative data, which spanned about nine months. Thematic analysis is acclaimed for offering a valuable and efficient method for conducting data analysis. The thematic analysis allows for discovering salient themes at various textual levels. Themes can then be organised and illustrated once they have been disclosed. Thematic analysis, thus, makes it easier to find and group fundamental, organising, and global themes (Clarke et al., 2015; Moloi et al.,2023). An organising theme is composed of a set of basic themes, and a group of organising themes is made up of a group of global themes. Themes are categorised according to the underlying narratives they tell.

Consequently, thematic analysis enables the division of a text to identify various groups of themes and their connections. This benefits data reduction, display, verification, and conclusion drawing by making these processes more manageable. The researcher undertook this approach using multiple steps following Thompson's (2022) coding procedures. Thompson (2022, p.1417) mentions that "a code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and evocative attribute for a portion of language-based or visual data." Further, Thompson (2022, p.1184) identifies what he refers to as "first cycle coding" in which he explains it as "a way to summarise segments of data initially. As a second cycle method, pattern coding is a way of grouping those summaries into a smaller number of categories, themes, or concepts." The inquirer read through each transcript several times before he started to code to become accustomed to the participants' voices. As Miles et al. (2018) suggest, the researcher completed the initial round of coding by underlining the likely codes in blue and writing the names of the initial codes in the margins of the transcripts to distinguish between different codes. Then, the investigator carefully interrogated the codes and deliberated on them with his supervisors to determine their worth and the viability of alternate interpretations.

After finishing the first coding cycle, the researcher created a master list of codes that guided the subsequent cycle. Later, the researcher made a new code set and recorded the interviews. The researcher then created categories by carefully examining the connections between the codes. The researcher organised the themes using pertinent quotes from the interview transcripts after defining them using the emerging categories to identify emerging themes from the data. Following the conclusion of the second coding round, the researcher copied the quotes containing participant clan names and pasted them into Microsoft Word below their code name to organise them into the appropriate code groups.

Importantly, the researcher used the participants' voices to support the findings by quoting from the transcripts when presenting the interview findings (Miles et al., 2018;Simuja & Silvanus,2023). To ensure the coherence of the data analysis with the theoretical frameworks, the researcher used the SCT as the overarching theoretical framework to understand how the rural Life Sciences teachers' interaction with technology could offer them opportunities to develop TPACK. On the other hand, the researcher utilised the TPACK framework as the analytical lens to examine the specific TPACK knowledge domains that the Life Sciences teachers in rural secondary schools developed. The next section explains how the research instruments were pilot-tested.

4.9 PILOT STUDIES

Bell et al. (2018, p.153) caution to "not take the risk, pilot test first." Thorough planning is one of the most compelling research strategies; pilot testing is typically a crucial part of this planning. According to Lemon and Hayes (2020, p.608), "a pilot study is a small-scale preliminary study conducted before the main research to check the feasibility or to improve the design of the research." In this study, the researcher pilot-tested to pre-test the research instruments to ascertain the absence of ambiguity and if they could gather the types of data the researcher intended to obtain (Bell et al., 2018). Consequently, the researcher administered the research instruments to a group of seven participants as part of a pilot phase to identify and rectify any shortcomings. Notably, the individuals chosen for the pilot were from an appropriate population but were distinct from the participants within the study's main sample. This differentiation was a deliberate choice made to prevent potential bias that might arise from pilot participants having previous familiarity with the research instruments, as highlighted by Taherdoost (2019). This approach was taken to ensure the reliability and validity of the instruments while minimising any potential influence on participants' responses.

The pilot study results showed that the initial research instruments' questions had overlapped. For instance, the response to question 6 contained the details requested in the original survey's question 7. After the pilot, question 7, which overlapped, was dropped. In addition, 56 of the original questionnaire questions did not touch on the context of the schools. Following the pilot study, it was discovered that the questionnaire would be of limited use without contextual information. Additionally, the questionnaire would not be coherent with the theoretical framework of this study (SCT and TPACK), which both acknowledge that teacher knowledge, such as TPACK, is context-bound (Koehler et al., 2013). This finding led the researcher to increase the questionnaire's size from 56 to 76 items to include questions about the contexts of the schools (see Appendix F). The other research instruments were not altered as they generated the type of data anticipated for the study.

Pilot studies, however crucial they are in research, are not without flaws. The pilot study results could influence researchers to draw the wrong conclusions or predictions. Additionally, while pilot test findings can offer evidence of the anticipated response rate, magnitude, and preliminary results, this is not always guaranteed as they frequently draw from smaller samples and lack a statistical foundation (Bell et al., 2018). Second, running a pilot study might limit researchers because it would require additional funding. Despite these drawbacks, piloting a study can help increase the likelihood that it will succeed in the actual research, which is why it was used in this study. The next section deals with the ethical considerations related to this research.

4.10 ETHICAL CONSIDERATIONS

This section details this study's ethical considerations. Informed by existent literature, research ethics are defined as "the moral principles governing research, from its origin through to collection and dissemination of results and beyond" (Kyngäs et al., 2020, p.46). Since this study involved human participants, there was a great need for the researcher to observe all the ethical dictates strictly. In this study, research ethics were addressed and implemented through procedures such as receiving ethics approval from Rhodes University (see Appendix J) and the Eastern Cape Department of Education (see Appendix K), gatekeepers' approval (see Appendix E), permission to audio-record responses (see Appendix C and D), norms of voluntary participation, confidentiality, anonymity, informed consent, feedback to the participants, and acknowledgement and recognition of traditional local authority. These are discussed in detail in the following sub-sections.

4.10.1 Ethics Clearance and Gatekeepers' Permission

Researchers who intend to conduct research on human subjects should seek approval from their institution's ethics review committee (Iphofen & Tolich, 2018). The researcher met the criteria for ethics by requesting permission from the Faculty of Education's Ethics Committee at Rhodes University and was approved (Ethical Clearance application number: 2022-5958-7224 (see Appendix J). In addition, according to Oliver (2010, p.15), "ethical procedures for data collecting involve obtaining the consent of people in authority (gatekeepers) to grant access to study participants at research sites." A gatekeeper is a person who has authority at a site, grants admission, assists researchers in accessing individuals and aids in identifying the sites to explore (Merriam & Tisdell, 2015). Accordingly, the researcher requested clearance from the ECDoE to research in the schools (research sites). The clearance was given (see Appendix K). Moreover, the researcher used this letter from the ECDoE to ask for the school principals' consent to work with the teachers at the research sites (see Appendix E). This is consistent with Oliver's (2010) assertion that getting consent before data generation is an element of informed consent and an ethical best conduct.

The researcher was committed to upholding the participants' rights, encompassing voluntary involvement, confidentiality, informed consent, respect, transparency, and safety, as Guillemin et al. (2018) outlined. Participants were explicitly informed about their right to voluntary participation and the freedom to withdraw from the research without any adverse consequences, as stipulated by Hamilton and Finley (2020). This understanding was reinforced as participants completed a consent form, a process reiterated verbally (see Appendices B to D). Before signing the consent forms, the researcher provided a comprehensive explanation of the research's objectives, procedures, the rationale for their inclusion, and the utilization of the study's findings, among other pertinent details (Cohen et al., 2018;Sepula & Simuja,2024) (see Appendix B to D).

Conversely, the researcher's existing familiarity with the teachers facilitated access to schools and classes, reducing challenges in securing entry. Initial school visits were not negotiation attempts but served as introductory sessions where the researcher discussed the research with the school principals and provided official authorization letters. However, inviting teachers to participate posed distinctive ethical considerations, considering their subordinate relationship to the researcher. When the researcher initially sought participants, misinterpretations arose among some teachers, fearing potential differential treatment if they declined participation. Concerns were voiced about potential biases in the researcher's interactions, with apprehensions that those involved in the study might receive preferential treatment. Additionally, teachers expressed unease about being observed by their supervisor, even though the research was unrelated to their classroom performance. To address these concerns, the researcher communicated the research's scope and purpose, emphasising its divergence from an evaluation of teaching abilities. The researcher emphasised a neutral and non-evaluative role as an observer, stressing the study's objective of capturing authentic classroom interactions rather than assessing individual teaching competencies.

4.10.3 Confidentiality, Privacy, and Anonymity

In this study, the researcher had to navigate a dilemma when researching with indigenous peoples regarding the conventional approaches to anonymity recommended by research methodology books, such as Cohen et al. (2018). These sources often stress the importance of concealing participants' real identities by assigning pseudonyms. However, it is essential to recognise that conducting research with indigenous peoples, particularly within their respective cultures' intricate fabric, demands a heightened sensitivity. For instance, the present research was conducted within African cultures, isiXhosa and SeSotho, where a distinct cultural norm prevails. In these cultures, addressing an adult by their first name is considered disrespectful, even if it is a pseudonym. This highlights the challenge of maintaining anonymity while respecting cultural norms. Culturally, in the Xhosa and Sotho traditions, adults are respectfully addressed by their clan names, which are of profound social significance and imbued with deep spiritual meanings. These clan names often carry more weight than surnames and can be associated with specific deities. The Xhosa and Sotho people believe that their clan names are intrinsically linked to the spirit of their ancestors. As a result, the clan names are so significant to the African peoples that they can be invoked in conflict resolution processes. For example, in conflict situations, the elders or leaders from the same clan may mediate disputes, drawing on the shared identity and common ancestry encapsulated in these clan names. Faced with the ethical imperative of respecting participants' cultures and the established principle of concealing real identities, the researcher collaborated with the participating teachers, seeking their input on the matter. The participants ultimately opted to be addressed by their clan names, which transcended mere identifiers in the context of this research. The provided clan names included Xaba, Manci, MaTshezi, Mkoena, Faku, MaMbotho, and MaZikhali.

4.10.4 Integrity, Respect, Honesty, and Transparency

The researcher vowed to guarantee that the study was conducted with honesty, integrity, respect, and openness (Iphofen & Tolich, 2018). The researcher explained the research processes, information, and outcomes to the greatest extent possible. The researcher took precautions to prevent falsifying, distorting, and misinterpreting information. This was further ensured by the fact that Dr. C. Simuja and Prof. K. M. Ngcoza supervised all stages of the research. Moreover, the researcher upheld the value of integrity by being punctual for all his meetings and appointments with the participants. Further, the researcher conducted the study in a highly open, honest, dignified, and transparent manner by disclosing all relevant data and findings to the participants and seeking their feedback.

Specifically, the researcher followed Shreffler and Huecker's (2022, p.137) advice that "the researcher should be objective and strive to avoid bias at all times while interpreting and analysing data." Consequently, the researcher made concerted efforts to adhere as closely as possible to data analysis standards. The researcher asked the participants to check the interview and the sharing circle discussion transcripts to uphold openness and honesty. Because of the cultural distinctions between the researcher's background and his participants, the researcher was aware of these when he dealt with the participants' perspectives and lived experiences in a particular cultural setting. The researcher discarded his preconceived notions from earlier studies to gain insight from the participants' viewpoints. Lastly, throughout the study, the researcher respected his participants' ages, languages, nationalities, customs, races, colours, genders, and marital statuses.

4.10.5 Feedback to the Participants

After completing this investigation, the researcher intends to send to all the participants the information they need to view the thesis in the Rhodes University electronic repository. Following the Department's guidelines for ethical approval, the researcher will also print copies of the thesis for the ECDoE (see Appendix K).

4.10.6 Recognition of Traditional Local Authorities

The schools used as research sites are found in rural communities where traditional leaders are highly respected, to the point where most schools have their names. In respect and acknowledgement of the traditional leaders, other SGB members and the researcher informed the Chiefs about this study in the schools. The following section addresses the issues related to the present study's trustworthiness.

4.11 ENSURING THE TRUSTWORTHINESS OF THE FINDINGS

Trustworthiness is the readers' confidence or trust in the research findings (Lemon & Hayes, 2020; Løvlie et al., 2023; Shenton, 2004). To achieve this, the core principles for a research's trustworthiness are validity and reliability (Quintão et al., 2020).

4.11.1 Validity and reliability of the findings

Validity refers to "the extent to which a concept is accurately measured" (Lemon & Hayes, 2020, p. 606). On the other hand, reliability is a research tool's capacity to accurately and consistently measure what it intends to measure (Heale & Twycross, 2015; Quintão et al., 2020). The researcher used several strategies to ensure reliability and validity. First, the researcher piloted the instruments before the study (see Section 4.9). The pilot study's findings led to a revision of the methodology, which altered some of the questions and wording of the research instruments, as discussed in Section 4.9.

Second, the researcher strengthened the process of generating the data. For instance, the researcher wrote down all the field notes as soon as possible after each participant interaction while the information was still vivid. In addition, the researcher used electronic equipment, like audio and video recorders, to capture all the discussions and classroom observations, enabling the researcher to provide in-depth representations of his observations and the contexts. After transcription, the researcher returned all the transcripts to participants for fact-checking, a process referred to as 'member checking' (Candela, 2019). Participants had the chance to correct factual errors and provide more clarity. The researcher only used the final transcript, which the participants had proofread. For participant anonymity and confidentiality, only the researcher had access to all transcripts. Every time the researcher engaged the participants, he wrote his reflections in a reflexive journal. Each reflection contained a summary of what the researcher did, specifics of what transpired, his assessment of the day, and reactions to the events. This allowed the researcher to use previous experience to inform the subsequent one because the researcher always concluded each entry with improvement recommendations.

Third, despite the absence of claims of bias-free research (Heale & Twycross, 2015), the researcher tried to limit his own bias in this study because he was conscious of its impact on the findings. Identification of the causes of bias, such as researcher attributes, sampling bias, and interpretation bias (Candela, 2019), was crucial for the researcher to develop strategies for minimising the prejudice and the danger it posed to the validity of this study. Through interactions with critical friends and colleagues, the researcher identified weaknesses in his sampling procedure, data interpretation, and the impact of his personal qualities on this study (Quintão et al., 2020). After working with them as their supervisor, the researcher had his own preconceived biases about the teachers' TPACK strengths and limitations. The researcher could have opted to work solely with competent teachers. However, instead, he developed a sampling procedure that allowed him to choose teacher participants based on the essential aspects of this research (i.e., subject taught and desire to participate) and not his subjectivities. The way that data is interpreted is another common way that bias is expressed. The researcher took care to separate his interpretation from the participants'. To reduce the impact of his own biases on the interpretation of the data, the researcher drew on the theoretical frameworks, which offered the language of descriptions and explanations of the facts. Findings were derived from the data, not from the researcher's personal biases (Lemon & Hayes, 2020; Løvlie et al., 2023).

Fourth, the researcher applied the tenets of triangulation to ensure validity. According to Flick (2022), there are four basic types of triangulations. These are methods triangulation, sources triangulation, theory triangulation, and analysts' triangulation. However, to strengthen the case study findings, Natow (2020) mentions the triangulation of sources and theories. In this study, the researcher triangulated four data collection tools (sources triangulation): the questionnaire, interviews, observations, and sharing circles. The researcher did this to ensure that the other instrument's strength would compensate for the weaker one (s). For instance, the researcher got more clarity from the participants during the semi-structured interviews than he could have through the questionnaire. This aligns with Natow (2020, p. 165) that "the important feature of triangulation is not the simple combination of different kinds of data, but the attempt to relate them to counteract the threats to validity identified in each." In addition, dissecting the phenomenon from two theoretical lenses, i.e., SCT and TPACK (theory triangulation), offered this study a more holistic and in-depth understanding of the teachers' TPACK development.

Fifth, peer debriefings were other methods the researcher utilised to enhance this study's trustworthiness (Scharp & Sanders, 2019). All full-time and part-time PhD scholars are invited to join the Department of Education at Rhodes University three times a year for PhD weeks. The researcher had the chance to talk about his work and solicit input from his peers during these PhD weeks. In addition, the researcher presented this study at local and international conferences, such as the South African Association for Research in Mathematics, Science and Technology Education (SAAMSTE) EC Chapter on 23 September 2022 and the South Africa-Swedish University Forum (SASUF) on 21 September 2022. The researcher's biases were examined, interpretations were probed, and interpretation grounds were elucidated on these platforms (Candela, 2019). Additionally, the researcher had critical friends who critiqued his work and frequently listened to him explain his ideas. The critical friends aided in keeping the researcher's interpretation of the facts accurate and honest with himself. These interactions with his peers during this research allowed the researcher to clean his thoughts of emotions and notions that would otherwise muddle excellent judgment (Hamilton & Finley, 2020).

Sixth, proper involvement is the dedication to hearing from and learning from various people interested in the study outcome (Merriam & Tisdell, 2015). High response rates, decreased attrition, better compliance, enhanced reported information correctness, and lack of linguistic and cultural obstacles contribute to the study's trustworthiness (Lemon & Hayes, 2020, p.682).

As previously said (see Section 4.7 - Positionality and reflectivity), the researcher learned isiXhosa to understand and respect the participants' culture better despite being a Shona speaker from Zimbabwe. As a result, the researcher could interact with teachers in their native language to lessen linguistic or cultural obstacles. Moreover, the researcher tried to involve the teachers in his research as often and meaningfully as possible. Unlike in Guillemin et al.'s (2018) study, where there were trust problems between the researchers and participants because the participants believed that "the researchers were performing research for their gain," this research intended to empower teachers to be more thoughtful of their TPACK. The researcher stressed this as much as he could.

Seventh, the researcher also increased the trustworthiness of this study by building a case study database that is open to external review by an authorised reviewer. All the data gathered was in this database. The researcher kept it in a folder on his desktop to be readily moved to another laptop for review. The database contains TPACK survey responses, interview transcripts, lesson observation notes, videos of teaching episodes, and sharing circle transcripts. Finally, the researcher kept a chain of evidence that was meant to make it possible for an outsider to trail the development of any evidence from the first research questions to the research conclusions and recommendations. The researcher provided enough references to the relevant sections of the case study database in his result analysis section. The researcher's database lists the actual evidence as well as the circumstances, such as the date and location of the interview under which it was gathered. The following section folds this chapter.

4.12 CHAPTER SUMMARY

Chapter 4 presented the research methodological framework guiding this research. The chapter commenced by expounding on the chosen research paradigm, which laid the philosophical foundation for the study firmly rooted in an interpretivist perspective. The qualitative research approach was subsequently presented, underlining the study's commitment to exploring the multifaceted nature of TPACK development within teachers' lived experiences. This approach facilitated a nuanced understanding of the intricate interplay between technology, pedagogy, and content knowledge in a real-world teaching context. The chapter then discussed the case study method employed, including the rationale for its selection. The research sites and participant sampling techniques, including purposive sampling, were also discussed. The appropriateness of research tools such as questionnaires, interviews, classroom observations, and sharing circle discussions for comprehensive data collection was highlighted, as was the systematic and rigorous thematic approach used for data analysis. Furthermore, the chapter discussed how the research's trustworthiness was reinforced by incorporating triangulation and pilot studies to validate findings and ensure reliability and validity. The chapter concluded by addressing ethical considerations, outlining steps to protect participants' rights and to obtain informed consent.

CHAPTER FIVE: PRESENTATION AND ANALYSIS OF RESULTS

> The landscape of technology integration in teaching remains in a perpetual state of evolution. As the multitude of technologies available continues to expand, so does the breadth of approaches teachers employ in integrating them into their practices. Thus, the ways in which technologies are woven into the fabric of teaching and learning are as varied and nuanced as the technologies themselves. (Niess, 2011)

5.1 INTRODUCTION

The epigraph above sets the tone about the continuous evolution of technology, which inevitably compels teachers to constantly adapt their approaches to integrating technology into teaching. This adaptation leads to new ways of leveraging technology in teaching-learning spaces, causing each teacher to bring their unique perspectives, preferences, and expertise to bear on the integration process. Consequently, a tapestry of approaches tailored to the teachers' unique contexts has emerged. This chapter, therefore, is premised on Research Question 1 to explore the teachers' reported practices, experiences, and ways they integrate technology in their classrooms, all through their individual and collective voices. The primary goal of this chapter (5) and chapters 6 and 7 is to present, analyse, and interpret the study's findings. The data presented were generated through a closed-ended questionnaire, semi-structured interviews, lesson observations, and sharing circle discussions. The data generation process spanned eleven months - from the second week of September 2022 to the third week of July 2023. Throughout this period, the researcher made the utmost effort to adhere to all the ethical requirements.

During the data presentation, analysis, and interpretation, the researcher was guided by the research questions, the reviewed literature, and the theoretical framework for this study. The researcher presents the questionnaire findings using frequencies, percentages, mean scores, and standard deviation values in the form of tables, graphs, and charts. Additionally, the researcher presents the semi-structured interviews and sharing circles discussion results thematically in a narrative form using excerpts or verbatim statements from the participants. In the spirit of triangulating the findings, the researcher then attempted to consolidate the findings from the various data generation instruments during the results presentation, interpretation, and discussion stages. Since this is one of the first studies of its kind to investigate teachers' TPACK development in rural secondary schools in South Africa, it is crucial to provide an overview of the research methodology before presenting the findings, which also applies to chapters 6 and 7. Next is the participants' demographic information, followed by the chapters' findings based on Research Question 1. A chapter summary then folds the chapter.

5.2 AN OVERVIEW OF THE RESEARCH METHODOLOGY

The methodological approach used in this study merits particular acknowledgement, as it stands as a pioneering effort in incorporating an indigenous research method (sharing circles) into TPACK research in rural South African schools. Recognising the methodological contributions of this study is vital for facilitating future research that aims to test or expand upon the methodologies required for such investigations (see Section 4.6.4). The present qualitative research, underpinned by the SCT and TPACK theoretical frameworks, was situated within the interpretivist paradigm. This study aimed to explore, through an investigative case study, the experiences and practices that shape the development of TPACK in secondary school Life Sciences teachers. The study was conducted in rural schools in the Joe Gqabi district in the Eastern Cape province of South Africa. Furthermore, the present investigation went beyond the present trajectory by distinguishing and isolating the various components of teachers' knowledge within TPACK.

5.2.1 Research Questions

Several relevant sub-questions specific to the context were formulated to comprehensively investigate the complex phenomenon of TPACK development in rural Life Sciences teachers. These sub-questions were designed to target multiple facets of the research question specifically.

1. How do rural secondary school Life Sciences teachers describe their ways of integrating technology?
2. How do rural secondary school Life Sciences teachers describe their technological pedagogical content knowledge?
3. What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?

Research Question 1 (RQ1) was formulated to deepen understanding of how technology integration occurs among rural Life Sciences teachers. It aimed to achieve this by examining the teachers' personal narratives and accounts of their teaching experiences involving technology tools. The objective was to uncover whether or not their interactions with these tools provided them with opportunities to construct and develop their TPACK. Furthermore, given the dynamic and context-dependent nature of TPACK, which is known to be unique to each teacher and teaching context (Cox & Graham, 2009; Warr & Mishra, 2023), Research Question 2 (RQ2) was designed to construct a nuanced understanding of the nature of the teachers' TPACK from their perspectives. Lastly, Research Question 3 (RQ3) aimed to unpack the contexts, experiences, factors, and practices employed by rural secondary school Life Sciences teachers who lack formal training in technology integration in their efforts to develop their TPACK.

5.3 DEMOGRAPHICS OF THE PARTICIPANTS

The first part of the questionnaire aimed to collect demographic information from the participants. Gathering information about the participants' demographic and personal characteristics was essential as these factors can influence the development of teachers' TPACK. Analysing this information offered insights into the contexts in which Life Sciences teachers develop their TPACK. Similarly to Nomlomo (2007), Finucane (2021), and Lauer (2022), this section presents the findings regarding four characteristics: age, gender, teaching experience, and level of education, as illustrated in Table 7.

Table 7: Demographics of Participants

Clan name	Gender	Age	Teaching experience	Highest qualification
Xaba	Male	37	13	BEd Life Sciences
MaMbotho	Female	34	10	Post Graduate Certificate in Education
Mkoena	Male	52	27	BEd Life Sciences & Agricultural Sciences
MaZikhali	Female	46	14	BEd Life Sciences & Natural Sciences
MaTshezi	Female	31	7	BSc Zoology
Manci	Male	29	6	BEd Life Sciences & Mathematics
Faku	Male	32	9	BEd Life Sciences

5.3.1 Gender of Respondents

The questionnaire asked the respondents to indicate their gender based on the following categories: (i) male, (ii) female, and (ii) other. Analysis of the questionnaire showed that out of the seven Life Sciences teachers who completed the questionnaire, four (n = 4, 57.1%) indicated they were female, and three (n = 3, 42.9%) were male. According to the research findings, more female teachers participated in this study than their male counterparts. These results are consistent with the findings of Moosa and Bhana (2023), who conducted a study on the inclusion of men in the teaching profession. Their research revealed a notable pattern of gender-based occupational segregation and the increasing predominance of female teachers within the South African educational landscape.

Nonetheless, it is essential to note that the effect of gender on TPACK development was not part of this study's scope and was not investigated; however, it might be an attractive future research area. Besides, previous investigations into the impact of demographics on the development of TPACK have produced inconsistent outcomes. For instance, Ibrohim et al. (2022) conducted a study involving 1357 high school science teachers to explore the influence of gender, teaching experience, place of teaching, and level of education on the TPACK of science teachers. The overall findings revealed that gender, teaching experience, place of teaching, and level of education did affect the teachers' TPACK. In contrast, Sastria (2023) examined the influence of gender, age, and qualifications on TPACK proficiency among 211 biology teachers. His ANOVA results showed no significant effects of gender and age on the levels of TPACK.

5.3.2 Age of Respondents

The questionnaire asked the respondents to indicate their ages based on the predefined age groups: (i) 21 and under; (ii) 22-30; (iii) 31-40; (iv) 41-50; (v) 51-60; and (vi) 61 and above. Out of the seven respondents, three teachers (n = 3, 42.9%) fell into the 31-40 age group, while two teachers (n = 2, 28.6%) belonged to the 22-30 age group. There was one teacher (n = 1, 14.3%) each in the 41-50- and 51-60-year-old age groups. According to Table 7, most Life Sciences teachers in the study sample (n = 5, 71.4% collectively) were in the 22-30- and 31-40-year-old age groups. This finding indicates that the sample primarily consisted of teachers who were 40 years of age or younger. It is worth noting that only one teacher was above 50, and none were over 60. The small number of teachers over 50 years old and none over 60 could be attributed to retirement, as most teachers in South Africa retire at 55-60. More so, some of the elderly teachers, perhaps more averse to technology, might have opted out of the study sample. Although age differences could potentially impact teachers' integration of educational technologies and TPACK development, the literature review conducted in this study did not show significant correlations between age and technology use or TPACK development. Therefore, this study did not examine the effect of age on TPACK development, as explained in section 5.3.1, but could be explored in the future.

5.3.3 Teaching Experience of Respondents

The questionnaire included a question regarding the respondents' teaching experience, categorized as: (i) 0-4 years; (ii) 5-10 years; (iii) 11-15 years; (iv) 16-20 years; (v) 21-25 years; and (vi) 26 or more years. The range of teaching experience reported by the respondents varied from 6 to 26 or more years, which is closely related to their age. According to Figure 8, the largest group of Life Sciences teachers (n = 4, 57.1%) had 5-10 years of teaching experience. The second largest group (n = 2, 28.6%) had 11-15 years of teaching experience, and one teacher (n = 1, 14.3%) reported over 26 years of teaching experience. The teacher with the least experience had been in the profession for six years, while the longest-reported teaching experience was 27 years. On average, the teachers in the sample had 12.29 years of teaching experience. All the sampled teachers had more than five years of teaching experience.

Based on these findings, it can be assumed that the Life Sciences teachers in this study are experienced teachers who would have had opportunities to familiarise themselves with and appreciate the usefulness of educational technologies. This assumption is based on the belief that experienced teachers may be more inclined to integrate technology into their classrooms due to several factors. Firstly, they are likely to have greater familiarity with technology through personal and professional development experiences, which makes them more comfortable using it in their teaching. This familiarity may enable them to integrate technology seamlessly and effectively into their teaching. Secondly, experienced Life Sciences teachers often possess a deeper understanding of teaching and learning (PK), which allows them to leverage technology more effectively (TK) to enhance their teaching practices (TPK). They can design engaging learning experiences incorporating technology and guide learners in productively using technology (TPACK).

Furthermore, experienced Life Sciences teachers may have had more opportunities for professional development related to technology use, such as attending conferences, workshops, or courses, to stay updated with the latest technological skills (TK). These professional development opportunities could give them new ideas and strategies to develop their TPACK. While it is important to note that technology integration in classrooms is not solely determined by experience, these factors contribute to why experienced teachers may be more likely to integrate technology into their teaching practices. Therefore, it was reasonable to assume that the Life Sciences teachers in this study would be capable of offering valuable insights into their experiences with technology integration and TPACK development.

5.3.4 Level of Education

Regarding the education level of the participants, the questionnaire included a question asking them to indicate their highest qualification from the following options: (i) Bachelor's degree, (ii) Post-Graduate Certificate, (iii) Master's degree, (iv) Doctoral degree, and (v) other. Table 8 illustrates the distribution of education levels among the Life Sciences teachers in the sample. It can be observed that most of the sampled teachers (n = 5, 71.4%) reported having a Bachelor of Education degree (BEd). One teacher (n = 1, 14.3%) held a Post-Graduate Certificate in Education (PGCE), and the other (n = 1, 14.3%) a Bachelor of Science degree (BSc). None of the participants reported having a Master's (Med or MSc) or Doctoral degree (PhD). It is important to note that all the participating Life Sciences teachers in this study possessed teaching qualifications, except MaTshezi, who holds a BSc in Zoology.

Nonetheless, most teachers in this study can be expected to possess high levels of CK and PK from their initial teacher training. Furthermore, it is worth emphasising that teachers with different qualifications, such as BSc and PGCE, were intentionally included in this study. The rationale behind this inclusion was that regardless of their specific qualifications, all teachers would have had some experience of teaching with technology. By including teachers with diverse educational backgrounds, the study aimed to capture a range of perspectives and experiences related to technology integration and TPACK development. The following section presents and analyses the findings of this study based on Research Question 1.

5.4 FINDINGS BASED ON RESEARCH QUESTION 1

This section presents the study's findings based on the question:

> How do rural secondary school Life Sciences teachers describe their ways of integrating technology?

Integrating technology in classrooms is an ever-evolving process, with teachers appropriating a wide range of approaches to incorporate technology into their teaching. The myriad of emerging and available technologies influences this diversity. In this study's context of secondary school Life Sciences teachers in rural schools, it was essential to understand their lived teaching experiences to shed light on their unique ways of integrating technology. These interactions with technology tools not only contribute to a deeper understanding of their ways of technology integration but can also provide opportunities to understand how they construct and develop TPACK. The data for Research Question 1 was generated through various instruments such as questionnaires, semi-structured interviews, sharing circle discussions, and lesson observations to explore these dynamics. This chapter presents the findings logically, examining the teachers' access to and utilisation of technology and then exploring the rationale for their technology use. Lastly, the section delves into the teachers' self-reported technical skills in using educational technologies. In contrast to the approach used by various qualitative researchers such as Nomlomo (2007), Finucane (2021), and Lauer (2022), who presented questionnaire findings through tables and bar graphs, the present study's researcher opted for using pie charts, a less conventional visual representation method in research reports. The following themes emerged from the data for Research Question 1.

- Teachers' Technology Access and Use
- The rationale for technology use
- Teachers' Self-Reported Technical Skills

5.4.1 Teachers' Technology Access and Use

In the questionnaire, teachers were prompted to specify the daily duration they engage with different technologies for both personal and professional purposes. Figure 14 illustrates the outcomes of this inquiry.

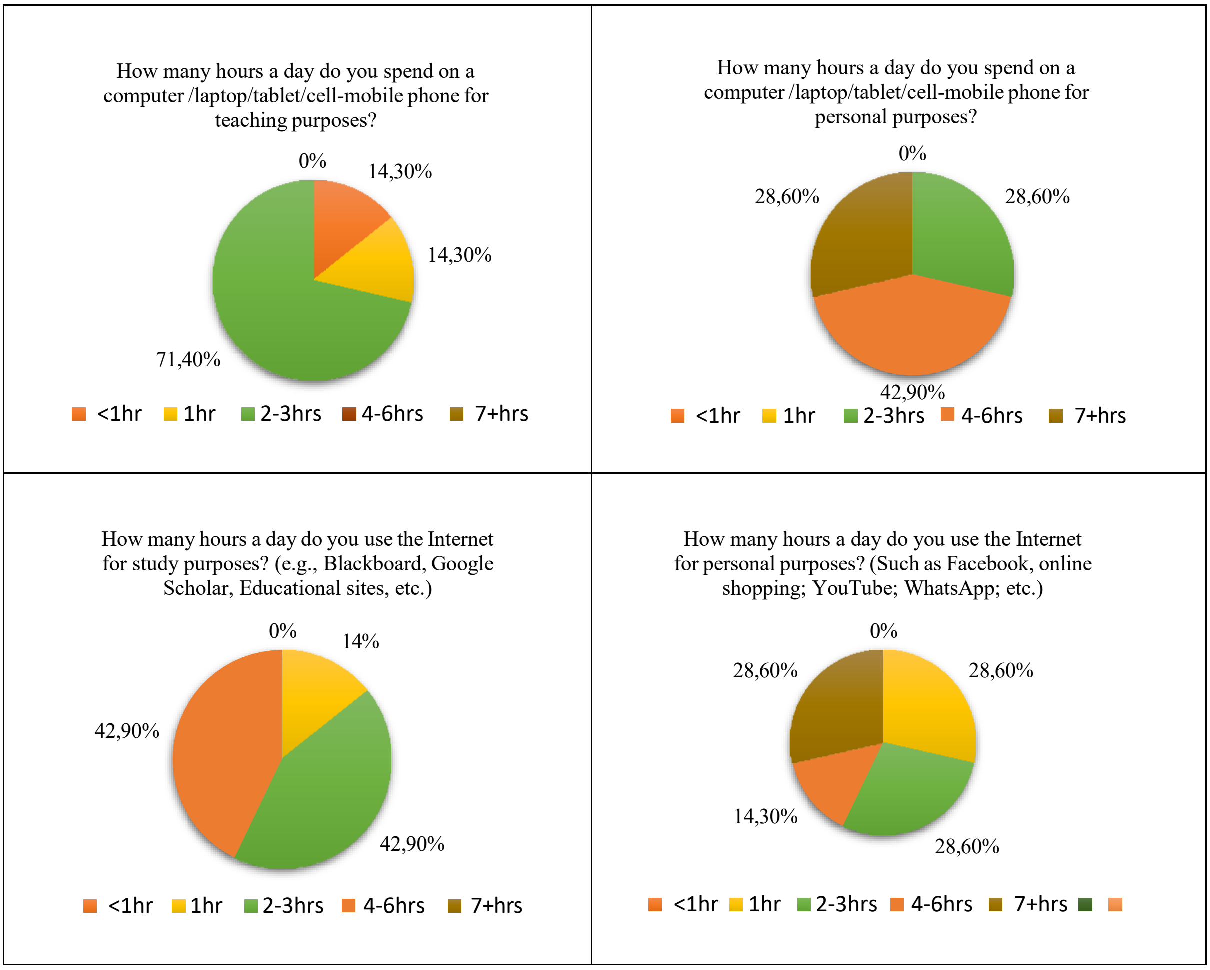


Figure 14: TPACK questionnaire findings – Teachers' technology access and use (n = 7)

It can be deduced from Figure 14 that all teachers used technologies per day. However, most respondents (n = 5, 71.4%) indicated spending over 4 hours daily on a computer, laptop, tablet, or cell-mobile phone for personal purposes. This finding suggests that teachers have access to computers, laptops, tablets, or mobile cell phones but mainly utilise them for personal purposes in their daily lives. This observation resonates with the notion of social interaction in which technology tools are not only confined to classroom use but are also embedded in society, where they are used for personal purposes.

Regarding using computers, laptops, tablets, or mobile cell phones for teaching purposes, most teachers (n = 5, 71.4%) only spend 2 to 3 hours per day, with no teachers spending over 4 hours teaching. This result indicates lower technology use for teaching compared to personal purposes. In addition, it can be further deduced from Figure 14 that respondents used the Internet daily. The findings further indicate that when using the Internet, most teachers (n = 4, 57.1%) reported spending 2 to 6 hours per day for study. Furthermore, there was a wide range of responses regarding Internet use for personal purposes, with two teachers (n = 2, 28.6%) reporting that they spend 1 hour, 2 to 3 hours and over 7 hours per day in each category. Only one teacher (n = 1, 14.3%) reported spending between 4 and 6 hours daily for personal purposes. It can also be seen that respondents accessed the Internet more than the computer.

Additionally, it is worth noting that most of the respondents in this study frequently utilise smartphones, tablets, the Internet, and computers. Interestingly, this finding diverges from Khashan's (2019) research, which explored the technology integration practices of secondary school teachers in Mississippi, USA, and revealed that mobile phones and iPads were the least utilised tools in science classrooms. This contradiction could stem from various factors. One plausible explanation is the differing educational contexts and technological landscapes in which the studies were conducted. The current study was situated in rural schools within the Global South, characterised by limited access to technological resources. This scarcity of technological resources compared to the Global North might have prompted rural teachers in this study to rely more on mobile phones as an essential pedagogical instrument.

On the contrary, Khashan's (2019) study was conducted in urban schools within the Global North, where teachers might have had better access to various technologies, mitigating the need to rely on mobile phones. Moreover, a significant temporal distinction exists between the studies, with a five-year gap separating Khashan's (2019) research from the current study conducted in 2023. This temporal gap might have influenced a shift in the adoption and incorporation of technology in education. Given the rapid evolution of technology, especially the integration of enhanced features within mobile phones, this study posits that attitudes and practices regarding their use in classrooms might have evolved, leading to an increased preference for mobile phones, as observed in the current research. Figure 14 indicates teachers' higher usage of these technologies for personal rather than teaching purposes. Nonetheless, these findings suggest that all participants actively use technology for teaching or personal uses. Subsequently, the forthcoming section delves into the rationale behind and the methods by which teachers integrate technology within their classrooms.

5.4.2 Rationale for Technology Use

This section offers a window into teachers' practices as they integrate technology into their classrooms, aiming to glean insights directly from their self-reported experiences. There are several reasons why obtaining information directly from teachers was crucial. Firstly, teachers are the primary implementers of technology within their daily classroom activities. Their extensive engagement positions them as repositories of significant expertise in technology usage. Learning from their experiences was pivotal in uncovering insights and strategies unique to their first-hand involvement. Secondly, teachers possess an intricate understanding of their specific contexts and classroom dynamics. By sharing their technology integration methods, they provide valuable insights into adapting and tailoring technology tools to suit the distinct needs of their subjects, grades, and learner demographics. Thirdly, teachers are perpetual learners, consistently striving to enhance their teaching practices. Through sharing their experiences and reflecting on their efforts in technology integration, this study explored how teachers continually update their knowledge, adopting the latest trends, best practices, and emerging technologies to develop their TPACK. The following sub-sections provide insights into the teachers' ways and purposes of integrating technologies on the above premises.

5.4.2.1 Source of information

In the semi-structured interviews, teachers were prompted to articulate the methods and objectives underpinning their use of technology. The findings highlighted that teachers employ diverse technological tools to access a wide array of resources from the Internet. These resources included e-books, past examination papers, teacher study guides, video clips, and marking guidelines. The teachers specified utilising these materials across various facets of teaching and learning, spanning from lesson planning, actual teaching, and assessment tasks to the critical analysis of learners' performance.

Manci notably highlighted his extensive reliance on technology in his teaching practices. He underscored the pivotal role of technology in enriching both his lesson preparation and delivery to learners. Specifically, he detailed the use of online resources to access supplementary information from websites and to establish connections with fellow teachers from different schools. In the classroom, Manci articulated his use of projectors for delivering PowerPoint-based lessons and integrating downloaded animated videos to augment the quality of his Life Sciences classes. Moreover, he elucidated his use of Office tools such as Word to craft educational materials like worksheets and assignments for his learners while managing learners' assessment records, including mark lists, through spreadsheet applications. In essence, Manci's perspective encapsulates his approach to leveraging technology in teaching.

> *I find technology to be extremely helpful in my teaching. It greatly aids me in preparing and delivering engaging lessons. I rely on technology to access valuable resources and teaching materials from the Internet and other schools. In my classroom, I frequently use projectors and PowerPoint presentations. Additionally, I develop worksheets and assess learner work using various technological tools.* (Manci)

Additionally, MaZikhali strongly values the efficacy of technology in delivering lessons that captivate and inspire learners, fostering a more effective learning process. She further permits her learners to use their mobile phones to access supplementary information. MaZikhali's perspective on the role of technology in teaching is succinctly captured in her statement.

> *If we use technology, learners will be better engaged and learn better. I often allow my learners to use cell phones to seek additional information whenever possible in my teaching.* (MaZikhali)

When sharing her teaching experiences involving technology, MaZikhali conveyed a profound belief in the significance of technology in the educational sphere. Yet, alongside this acknowledgement, she underscored the necessity of vigilant oversight regarding learners' use of technology. MaZikhali highlighted the potential hazards of learners accessing unsuitable or unwanted information from the Internet in the absence of proper supervision. Her reflections encapsulate this sentiment:

> *In today's digital age, using technology for teaching can improve the learning experience. It simplifies the teaching process, although it does require extensive preparation. However, I have concerns about the potential risks involved when learners are not closely supervised when using technology. There is a possibility that they may stumble upon inappropriate or misleading information. Nonetheless, with proper monitoring and guidance, I support using technology for teaching and learning*. (MaZikhali)

Like MaZikhali, MaMbotho also reported that she used technology to disseminate ideas, exploring online materials in addition to textbooks to obtain supplementary information. She mentioned:

> *Whenever I have the opportunity, I use the Internet to share ideas. Additionally, technology allows me to explore a wide range of resources and access supplementary information online beyond what is provided in textbooks.* (MaMbotho)

Furthermore, Xaba elaborated on his use of technology to facilitate the delivery of Life Sciences concepts, making them more accessible and engaging for his learners. He expressed that:

> *Technology makes teaching easier, especially in teaching Life Sciences complex diagrams. I just project the diagrams and images, which saves me a lot of drawing, which I am not good at.* (Xaba)

The evident reliance on videos and PowerPoint slides in Xaba's use of technology signals a teacher-centric approach to integrating technology in the classroom. When queried about his learners' engagement with technology for learning, he highlighted his encouragement for them to utilise the Internet for information retrieval. Nonetheless, he acknowledged that their opportunities for independent use were restricted as he managed and dictated the timing and manner of technology utilisation in his class. In his own words:

> *In my classroom, the decision regarding the use of technology is solely made by me, leaving learners with little to no voice in the process.* (Xaba)

Regarding the teachers' use of technology as an information source, the above findings provided valuable insights into the technology used to access Internet resources, such as e-books, past examination papers, study guides, video clips, and marking guidelines. These digital materials are used across various aspects of the teaching and learning process, from lesson planning, lesson delivery, assessment, and performance analysis. Furthermore, this study revealed that teachers utilise projectors, PowerPoint presentations, and downloaded animated videos to facilitate lesson delivery and enrich the learning experience. However, Berger and Wolling (2019) contend that relying solely on technology to acquire information, such as utilising YouTube for accessing videos, indicates a lower degree of technology integration. Conversely, creating multimedia displays incorporating simulations and animations exemplifies a higher level of integration.

Therefore, if Berger and Wolling's (2019) assertion holds true, then most teachers in this study operate at a low level of technology integration. While this may be so, this study acknowledges the efforts that the teachers in rural schools, who lack formal technology integration training, are making as a springboard for higher technology integration. Moreover, the findings reveal that the teachers use productivity tools within the Office suite to generate worksheets, assignments, and spreadsheets to track learner assessments. Furthermore, most teachers expressed a firm conviction regarding the significance of technology in contemporary teaching and learning environments. Overall, the teachers demonstrated a keen awareness of the potential of technology to enhance teaching and learning experiences. They acknowledged its capacity to provide additional resources, foster learner engagement, and streamline the teaching process. However, the teachers also emphasised the need for careful monitoring and guidance to ensure responsible and effective utilisation of technology while addressing concerns regarding learners accessing inappropriate content.

5.4.2.2 Creating real-life learning experiences

In the interviews, it emerged that certain teachers leverage technology to provide authentic, real-life experiences for their learners. MaMbotho, for example, highlighted that her use of technology varied based on the specific nature of her lessons. She integrated technology to complement her teaching by offering additional information through video clips. Additionally, she mentioned implementing inquiry-based and simulation to provide her learners with genuine, real-world learning experiences. According to her insights, she observed enhanced learning outcomes in learners when technology was integrated. Over her ten-year career, she witnessed technology's positive impact on science education.

> *With video clips and online materials, my learners learn better, and I can also save time. Over the years, I have seen the changes technology has brought into teaching - a big move in innovations*. (MaMbotho)

Similarly, MaTshezi, with a robust science background stemming from her BSc in Zoology, highlighted the pivotal role of technology in bridging the divide between classroom instruction and real-life applications. She underlined that technology offers learners valuable exposure and widens their access to supplemental information beyond textbooks. MaTshezi also pointed out that the visual nature of technology enhances learning outcomes and elevates the perceived value that learners place on lessons infused with technology compared to traditional teaching approaches.

> *Technology is key in this 21st century. It offers valuable exposure and access to information beyond textbooks. It provides interactive elements that improve comprehension and retention of Life Sciences concepts. I believe technology fosters collaboration, critical thinking, and problem-solving skills, which we want to see in our learners*. (MaTshezi)

However, while MaTshezi extolled the virtues of technology, MaZikhali voiced apprehensions regarding the potential drawbacks of its excessive use. She raised concerns that an overdependence on online information could adversely affect learners' essential skills, such as handwriting and drawing, which are vital in science. Furthermore, she expressed worries that an excessive emphasis on technology might inadvertently lead to a neglect of crucial cultural norms and values. In her own words, she conveyed:

> *Technology is crucial in providing learners with exposure beyond textbook knowledge and connecting it to real-life situations, fostering innovation. However, there is a concern that excessive use of technology may lead to a dependency on it. I worry that this can disrupt essential skills such as writing, drawing and even spelling. Moreover, there is a risk that extensive use of technology could overshadow the importance of fundamental cultural norms and values. I do not know how a balance can be struck and ensure that the preservation of core skills and values accompanies technology integration.* (MaZikhali)

From the findings above, the interviewed teachers acknowledged the potential of technology to create real-life learning experiences for their learners. By incorporating video clips, inquiry-based strategies, simulations, and online platforms, they indicated that they aimed to provide learners with opportunities to engage with authentic and relevant scenarios. These findings align with the research conducted by Canada et al. (2014), who employed the TPACK framework to examine technology integration practices among 433 science teachers in Manitoba. Their study revealed that science teachers' primary motivation to integrate technology was to offer authentic learning experiences that connect with contemporary issues, real-life situations, and challenges. This approach aimed to foster profound, meaningful, and dynamic learning while enabling learners to develop essential scientific skills and grasp fundamental concepts. In sum, the teachers' responses showed that they recognised the potential of technology to create real-life learning experiences that enhance learner engagement, learning outcomes, and critical thinking skills. However, they also cautioned about the need to balance technology integration and the preservation of essential skills and cultural values. By achieving this equilibrium, teachers can effectively harness technology to create meaningful learning opportunities for their learners.

5.4.2.3 Promoting learner-centeredness and motivation

Moreover, when questioned about their utilisation of technology and its specific purposes, certain teachers emphasised employing technology to teach abstract scientific concepts, stimulate and foster interest in learners, and diversify their teaching methodologies. One teacher, MaTshezi, exemplified this by mentioning:

> *I use technology to teach abstract concepts in Life Sciences and motivate my learners, enhancing their understanding. I see technology as an audio-visual form of teaching, which adds more diversity to my teaching, and my children (learners) love it.* (MaTshezi)

Additionally, Faku concurred with MaTshezi, affirming that technology is particularly well-suited for a subject like Life Sciences, which is distinguished by its abstract concepts. He further elaborated:

> *Technology fits quite appropriately with Life Sciences. There are many experiments on the subject which are easily taught using technology. I find many differences in teaching while using technology as compared to traditional teaching methods.* (Faku)

Contrary to the above teachers, Mkoena, the oldest and most experienced teacher in the study sample, voiced a concern that technology might not cater to all learner groups. His concern flowed from his observation that some learners hail from low-income families in disadvantaged communities where the learners would not have had access to technology tools. In his analysis, the learners from low-income families might lack the prerequisite technological skills to use certain technologies. He empathised as follows:

> *However, since learners have different learning styles and come from various backgrounds, technology lessons may not be favourable for some of them, especially those who come from low-income families who never had some basic technologies at home. These children might be left behind as they may lack technology skills*. (Mkoena)

Like MaTshezi, MaMbotho detailed the essential nature of technology in her teaching. She outlined key reasons for this assertion, citing technology's capacity to motivate and augment comprehension, fostering a passion for the subject among her learners. Furthermore, she observed that her learners displayed heightened creativity, confidence, and motivation in her classes. She articulated:

> *Technology motivates learners and enhances their level of understanding, and learners become more responsible, creative, and analytical; using technology helps me cover the syllabus faster.* (MaMbotho)

MaMbotho expanded on her primary use of technology within the same discourse, particularly in presenting intricate lessons. Emphasising its role in diversifying her teaching methodologies, she underscored how technology facilitates the implementation of a learner-centred approach, a factor that significantly motivates her learners. She elucidated:

> *I use technology to introduce diversity into my teaching strategies and transition from a teacher-centred to a learner-centred learning environment, which I find to motivate my learners.* (MaMbotho)

When probed to elaborate more on how exactly technology aids her in motivating her learners to learn, MaMbotho explained:

> *Daily, I rely on technology for routine tasks such as browsing the Internet and downloading videos and images. These videos and images help me explain the science concepts much easier, making it easier for my learners to understand them.*

Learners who find learning something easy become more motivated to learn even more challenging tasks. (MaMbotho)

In the same vein, MaZikhali emphasised the necessity of technology in motivating learners and exposing them to the digital realm. She expressed that technology enables the exploration of new domains that may not be covered through traditional teaching methods. Furthermore, MaZikhali highlighted the potential of learners' utilisation of technology to influence society and the learners' future careers directly. She explained as follows:

I believe teaching with technology helps meet learners' technological needs and introduces them to the digital world. Technology offers great potential for exploring new areas beyond traditional teaching methods. Additionally, the skills and knowledge acquired by learners in school directly impact technology use in society and their future careers. (MaZikhali)

Further, the analysis of the teachers' responses indicates that all the teachers concurred with each other regarding using technology to motivate learners. For example, in addition to what other teachers had said, Xaba expressed that technology holds great importance as it motivates learners and fosters values like teamwork and effective communication:

Technology increases the motivation of learners, and they learn teamwork values, I find that technology can encourage learner-centred learning and can be used for collaborative learning and communication among the learners. (Xaba)

Xaba's earlier response reveals an intriguing finding: technology has the potential to foster teamwork among learners by encouraging collaborative engagement. If this finding holds true, it implies that incorporating technology into teaching can cultivate crucial teamwork and collaboration skills essential for their future professional pursuits. Additionally, Xaba emphasised the immense value of technology in effectively communicating scientific concepts through diverse teaching approaches. According to Xaba, leveraging technology has led to notable enhancements in learning outcomes compared to traditional methods like chalk and board.

> *When I compare the teaching mode using chalk and board and technology, I can see a vast difference in the learning outcomes among learners. They tend to do well when taught using technology.* (Xaba)

More so, Mkoena proposed that learners should be granted more significant opportunities to participate in the decision-making process and the use of technology. He expressed that offering learners more chances to actively engage with the learning process is essential instead of solely acquiring information. He proposed that:

> *As teachers, we should provide more opportunities to learners to make them active learners; rather than just getting information, we must allow learners to use technologies in their learning rather than us always having to use technology in teaching.* (Mkoena)

The responses above revealed that teachers leverage technology to foster a learner-centred environment and enhance classroom motivation. These teachers highlighted technology's efficacy in teaching intricate scientific concepts and piquing learners' interest. They stressed that incorporating technology can make teaching more varied, visually appealing, and engaging, thereby facilitating improved comprehension. This is achieved by accommodating diverse learning styles and actively empowering learners to participate in the educational process. This discovery is in consonance with the findings of Mariam and Levan (2023), who reported that science teachers employ technology to bolster learner engagement and learner-centred pedagogy. Nevertheless, the teachers also cautioned that it is imperative to consider their learners' diverse needs and backgrounds, ensuring equitable access and providing support for developing their technological skills.

5.4.2.4 Fostering Inclusive Learning

Related to the above theme, another noteworthy finding that emerged was the consensus among most teachers regarding diverse learning styles among learners, including visual, auditory, and kinesthetic preferences. The teachers expressed that technology could be crucial in accommodating these learning styles by exposing them to diverse audio-visual pedagogical tools such as simulations, videos, and pictures using data projectors, smart boards, and various applications (Apps). The teachers indicated that this approach could cater to all learners' individual needs. For instance, MaTshezi highlighted that her teaching approach prioritises

Apps to engage learners. Hers is one of the two classrooms from the participants that is fitted with a SMART board with Internet connectivity. The other classroom with a SMART board belonged to MaMbotho. MaTshezi explained as follows:

> *My focus in using technology tends to be on the Apps. I search for Apps that would help me explain things clearly to my learners or will help them.* (MaTshezi)

Further discussion with MaTshezi made it clear that she heavily relied on her diverse technical experiences and skills in using the SMART board. Upon observing her classes, it could be noted that every second and every detail is meticulously executed according to her lesson plan. MaTshezi consistently utilises the SMART Board as part of her teaching methodology, recognizing its importance in aiding learners' focus. She navigated the Apps on the SMART board so well without difficulty. Additionally, she employed PowerPoint presentations to highlight key ideas and concepts from the lessons. Regarding her usage of the SMART board technology, the teacher stated as follows:

> *Planning lessons with the SMART Board goes beyond simple step-by-step teaching for learners. I use technology to present Life Sciences concepts uniquely and highlight the underlying principles that may be difficult to explain. In other words, the dynamic nature of the SMART Board enables me to annotate and emphasise concepts more effectively than traditional chalkboard methods. Also, like a computer, I can keep my lessons hidden until needed.* (MaTshezi)

The above response indicates some pedagogical intent MaTshezi had during lesson planning and delivery using the SMART Board. MaTshezi's ideas of thinking about how to use the SMART Board during lesson planning is a worthy practice. This indicates the presence of TPACK in the teacher. Furthermore, MaTshezi explained that the SMART Board allowed her to save previous lessons and helped her reflect on and understand what was successful and what was not:

> *It enables me to have different versions for my classes. For instance, with the data management course, I have two different classes; if I have a longer lesson, I can save it and restore it to the next class where that particular class left off. And I can also save these lessons.* (MaTshezi)

In addition to MaTshezi's use of the SMART Board, MaMbotho, who also has the technology in her classroom, mentioned that for her, an essential feature of the SMART Board is that the writing and drawings can be easily erased when a new slide is selected. However, as MaMbotho explained, the researcher felt that the ease of erasing on the SMART Board could be advantageous in clearing the board or hinder teaching intentions if something deemed essential is unintentionally deleted. To this concern, the teacher indicated that she discerningly distinguishes between the uses of SMART Boards and blackboards, utilising both in her teaching to effectively present details to her learners. She stated as follows:

> *I always use the SMART Board and the blackboard in my lesson planning. Typically, I utilise the SMART Board to present questions while the solutions are written on the whiteboard. This is because although the SMART Board is useful, its size is limited to 1.2 to 1.5 meters. When I turn the electronic page, the previous content disappears. Therefore, I use the SMART Board to highlight and pose questions while writing the actual solutions on the blackboard. This way, the solutions remain visible for learners who may require additional time to copy them into their notes. Furthermore, if a learner later approaches me with a question, I still have some slides available to refer to*. (MaMbotho)

Indeed, the researcher observed the MaMbotho using the SMART Board and blackboard to teach the topic of Plant responses to the environment in Grade 12 (see Figure 15), as she described.

Figure 15: MaMbotho's SMART Board-fitted classroom

MaMbotho adeptly segregated straightforward questions and primary concepts, displayed on the SMART Board, from the solutions and problem demonstrations presented on the conventional blackboard. The researcher also noted the teacher's enthusiasm for sourcing digital materials pertinent to her lessons, such as video clips, simulations, and documents. The lesson highlighted the benefits of simulations on Geotropism and Phototropism. It allowed learners to vividly perceive how plant roots and stems reacted to environmental cues like light and gravity. While such experiments typically require up to three weeks to yield results in real-life settings, MaMbotho's use of simulations enabled learners to observe the results within minutes.

Furthermore, the digital simulation allowed the teacher to review and revisit any lesson segment. Nevertheless, it was intriguing to discover that in this study's sample, there was one teacher who utilised simulations, although most did not integrate this innovative technology into their teaching practices. This observation aligns with the findings of Chernikova et al. (2020), indicating that science teachers scarcely utilise simulations. Although MaMbotho utilised simulations, the researcher noted some limitations during the lesson observation. For instance, the availability of suitable videos and simulations posed a challenge, as many lacked the necessary quality for teaching purposes. Moreover, some of the videos were linked to unreliable web addresses, making them susceptible to sudden disappearance. Despite these challenges, the researcher found both the use of simulations and the teacher's approach beneficial for both the teacher and her learners, marking a positive stride in the right direction.

Overall, the responses above indicate that the teachers acknowledge the presence of diverse learning styles among learners, including visual, auditory, and kinesthetic styles. On this understanding, the teachers view technology as a valuable tool for accommodating these learning styles. The teachers appreciated the inclusive nature of technology by providing audio-visual pedagogical tools such as simulations, videos, and pictures through data projectors and SMART Boards. However, it is crucial to note that there are contrasting findings in the literature regarding the use of SMART Boards by science teachers. For example, in Vermette and Hechter's (2014) and Kazmi and Mohammad's (2023) investigations, most science teachers were found to utilise the SMART Boards. However, few teachers utilised them in the study carried out by Larijani and Abedi (2021). In the present study, the findings revealed a limited use of the SMART Boards, with only two teachers using the technology. Therefore, this study contradicts Vermette and Hechter's (2014) and Kazmi and Mohammad's (2023) findings but confirms the findings by Larijani and Abedi (2021).

The above contradictions could be explained by Koehler and Mishra's (2007, p.137) suggestion that technology integration in teaching is a "system that comes with its own affordances and hindrances that make some technologies more applicable in some situations than others". In the context of this study, set within rural and resource-limited areas, only two schools were equipped with SMART Boards. This shortage of technological infrastructure largely contributes to the minimal usage of SMART Boards. Additionally, during classroom observations, it was evident that MaTshezi actively gathered digital resources, including video clips, simulations, and documents, aiming to enrich the learning process. The employment of simulations proved notably valuable, allowing learners to comprehend intricate concepts, like plant responses to environmental stimuli, which would typically necessitate weeks to observe in real-life experiments. Nevertheless, challenges emerged, notably the difficulty in sourcing appropriate simulations and the unreliability of some online resources. Despite these hurdles, using simulation video clips was recognised as beneficial, facilitating an inclusive learning environment.

5.4.2.5 Saving time and effort

In further answering the question about the ways and the purposes for which the teachers use technology, most expressed their use of technology to save time and effort. Upon analysing their interview transcripts, it became evident that the teachers primarily used technology for information presentation. They further indicated that presenting lessons with technology saves time and effort. For example, Xaba believed that technology could expedite and simplify lesson delivery in the following statement:

> *Instead of writing things on the board, I can just use the projector to present them.* (Xaba)

However, contrary to Xaba, Mkoena held a divergent view from the narrative that technology saves time. The teacher seemed to prefer using the chalk-and-talk method. From the classroom visit, it was evident that his classroom lacked proper technological equipment. See Figure 16 below.

Figure 16: Mkoena's Data projector-fitted classroom

As depicted in the above images, the sole technology available in Mkoena's classroom is a malfunctioning data projector alongside a whiteboard and a blackboard. To facilitate any technological aid, the teacher was required to bring in a laptop, a mobile projector, and extension power cables, a process that proved to be time-consuming, contradicting the intended purpose of technology to streamline educational processes. Consequently, the teacher resorted to using chalk on the blackboard, as depicted in picture 1, during a Grade 12 Genetics lesson. This recurrent experience of transporting, setting up, and dismantling the devices likely contributed to Mkoena's dissatisfaction, stating that the use of technology consumed valuable lesson time, as expressed below:

> *Technology helps deliver information, but it is not essential. That is fine if I can explain something clearly without relying on technology. While I had prepared PowerPoint presentations for my lessons, I have not used them in a long time due to the lack of available technological equipment. Bringing my own projector and setting it up is time-consuming and impractical. I wish there was a dedicated room fitted with technology to save time. Otherwise, using my own devices eats into valuable class time.* (Mkoena)

Likewise, Manci acknowledged the potential for technology to expedite lesson delivery, yet he did not deem it indispensable. He paid minimal attention to how extensively or in what ways his learners could benefit from integrating technology into the classroom. His reluctance to adopt technology stemmed from citing the scarcity of resources and his inclination to hasten lesson delivery. It seemed evident that he favoured his traditional teaching methods, although he did not explicitly articulate this preference. His classroom has two projector screens and Wi-Fi connectivity (see Figure 17 below).

Figure 17: Manci's Overheard projector screen-fitted classroom

During the lesson observation, it was noted that Manci used a video projector to allow learners to see the visuals and images related to the lesson's content. During the Sharing circle, Manci expressed that using PowerPoint to present key points helped him visually convey important information to the learners. Notably, what distinguished Manci was his discernment that technology ought not to supplant teaching but, instead, function as a tool to amplify learners' grasp of scientific concepts. He articulated this viewpoint as follows:

> *Technology is merely a tool. It serves as a means of presentation and does not act as a teacher itself. It represents a distinct approach. When I engage in teaching, I strive to incorporate visual elements and utilise various resources. I accommodate different learning styles. The effectiveness of technology depends on the specific situation; it may be beneficial in some instances and not as much in others. It depends on what you aim to achieve and when and where it is appropriate to use it.* (Manci)

The quoted passage suggests that teachers who perceive technology as time-consuming in their lessons often do so due to a lack of essential classroom equipment. Surprisingly, even teachers like Faku, who have access to technological resources in their classrooms, are reluctant to utilise them. Faku cited that using videos to present information consumed more time than initially anticipated. This time constraint led him to revert to his preferred traditional teaching methods, sidestepping technology. Another reason for Faku's tepid stance towards technology is the lack of interest exhibited by his learners in the videos from previous lessons. He noted that his learners struggled to comprehend the 'heavy' English accent in these videos, leading to disengagement and passivity among the learners. This adverse experience left Faku demotivated to incorporate technology into his teaching. Consequently, the absence of necessary technology resources and the challenges associated with selecting relevant educational materials may provide a convenient rationale for teachers to avoid integrating technology into their classrooms.

Moreover, the teachers' discussions during the sharing circles further shed light on their ways and purposes for using technology. As what emerged from the semi-structured interviews, it became evident that their primary purpose for using technology in teaching was merely to save time, which is a limited perspective when it comes to learning and teaching. Their focus was primarily on using available devices as presentation tools rather than exploring the potential learning outcomes or considering learners' active use of technology. For instance, in the case of Manci, there was no emphasis on leveraging the tools for learning purposes or enabling learners to utilise them. When asked about involving learners in technology use, the only suggestion was to assist the teacher in operating the devices. This lack of learning rationale was apparent in Manci's statement:

> *I do not allow my learners to use the devices with me for a couple of reasons. Firstly, I have limited time; if a learner operates the laptop, it can take up to a day. Secondly, I have concerns about the devices themselves. I worry that the learners might accidentally click buttons or switch them off, wasting my time and creating issues.* (Manci)

Once more, Mkoena staunchly advocated for Manci's authoritative control over technology within his classroom, particularly concerning time management. Notably, Mkoena exhibited a pessimistic perspective and an unfavourable attitude towards integrating technology in educational settings. This negative outlook aligns with Mkoena's evident lack of TPACK, as indicated by his responses to the questionnaire. Mkoena's aversion to technology is underscored by his belief that its use could diminish communication between himself and his learners, potentially leading to a lack of interest and attention during lessons. In his view, this could result in the elongation of the time required to teach specific concepts. Mkoena articulated this sentiment, stating:

> *I believe that using technology in the classroom is subjective. Personally, I do not prioritise the extensive use of technology in my teaching. I have observed that*

> *incorporating technology negatively impacted my learners' communication and attention levels. I have also noticed that a colleague who uses technology has a higher failure rate among learners in their final exams compared to my classroom.* (Mkoena)

Mkoena's pessimistic outlook and restricted technological proficiency stem from various factors. Acknowledging his deficient technological skills, he admitted to lacking competence in tasks such as downloading videos from YouTube and effectively using spreadsheet software. Despite participating in technology training workshops, Mkoena found them unhelpful, emphasising their focus on basic computer operations rather than addressing his specific pedagogical requirements. This inadequate and generic training left him feeling uncertain and daunted by technology. Additionally, Mkoena's hostile stance towards technology might be influenced by observing the unsuccessful experiences of other teachers. When questioned about witnessing successful instances of technology integration in teaching, he indicated a lack of such examples. These adverse vicarious experiences have contributed to his diminished self-efficacy and reinforced his belief that technology may not be helpful in the classroom. In summary, Mkoena's limited knowledge and exposure to adverse experiences have shaped his unfavourable perception of technology, impeding his willingness to embrace it as a pedagogical tool:

> *Yes, I perceive many individuals as geniuses due to their self-development. However, I personally do not like learning from them. Let me give you an example of a colleague who has made significant personal progress despite being 57 years old. He takes a passive approach by using technology to deliver lessons without much concern for the learners' understanding. His approach is that his responsibility lies in delivering the lesson, while learners should study at home to pass.* (Mkoena)

The findings above indicate that the teachers' perspectives on using technology in their classrooms are primarily focused on saving time and effort in lesson delivery. They viewed technology as a means of presenting information quickly and easily, such as using projectors to display content instead of writing on the board. Like in the present study, Kriek and Stols (2010), Vermette and Hechter (2014), and Kazmi and Mohammad (2023), in their studies of science teachers' use of technology, found that although teachers have a wide range of educational technologies, they tend to use certain technologies more than others. For instance, PowerPoints were the most used by science teachers due to their time-saving and ease of use. However, the prevalent use of technology appears unidimensional, with limited consideration given to learners' active engagement or the potential of technology to enhance their learning experience.

Additionally, some teachers expressed reservations about the perceived time-consuming nature of setting up and utilising technology in the classroom, particularly when faced with inadequate equipment. Their perception of technology predominantly as a tool for information delivery restricts exploration of its potential for fostering active learning. Factors such as limited access to resources, negative experiences, and concerns about learner engagement and control over technology further influence teachers' choices. In summary, the identified potential of technology to facilitate active learning, improve comprehension, and encourage learner participation remains unrealised and underexplored in the teaching practices of these teachers.

5.4.2.6 Enhancing learner engagement and productivity

During the semi-structured interviews, certain teachers conveyed a different perspective, indicating that they employed technology not merely as a time-saving tool but also as an instrument to enhance learners' engagement and productivity. A notable illustration of this approach is found in MaMbotho's articulated purpose for utilising technology. In addition to saving time and effort, MaMbotho expressed a broader objective of leveraging technology to augment her learners' engagement and comprehension of the lessons. The following teachers' responses encapsulate their distinct purposes for integrating technology:

> *In my teaching, I use technology to enhance my learners' engagement in the lessons. For instance, I use interactive digital resources and multimedia presentations to create a dynamic and immersive learning environment.* (MaMbotho)

> *I draw inspiration from teachers who understand the potential of technology beyond mere convenience. I use educational apps and interactive software to captivate learners' attention, encourage their active participation, and deepen their understanding of Life Sciences.* (MaZikhali)

When it comes to integrating technology into my teaching approach, I prioritise learners' engagement. I view technology as a valuable instrument for enhancing the learning experience. By actively involving learners through technology, I aim to promote their understanding of the lessons and nurture their overall academic growth. (MaTshezi)

When questioned about the ways in which technology contributes to augmenting learner engagement and productivity, the teachers provided the following responses:

The multimedia presentations, interactive simulations, and educational apps allow learners to actively interact with the content and participate in hands-on learning experiences. For example, I design quizzes using Google Forms; these quizzes are self-marking so learners can receive immediate feedback for their work. This allows learners to track their progress and focus on improvement areas. I think such levels of engagement and individualized learning lead to increased productivity and a deeper understanding of the content. (MaZikhali)

Through Telematics and other virtual learning platforms, learners can connect and interact with their peers, fostering a sense of community and encouraging active participation. This means that technology opens opportunities for learners to engage and interact with people around the globe. (MaMbotho)

Furthermore, upon analysing MaZikhali's interview transcript, it becomes apparent that she perceives technology as an indispensable tool in the contemporary teaching and learning landscape. She holds a robust conviction that technology has rendered her teaching more accessible and interactive for learners. MaZikhali underscores the significance of expanding technology integration within schools, advocating for both principals and teachers to prioritise this imperative. According to her perspective, the incorporation of technology into teaching holds the potential to enhance the learning experience markedly. MaZikhali conveyed her thoughts on this matter with the following statement:

Technology has become an essential part of teaching in the current era, and its absence can hinder teaching and learning. As technology advances, it becomes essential for teachers to acquire the necessary skills to navigate and utilise these

> *tools. Personally, I strongly believe that using technology in teaching enhances interactivity and engagement among learners. Looking ahead, I envision a future where schools embrace even more technological advancements, such as video conferencing, to enrich the learning experience further.* (MaZikhali)

In the same vein, Manci confirmed technology's positive role in improving the learning experience. From his teaching experience, the teacher concedes that technology opens limitless learning opportunities for learners. He mentioned as follows:

> *I have witnessed firsthand how technology positively impacts learning. With educational software, online resources, and multimedia tools, learners can actively engage with the material and interactively explore concepts. Furthermore, technology facilitates real-time collaboration and communication, enabling learners to connect with experts and peers from all over.* (Manci)

In addition, in the sharing circle discussions, the teachers were prompted to share insights on their use of technology and its specific purposes. Additionally, they were asked about the distinctions in teaching Life Sciences with and without technology. MaZikhali remarked that teaching without technology might yield success for a limited audience, whereas integrating technology could draw in an additional cohort of learners who may not have traditionally comprehended explanations solely through oral instruction and chalkboard presentations. Reflecting on this, MaZikhali stated:

> *Without technology, teaching would be limited to old-fashioned methods like writing on a blackboard. However, nowadays, technology offers the opportunity to go beyond that by incorporating visual aids and hands-on demonstrations. It enriches the learning experience and helps learners better understand the concepts being taught.* (MaZikhali)

In the same sharing circle discussions, MaTshezi detailed her use of PowerPoint slides as a lesson presentation, significantly diminishing the necessity for chalkboard writing and saving valuable instructional time. MaTshezi underscored the efficacy of this approach in elucidating abstract concepts. Through the integration of SMART Boards, learners could visually explore images and diagrams, thereby improving their comprehension of complex subject concepts.

During the discussion, MaMbotho voiced her support for MaTshezi's methodology and offered a specific example related to teaching the topic of pregnancy. MaMbotho highlighted how technology facilitates visual comprehension, enabling learners to understand the intricate process of how a baby forms and develops in the womb. The experiences shared by MaTshezi and MaMbotho underscore the advantages of integrating technology, mainly through PowerPoint slides and SMART Boards, in the teaching process. MaMbotho's adoption of PowerPoint slides signifies a departure from traditional chalkboard methods, presenting a more efficient and time-saving approach to lesson delivery. By incorporating visual aids and multimedia elements, MaMbotho enhances the learning experience, fostering a deeper understanding of abstract concepts.

Overall, the mention of SMART Boards in teaching Life Sciences further emphasises the value of technology in visualising complex concepts. MaMbotho mentioned that learners can see pictures and videos on the SMART Boards, which suggests that visual representations are crucial in promoting comprehension and engagement. More so, MaTshezi's agreement with MaMbotho's approach further strengthens the case for incorporating technology in teaching. MaTshezi provides a concrete example related to teaching the topic of 'Pregnancy', where technology allows learners to witness the formation and development of a baby in the womb, something they could not observe otherwise. By leveraging visual resources, MaTshezi demonstrates how technology provides a unique opportunity to bring theoretical knowledge to life, creating a more vivid and immersive learning experience. In sum, both the interview and sharing circles findings suggest that technology, such as PowerPoint slides and SMART Boards, can significantly enhance teaching practices. It saves time, facilitates visual learning, and enables the comprehension of complex topics. The use of technology not only enhances the effectiveness of teaching but also engages learners by making abstract concepts more tangible and relatable.

Furthermore, during the lesson observation of Xaba's lessons, it became apparent that the teacher. Despite having 13 years of teaching experience, Xaba had only been trying to use technology for four years since she received a laptop from the Department of Education. Interestingly, Xaba's classroom was installed with essential technology, including a computer, projector, and Internet access. It is worth noting that this equipment was not provided by the Department of Basic Education but was donated by Vodacom, a company that installed these devices in each classroom. Furthermore, the company also set up a wireless Internet network in the school, ensuring Internet access from all classrooms. Additionally, the school possessed a science lab and a resources room, both equipped with interactive whiteboards. Moreover, the school also has a computer lab with computers and Internet access. The following pictures (Figures 18 and 19) show Xaba's classrooms.

Figure 18: Xaba's classroom with various technologies

Figure 19: Xaba's classroom with various technologies

Despite the extensive access to technology and resources, Xaba appeared not to be utilising the resources optimally in his teaching. When asked why it appeared so, the teacher explained as follows:

> *I have been hesitant to fully utilise the available technology in my teaching for several reasons. Firstly, my limited experience with technology and lack of training in integrating it into the curriculum has made me feel uncertain and apprehensive about incorporating it effectively. Secondly, I have been accustomed to traditional teaching methods throughout my long teaching career, making transitioning to a more technology-driven approach challenging. Lastly, the absence of formal support or guidance from the Department of Basic Education in utilising the donated technology has left me unsure about the best practices and pedagogical*

> *strategies to adopt. As a result, I have not fully explored the potential of the technology at my disposal in enhancing learner learning experiences. Honestly, I feel like I was thrown into a sea of technology without being made ready for it.* (Xaba)

Xaba's explanation highlights the complex factors influencing most teachers' limited integration of technology. These factors include personal hesitance due to lack of experience and training, resistance to change from traditional teaching methods, and the absence of comprehensive support and guidance from relevant authorities. As for many other teachers, this finding portrays a missed opportunity for Xaba to leverage the available technology effectively and potentially enhance learner engagement and learning outcomes. During the lesson observation, it could be noted that out of a range of available technologies, Xaba relied more on his laptop and projector for lesson presentations.

In addition, it also became apparent that Xaba's colleagues developed the PowerPoint slides he used. In other words, Xaba primarily relied on pre-existing presentations provided by colleagues and used them without adapting them in terms of quality or relevance to his learners. Like most teachers, the primary criterion for Xaba's selection of these presentations was time-saving, as he reported that he often felt constrained by limited teaching time. So, by using ready-made slides, Xaba aimed to expedite the lesson delivery process. However, the materials' quality and suitability were not considered. Consequently, Xaba observed a lack of interest and engagement among learners when these materials were utilised. This perceived disinterest and inactivity among learners led Xaba to prefer teaching without relying on technology.

Furthermore, Xaba's response that he felt he was thrown into a sea of technology without support is concerning. This experience highlights the importance of not only providing access to technology but also offering support, training, and guidance to teachers to ensure effective integration and utilisation of technology in the classroom. Additionally, it emphasises the need for teachers to develop their own digital literacy and pedagogical understanding to make informed decisions about the use of technology, considering factors such as quality, relevance, and learner engagement.

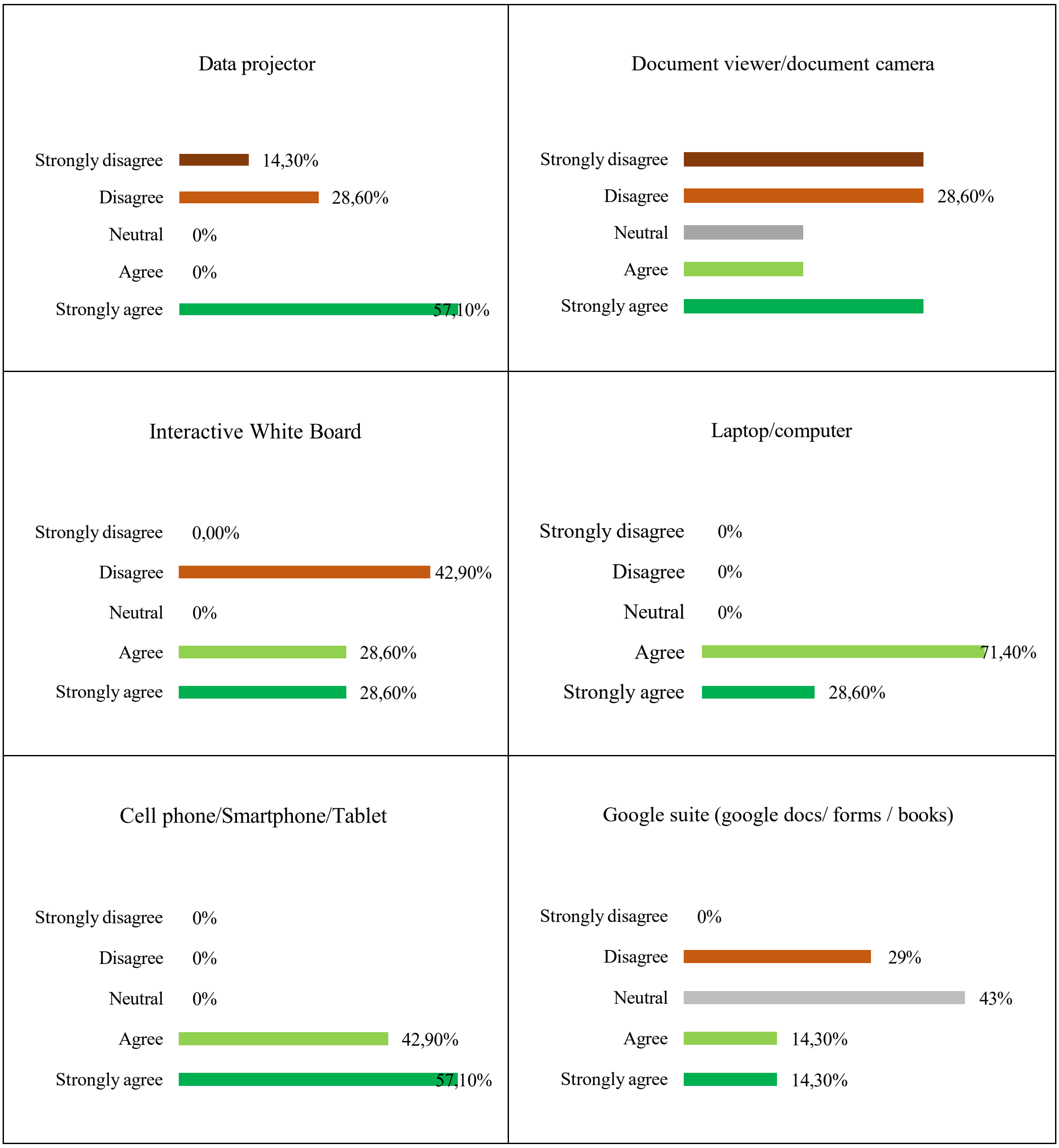
Taken together, the interview and sharing circles responses and lesson observations showed that some teachers demonstrate a progressive and learner-centred approach to integrating educational technologies into their teaching. It also became clear that teachers are beginning to view technology as a valuable tool for enhancing teaching and learning rather than replacing traditional methods. The teachers show a thoughtful selection of various technologies, such as simulations, videos, and interactive whiteboards, to address various pedagogical purposes. This resonates with the epigraph above that as the multitude of technologies available continues to expand, so does the breadth of approaches teachers employ in integrating them into their practices (Niess, 2011). For some teachers, these technologies are carefully chosen to serve specific pedagogical purposes, emphasising learner engagement, active learning, collaboration, and personalised experiences. By leveraging these technologies, the teachers aim to facilitate learner participation, critical thinking, and communication skills, creating inclusive and interactive learning environments.

Furthermore, the findings indicate that the teachers demonstrated a better view of technology. Besides merely using technology as a presentation tool, some teachers aim for their learners to use technology to support their learning and construct their knowledge. This could imply that the more precise the vision of technology a teacher has, the more effective implementation of technology they would demonstrate. The interpretation of the interview responses reveals the teachers' insightful perspectives on the significance and impact of integrating technology into teaching practices. Most responses reflected an awareness of technology's potential benefits in increasing learners' engagement and productivity.

More interestingly, the teachers clearly understand technology's role in creating a more dynamic and immersive learning environment, although some teachers indicated that they face challenges in this area. They highlight utilising digital resources, such as multimedia presentations and educational apps, as an effective means to capture learners' interest and actively involve them in learning. Overall, the interpretation of the findings showcases the teachers' comprehensive understanding of technology's potential as a powerful tool in rural Life Sciences teaching. When employed strategically, the teachers recognise that technology can enhance learners' engagement, foster a deeper understanding of the lessons, and cultivate critical thinking skills. The following sub-section discusses the teachers' technical skills needed to utilise some technological tools for teaching purposes.

5.4.3 Teachers' Self-Reported Technological Skills

The questionnaire asked the teachers to indicate their agreement or disagreement regarding the technical skills needed to use the given technologies. Figure 20 below presents responses categorised into five levels of agreement: "Strongly agree," "Agree," "Neutral," "Disagree," and "Strongly disagree," with corresponding percentages representing the frequency of each response.



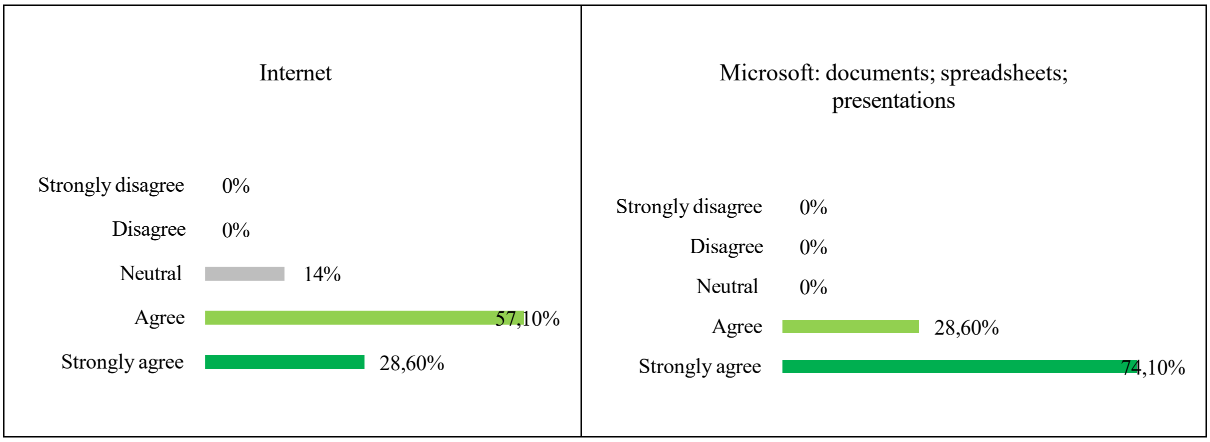


Figure 20: TPACK questionnaire findings – Teachers' technical skills (n = 7)

Figure 20 above provides valuable insights into the proficiency levels of teachers when using different technologies. The findings revealed that data projectors, laptops/computers, Microsoft Office suite (word, spreadsheets, presentations), and mobile/smartphones are the main teaching technologies used by the teachers. Furthermore, the analysis shows that technologies such as interactive whiteboards and document viewer/document are moderately used in teaching. In addition, teachers use technologies such as Google Suite (Google Docs, forms, books) the least. Most teachers demonstrated solid technological skills using laptops/computers, mobile devices, the Internet, and Microsoft tools. Most of them strongly agreed and agreed that they possess the technological skills required to use the technologies, indicating high confidence and competence in these areas.

However, it is essential to note that certain technologies revealed varied levels of technical skills among teachers. For example, data projectors yielded mixed results, with four teachers (n = 4, 57.1%) expressing strong agreement in their ability to use this technology effectively. Moreover, two teachers (n = 2, 28.6%) indicated disagreement, and one teacher (n = 1, 14.3%) strongly disagreed, suggesting potential challenges or a lower level of technical proficiency in utilising data projectors. Similar trends were observed with document viewer/document cameras, where responses were divided. While two teachers (n = 2, 28.6%) strongly agreed and one agreed (n = 1, 14.3%), thus exhibiting solid technical skills in using document viewer/document cameras, an equal proportion expressed disagreement. That is two teachers (n = 2, 28.6%) disagreeing, one teacher strongly disagreeing (n = 1, 14.3%), and another (n = 1, 14.3%) opting to remain neutral. This finding indicates a high variability in teachers' abilities and comfort levels in utilising document viewer/document cameras. From this finding, one can deduce that most teachers who participated in the study had low technical skills needed to utilise document viewer/document cameras.

Further analysis of the teachers' responses reveals that the interactive whiteboards also showed mixed levels of technical skills among teachers. While two teachers (n = 2, 28.6%) strongly agreed and the other two (n = 2, 28%) agreed, resulting in 4 teachers (n =57.1%) demonstrating strong technical skills in using interactive whiteboards, a significant portion of three teachers (n = 3, 42.9%) showcased a lower level of competence. This result implies that nearly half of the teachers who participated in this study regard themselves as having less technological skills to utilise the interactive whiteboards. One possible explanation for the high number of teachers with low interactive whiteboard technical skills could be that they might not have appropriated the technology as they hail from rural schools that do not have whiteboards.

As for laptop/computer usage, the findings revealed that two teachers (n = 2, 28.6%) strongly agreed, and five teachers (n = 5, 71.4%) agreed with their technical skills in utilising laptops or computers. Interestingly, no neutral, disagree, or strongly disagree responses were recorded. These findings indicate a significantly high level of technical skills among all the teachers (n = 7, 100%) when using laptops or computers. Most teachers agreed, suggesting they possess the necessary skills and confidence to effectively leverage these technologies in their teaching practices. This finding aligns with the growing integration of technology in education. It underscores the need to tap into the teachers' proficiency in utilising laptops or computers as essential tools for teaching and accessing educational resources. Regarding mobile devices, positive responses were received, with four teachers (n = 4, 57.1%) strongly agreeing and an additional three teachers (n = 3, 42.9%) agreeing that they possess the technical skills to use the mobile devices. Overall, all the teachers (n = 7, 100%) demonstrated strong technical skills, showing proficiency in utilising mobile phones, cell phones, smartphones, or tablets. These percentages suggest teachers' high level of comfort and competence in incorporating these devices into their teaching practices.

In contrast, concerning the Google Suite tools, only a small percentage of teachers (n = 1, 14.3%) strongly agreed, and (n = 1, 14.3%) agreed with their technical skills, indicating a lower level of proficiency in using these tools. A significant proportion (n = 3, 42.9%) remained neutral, reflecting a lack of solid opinion or uncertainty. Furthermore, two teachers (n = 2, 28.6%) expressed disagreement, potentially indicating challenges when utilising Google Suite. The analysis also highlighted positive responses toward utilising the Internet, with four teachers (n = 4, 57.1%) agreeing and an additional two teachers (n = 2, 28.6%) strongly agreeing that they possess the technical skills to utilise the Internet. Overall, six teachers (n = 6, 85.7%) demonstrated strong technical skills and proficiency in leveraging the Internet for teaching purposes. While this may be so, it is essential to note that these are teachers' self-reported skills, which may not reflect the actual proficiency in practice. The same can be said regarding the Microsoft Office tools. The Microsoft tools, such as documents, spreadsheets, and presentations, showcased strong technical skills among teachers. Four teachers (n = 4, 57.1%) expressed strong agreement, and an additional two (n = 2, 28.6%) agreed that they possess the technical skills to use the Office tools, with one teacher (n = 1, 14.3%) remaining neutral. Like the Internet, most teachers who participated in the study (n = 6, 85.7%) expressed strong proficiency and good competence in utilising these applications.

Overall, the analysis above provides a comprehensive overview of teachers' technological skills in using different technologies. The findings indicate that teachers possess strong technical skills when using laptops/computers, mobile devices, the Internet, and Microsoft Office tools. They reported high levels of confidence and competence in these areas, demonstrating proficiency in incorporating these technologies into their teaching practices. However, the results also reveal high variability in teachers' technical skills with specific technologies. For instance, data projectors, document viewer/document cameras, interactive whiteboards, and Google Suite tools showed mixed proficiency levels among the teachers. While some teachers demonstrated strong technical skills in using these technologies, others expressed lower levels of competence. It is worth noting that the study highlighted potential challenges or lower proficiency levels in utilising data projectors, document viewer/document cameras, and interactive whiteboards. These technologies elicited various responses, from strong agreement to strong disagreement, indicating differences in teachers' abilities and comfort levels with these tools. This observation suggests that some teachers face difficulties or have limited technical skills when effectively utilising these technologies.

Indeed, it is crucial to acknowledge that these findings are derived from self-reported skills, and there may be a divergence between teachers' perceived proficiency and their actual implementation of technology in the classroom. While teachers may perceive themselves as possessing strong technical skills, the analysis underscores the need to consider the potential disparities between reported proficiency and the practical application of technology. This recognition highlights the need for targeted training and support to enhance teachers' technical skills, particularly in areas lacking proficiency. Offering focused professional development opportunities can empower teachers to improve their competence with tools such as data projectors, document viewer/document cameras, interactive whiteboards, and Google Suite. This, in turn, would enable them to effectively integrate these technologies into their teaching practices, leveraging their full potential to enhance their learners' learning experiences. By bridging the gap between perceived and actual technical proficiency, such initiatives contribute to a more seamless and impactful technology integration in the educational setting.

5.5 CHAPTER SUMMARY

This chapter presented the findings that address Research Question 1: 'How do rural secondary school Life Sciences teachers describe their ways of integrating technology?' The chapter began by providing an overview of the study and proceeded to present the findings derived from the questionnaire, semi-structured interviews, lesson observations, and sharing circle discussions. The chapter revealed a predominant representation of female participants (57.1%) and a young sample, with the majority falling within the 22-40 age groups (71.4%). While teaching experience varied, most teachers reported having 5-10 years of experience (57.1%). Moreover, the educational qualifications primarily comprised Bachelor of Education degrees (71.4%). Regarding the teachers' access and use of technology, the findings indicated a lower usage of technology for teaching purposes than for personal use, although all teachers incorporate technology.

Regarding the purposes for which teachers utilise technology, the findings demonstrated that most teachers use it as a source of information, create authentic learning experiences, and foster learner-centeredness. Moreover, the findings revealed that most teachers employ technology to motivate learners, promote inclusivity, and enhance engagement and productivity. From the purposes for which teachers leverage technology, it was evident that some teachers exhibit a thoughtful approach to integrating technology. This thoughtful approach entailed selectively choosing specific technologies aligned with pedagogical objectives to facilitate active learning, collaboration, and personalised experiences. These teachers recognised technology as a valuable tool rather than a mere substitute for traditional methods. The findings also suggest improving teachers' perspectives on technology, focusing more on learners utilising technology to support their learning and construct their knowledge.

In terms of technical skills, there was variability in proficiency levels among teachers. While strengths were observed in using laptops, computers, mobile devices, the Internet, and Microsoft Office tools, low proficiency levels were reported for technologies such as document cameras, Interactive whiteboards, and Google Suite tools. This indicates potential challenges or limited skills in effectively utilising these technologies for teaching. The following chapter addresses this study's second research question: 'How do rural secondary school Life Sciences teachers describe their technological pedagogical content knowledge?'

CHAPTER SIX: PRESENTATION AND ANALYSIS OF RESULTS

> TPACK as an emergent knowledge form is complex and context-dependent, and the effect of different contexts is that the nature of TPACK is unique, temporary, situated, idiosyncratic, adaptive, and specific and will be different for each teacher in each situation. (Cox & Graham, 2009, p.47)

6.1 INTRODUCTION

The epigraph above underscores that TPACK, as an evolving form of knowledge, is intricate and influenced by various contexts (Kohler & Mishra, 2007). As Cox and Graham (2009) state, the diverse contexts significantly impact the nature of TPACK, rendering it unique, transient, situated, personalised, adaptable, and specific to individual teachers in each situation. The researcher presents the study's findings in this chapter, focusing on research question 2. By examining the self-reported TPACK of Life Sciences teachers, valuable insights are gained into the nature of their TPACK within the specific context of rural secondary schools. To address RQ2, data were collected through a combination of the TPACK questionnaire, semi-structured interviews, sharing circle discussions, and lesson observations. The researcher presents the questionnaire findings using tables, graphs, and charts, showcasing frequencies, percentages, mean scores, and standard deviation values.

Furthermore, in this chapter, the researcher presents the results of the semi-structured interviews and sharing circle discussions thematically, narratively portraying excerpts or verbatim statements from the participants. In the spirit of triangulating the findings, the researcher then endeavoured to integrate the findings from the different data generation methods during the interpretation and discussion stages. This chapter is organised into sections and sub-sections. The first section examines the teachers' understanding of TPACK and then explores their self-reported TPACK proficiency, where they articulate their understanding of TPACK. Finally, the chapter concludes with a summary of the key points discussed. The next section addresses Research Question 2.

6.2 RESEARCH QUESTION 2

This section focuses on addressing the question:

> How do rural secondary school Life Sciences teachers describe their technological pedagogical content knowledge?

As indicated in Section 6.1, data for Research Question 2 were generated using a questionnaire, semi-structured interviews, lesson observation and sharing circle discussions. The subsequent sub-section presents the findings on the teachers' TPACK understanding.

6.2.1 Teachers' TPACK understanding.

It was necessary first to establish the teachers' understanding of the concept of TPACK as a knowledge form. To achieve this, section A of the questionnaire asked the teachers to mark their choice with an X. The results are shown in Figure 21 below.

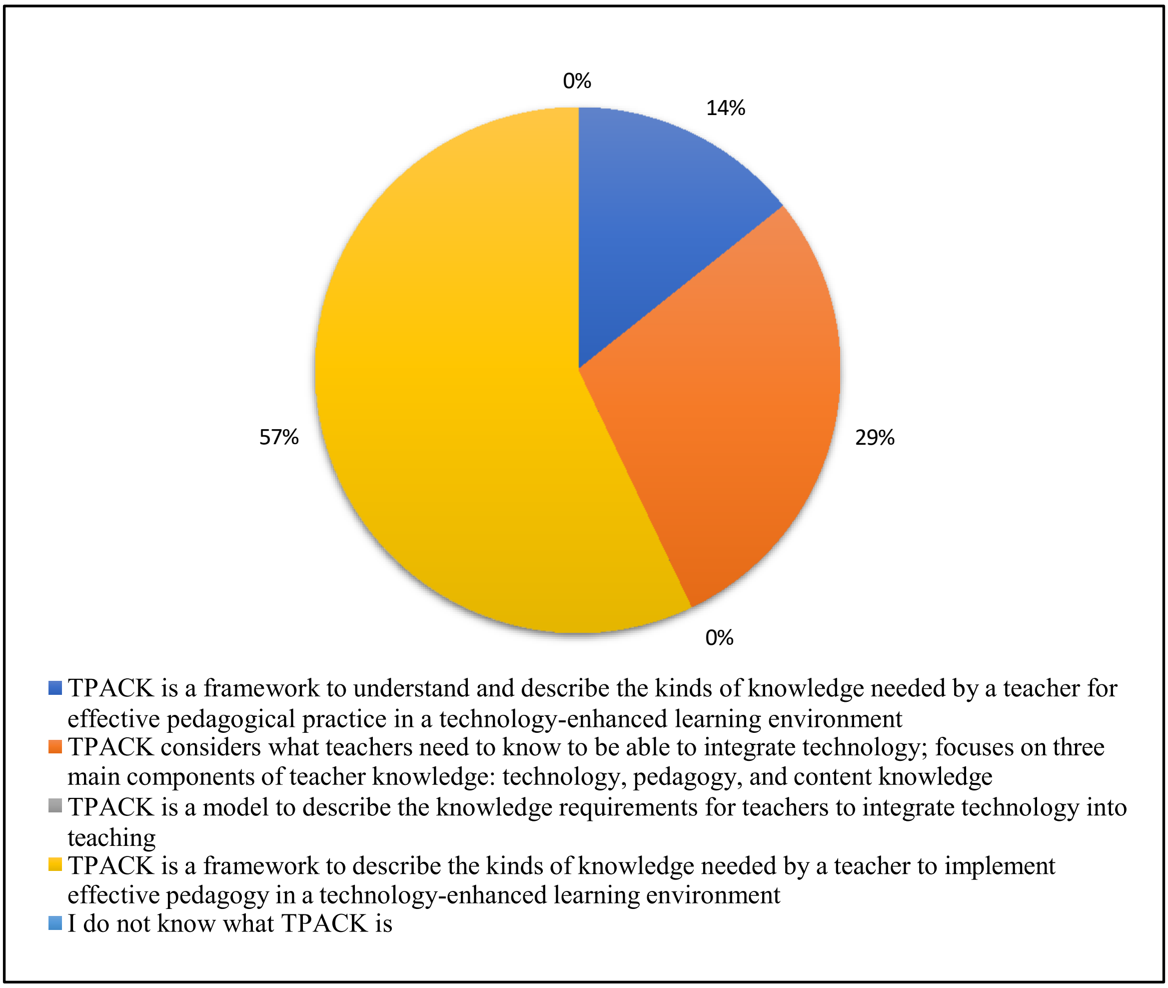


Figure 21. TPACK questionnaire findings – Teachers' understanding of TPACK (n = 7)

According to Figure 21 above, most teachers, Xaba, MaMbotho, Manci, and Faku (n = 4, 57%), indicated that TPACK serves as a framework to describe the necessary knowledge for effective pedagogy in a technology-enhanced learning environment. Meanwhile, two teachers, Mkoena and MaZikhali (n = 2, 29%), understood TPACK as a way to consider the knowledge required for integrating technology, focusing on three key components: technology, pedagogy, and content knowledge. Conversely, one teacher, MaTshezi (n = 1, 14%), viewed TPACK as a framework to understand and describe the knowledge needed for effective pedagogical practice in a technology-enhanced environment.

From the teachers' responses, it is encouraging that most teachers who participated in the study (n = 4, 57%) correctly understand TPACK. However, a significant proportion of the sampled teachers (n = 3, 43%) provided definitions that do not accurately articulate what TPACK entails. This suggests that the TPACK framework is not widely known among all teachers in rural secondary schools. One explanation for the lack of TPACK understanding by close to half of the study participants could be the newness of TPACK both as a concept and as a form of teacher knowledge. This finding is consistent with the research conducted by Olayinka, Ngcoza, Simuja, and Shambare (2023), which indicates that teachers in South Africa lack familiarity with TPACK primarily due to its recent emergence in education.

Furthermore, while many teachers lack a proper understanding of TPACK, the questionnaire responses revealed that all the teacher participants recognised the connection between the TPACK framework and the knowledge required for integrating technology into teaching. The teachers also acknowledged the three primary knowledge constructs, technology, pedagogy, and content, in the teaching process. The teachers' TPACK understanding was raised sharply with the teachers during the semi-structured interviews. Specifically, the teachers were asked to explain their understanding of TPACK. In their interview responses, one of the teachers, Manci, provided the following response:

> *I need to know more about the TPACK framework and how it precisely applies to my teaching context; my teaching context differs from others.* (Manci)

An analysis of Manci's response showed the teachers' lack of confidence in his understanding of TPACK. Similarly to Manci, most teachers acknowledged that their teaching context is unique and distinct from others. As a result, the teachers appreciated the need for a deeper understanding of TPACK tailored to their individual circumstances. Furthermore, Xaba indicated that TPACK was new to him but that he had gained some insight into it through participating in this research. He stated as follows:

> *TPACK is new to me. I need to know more about the framework and how it fits into my pedagogy.* (Xaba)

The above response supports the notion that TPACK is a newfound teacher experience. By acknowledging that TPACK is new to him, Xaba revealed a genuine willingness to expand his knowledge base and enhance his pedagogical skills. This finding was encouraging, suggesting a fertile ground for teachers to develop their TPACK. Furthermore, MaMbotho emphasises comprehending how the TPACK framework aligns with her unique teaching context. She seemed to understand that her teaching context has specific challenges, implying her recognition of the need to tailor their pedagogical approaches when integrating technology. The teacher mentioned that:

> *I have used technology in my teaching before, but I am curious to understand what TPACK really entails. My little understanding of TPACK is based on what I have learned in this study. I am eager to expand my knowledge about TPACK and discover how it can enhance my teaching in my specific teaching context, which is rural.* (MaMbotho)

This awareness of the role of context in influencing technology integration in teaching highlights MaMbotho's dedication to adapting her pedagogical strategies to meet her learners' specific needs and circumstances. By actively seeking to understand how TPACK can be applied in her teaching context, MaMbotho demonstrates a proactive approach towards a desire to improve her teaching methods. In other words, by expressing a need to learn more about the TPACK framework, MaMbotho acknowledges the value of translating theoretical knowledge into practical implementation in her specific classroom contexts. This is a worthy finding as it shows that the teachers' pedagogical decisions and integration of technology are rooted in their specific contexts. Overall, the teachers' interview responses underscore their openness, reflective mindset, and commitment to enhancing their pedagogy through a better understanding of TPACK. While nearly half of the teacher participants demonstrated a poor understanding of TPACK, it was interesting that the interview findings reflected their genuine willingness to expand their TPACK and seek effective ways to integrate technology into their teaching, ultimately supporting learning.

Combined, the findings converge between the TPACK questionnaire and semi-structured interview responses. There is a consistent pattern, highlighting a common theme regarding the limited knowledge and understanding of TPACK in rural school contexts. The findings suggest that there is still much to be explored and understood regarding TPACK understanding and its application by Life Sciences teachers in rural schools. From the above findings, one can conclude that until teachers understand how TPACK influences and supports meaningful technology integration in teaching, the full potential of technology in rural classrooms may remain untapped. The following sub-section delves into the teachers' self-reported TPACK proficiency.

6.2.2 Teachers' self-reported TPACK proficiency

The TPACK questionnaire was employed to generate data on Life Sciences' TPACK proficiency. The teacher participants responded to Likert-type scale items regarding their TPACK proficiency, indicating their responses: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree. It is crucial to underscore that the Likert scale is a well-established method for quantifying participants' responses to questionnaire statements or items. This scale is used extensively in educational and social sciences research (for example, see Dong et al., 2015; Kapici & Akcay, 2023; Koehler & Mishra, 2005; Luo et al., 2023) to measure proficiency, perceptions, and subjective experiences, making it suitable for the current research. The teachers' responses were averaged for each of the six domains of the TPACK items. The researcher used Microsoft Excel spreadsheet formulas to calculate averages for each domain. In addition, the researcher used the spreadsheet to calculate the means (M) and standard deviations (SD) of the teachers' questionnaire responses. While statistical measures like M and SD are commonly associated with quantitative research, it is essential to emphasise that they can also find applications in qualitative studies for specific purposes, as discussed in Section 4.8. Notably, scholars such as Nomlomo (2007), Finucane (2021), and Lauer (2022), among others in the literature, have employed numerical figures such as M and SD to present their qualitative findings. More so, the present study argues that M and SD are not the only statistical measures used in qualitative research. Other measures, such as frequency counts and percentages, offer a more comprehensive understanding of the data.

Moreover, it is critical to remember that M and SD are numerical representations that do not convey the entirety of the narrative. Researchers must always interpret these numbers within the broader context of the qualitative data. Similarly to Lauer's (2022) qualitative investigation in the current study, the researcher utilised M and SD to summarise and compare different data sets encompassing teachers' CK, PK, PCK, TK, TPK, and TPACK. However, it is crucial to clarify that these measures were not employed to draw statistical inferences about the entire population. Instead, their purpose was to offer a more nuanced understanding of the data within the scope of the study's sample and context. For a comprehensive display of the findings, the mean scores and SD values are presented in Table 8 below.

Table 8. Mean scores for the TPACK domains

Domain	N	Mean	SD	Min	Max
CK	7	4.4048	0.25198	4.00	5.00
PK	7	4.3036	0.39434	4.00	5.00
PCK	7	3.6429	0.80178	2.00	5.00
TK	7	3.4048	0.77494	2.00	5.00
TPK	7	3.0816	0.67440	2.00	4.00
TPACK	7	2.7143	0.75593	1.00	4.00

Table 8 displays the mean, SD, minimum, and maximum values for the six TPACK domains. These TPACK domains can be divided into two groups: three are non-technology-related (CK, PK, and PCK), and the other three are technology-related (TK, TPK, and TPACK). The non-technology domains exhibited higher mean scores, all above 3.6, CK (M = 4.4048, SD = 0.25198), PK (M = 4.3036, SD = 0.39434), and PCK (M = 3.6429, SD = 0.80178). Furthermore, the standard deviations for these domains were lower, indicating that Life Sciences teachers possessed a more profound knowledge of subject matter and pedagogy. On the other hand, the mean scores for the technology-related domains were lower than the no-technology-related domains, i.e., TK (M = 3.4048, SD = 0.77494), TPK (M = 3.0816, SD = 0.67440) and TPACK (M = 2.7143, SD = 0.75593). The computations in Table 8 were graphically represented as a bar graph in Figure 22. The purpose of the bar graph is to enhance the visualisation of the TPACK scores and facilitate a better understanding of the distribution of scores across the different domains.

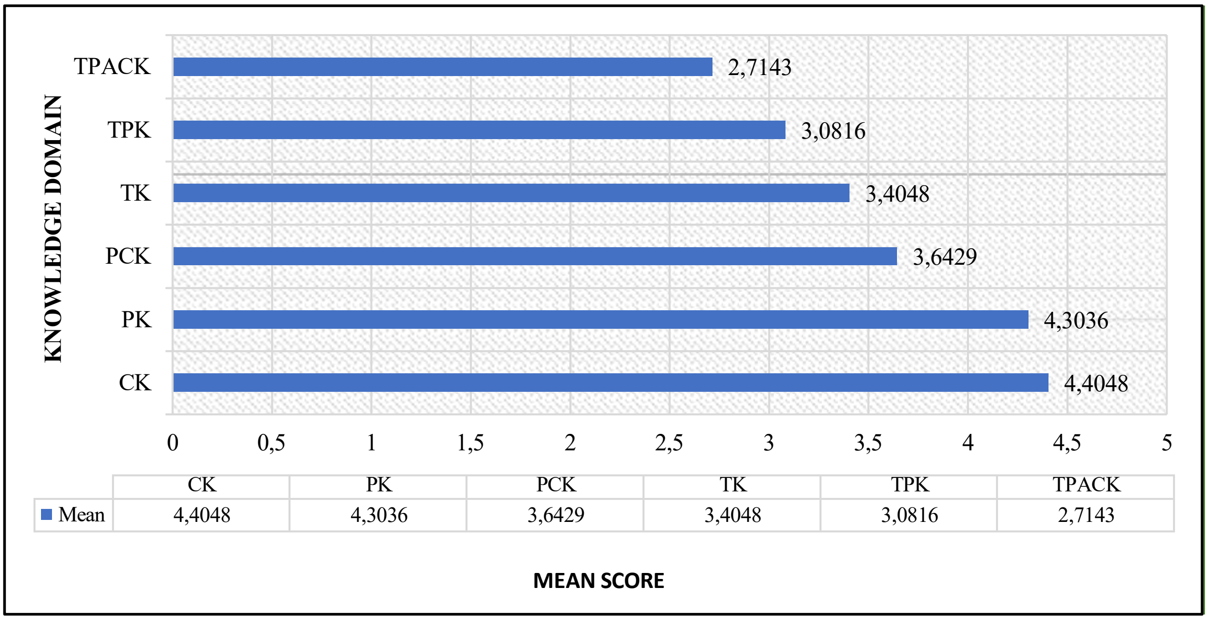


Figure 22: TPACK questionnaire findings – TPACK domain levels (n = 7)

From Figure 22, the Life Sciences teachers reported the highest level for CK (M = 4.4048, SD = 0.25198), followed by PK (M = 4.3036, SD = 0.39434). Furthermore, the dual-components PCK (M = 3.6429, SD = 0.80178) and TPK (M = 3.0816, SD = 0.67440) ranked lower than the single-component knowledge domains CK (M = 4.4048, SD = 0.25198) and PK (M = 4.3036, SD = 0.39434). In addition, the questionnaire findings above indicate that TPACK has the lowest mean score (M = 2.7143, SD = 0.75593) when compared to the other technology-related domains, i.e., TK (M = 3.4048, SD = 0.77494) and TPK (M = 3.0816, SD = 0.67440). These findings support the investigation conducted by Doukakis et al. (2021) in Italy, which explored the TPACK development of 1032 secondary school science teachers regarding CK, PK, TK, and the amalgamation of these components. The data for this study was collected using Schmidt et al.'s (2009) TPACK instrument, which the current study also used. Doukakis et al.'s (2021) findings demonstrated higher CK and PK ratings (with average mean scores of 4.37 and 4.18, respectively). However, the secondary school science teachers were less confident in their PCK and TPK (with average mean scores of 3.51 and 3.68, respectively). These findings offer valuable insights into the teachers' levels of TPACK, indicating that teachers may exhibit varying levels of TPACK domains as they develop their overall TPACK. Furthermore, the questionnaire findings revealed that specific TPACK components may be more prominent than others in the teachers' overall TPACK.

The researcher acknowledged their limitations while employing the TPACK questionnaire scales in this study. One concern was the reliance on self-reporting, which could potentially undermine the validity of the scales. The teacher participants might have overrated or underrated their abilities in certain areas, posing a threat to validity. Furthermore, it is worth noting that teachers' self-reported knowledge does not always align with their actual classroom practices (Silverman, 2020). Additionally, Shenton (2004) and Taherdoost (2019) contend that many TPACK questionnaire items primarily assess self-efficacy or confidence rather than actual knowledge. Nonetheless, researchers, including in the present study, have the freedom to select suitable methods that align with their objectives and report them accordingly (see section 4.5).

Despite the critiques of using TPACK questionnaire scales to assess teachers' TPACK, the focus of the discussion in this research is not discarding the questionnaire entirely but on the importance of triangulation. Speed (2019) argues that teachers' knowledge is not directly observable but reflected in their actions, professional artefacts, and declarative statements. Therefore, this study employed triangulation by combining questionnaire findings with interviews, sharing circle discussions, and lesson observations. When explored through the semi-structured interviews, the interview data was coded to identify high, moderate, and low TPACK proficiency among the teachers.

Statements that reflected TPACK proficiency were coded accordingly [coding in brackets], while ambiguous statements prompted further probing questions to ascertain the teachers' TPACK proficiency relating to the specific domains. For example, one participant, MaZikhali, expressed in her semi-structured interview that CK is more straightforward to grasp, followed by other single-component knowledge forms such as PK and TK. However, challenges arise when it comes to effectively conceptualising and integrating these different forms of knowledge without much experience or guidance on how to do so. This challenge may have contributed to the reduced mean scores observed in PCK and TPK. The lower mean scores for PCK and TPK indicate a need for further support and professional development to understand how the individual TPACK domains work in unison effectively. Regarding the different TPACK domain levels, MaMbotho stated as follows:

> *That is why I am strongest in content (strong CK)- because it is very clear and defined, and then the technologies and strategies (low TPK) - I need to find the link*

and connect them up somehow without the strongest knowledge base to do so (low TPACK). (MaZikhali)

It is important to note that the questionnaire and interview findings indicate that Life Sciences teachers demonstrate a more robust understanding of their CK and PK compared to the other TPACK knowledge domains. One explanation for the teachers' stronger CK could be attributed to the emphasis on subject specialisation within the South African educational system. As discussed in section 4.2 of the study, teachers are required to have a degree in their respective subjects, equipping them with in-depth knowledge in their fields. This specialisation may contribute to their high levels of CK in Life Sciences. Additionally, the focus on improving pedagogical skills during the TD workshops may have played a role in the teachers' high PK levels. As a Subject advisor who often conducts the TD workshops as part of his job, the researcher has first-hand knowledge of how these workshops focus on CK and PK. Figure 23 below shows the researcher conducting a Content gap workshop and a 'How I teach workshop'.

Figure 23. Researcher conducting content gap and 'How I teach' workshops

The TD development programmes prioritise the development of CK and PK domains, which further contributed to the teachers' advanced understanding in these areas - however, the lower proficiency in TK.

On the other hand, the technology-related TPACK domains had lower mean scores than the non-technology ones, with TK (M = 3.4048, SD = 0.77494), TPK (M = 3.0816, SD = 0.67440), and TPACK (M = 2.7143, SD = 0.75593). Notably, the Life Sciences teachers' TK domain was high (M = 3.4048, SD = 0.77494) but dropped when amalgamated with the other two knowledge constructs (CK and PK) to form TPK (M = 3.0816, SD = 0.67440) and TPACK (M = 2.7143, SD = 0.75593). This finding indicates that a strong foundation in the non-technology domains of CK, PK, and PCK is crucial, as integrating TK into these domains to form TPACK should be based on a solid understanding of these foundational domains. In addition, the higher mean for TK compared to other technology-related domains emphasises its significance and influence on the overall development of TPACK among Life Sciences teachers in rural schools. As previously discussed, the teachers could benefit from professional development programs that specifically target the enhancement of their TK and skills to keep pace with the continuous introduction of new technology tools in education.

Upon further exploration through semi-structured interviews, it became evident that the Life Sciences teachers exhibited different levels of TPACK components depending on the specific question they were asked to respond to. This variability in TPACK proficiency was apparent in the statements provided by Manci, as exemplified below:

> *In terms of my confidence levels, I feel highly confident in the content knowledge (strong CK) I acquired during my first degree. I have a solid foundation in this area. I have some confidence regarding pedagogy, and I anticipate that my skills will significantly improve with more experience (moderate PK). However, when it comes to technology, I have had no formal training specifically required. While there are opportunities to participate in workshops, they were not strongly emphasized. Therefore, I believe that incorporating some form of technology training would be extremely valuable and beneficial to the program (low TK).* (Manci)

Manci's response suggests that the Life Sciences teachers' TPACK is context-dependent and may vary depending on the specific aspects of TPACK being addressed. It reinforces the notion that TPACK is a complex and dynamic construct, requiring teachers to draw upon different combinations of their CK, PK and TK depending on their tasks and challenges. It can be seen in Manci's response that the teachers can exhibit different proficiency levels in their individual TPACK domains. In all the teachers' responses, it is worth noting that self-reported levels of TPACK differed in this study depending on specific factors, such as the grade. For instance, Mkoena demonstrated strong CK and confidence in teaching Grade 12 Life Sciences.

> *I possess comprehensive and extensive content knowledge for Life Sciences in Grade 12 (strong CK for G12). I can connect the subject content to real-life situations because I deeply understand the content. Moreover, I have expanded my knowledge beyond the core concepts and can readily identify how they can be applied in practical, real-world scenarios (strong PCK for G12). Making these connections comes naturally to me.* (Mkoena)

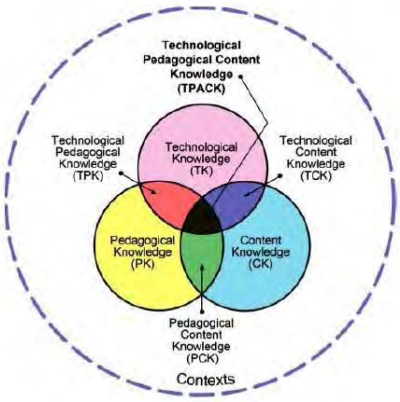
On the other hand, when faced with the prospect of teaching Grade 10 Life Sciences, Mkoena conveyed a sense of apprehension and lack of confidence, expressing his feelings as:

> *If I were assigned to teach Grade 10 Life Sciences, I would feel extremely overwhelmed and anxious, as if I were on the verge of having a heart attack (low CK for G10).* (Mkoena)

The former statement was coded as strong self-reported CK and PCK, and the latter was coded as self-reported CK. This is clear evidence that TPACK and its individual knowledge domains are not static but vary depending on the context, such that a teacher's TPACK can be different for each grade within the same subject. Therefore, it is crucial to be precise with understanding the individual TPACK domains rather than attempting to assess an 'overall' self-reported TPACK, as later Research Question 3 uncovered related experiences that were identified and cross-referenced to determine sources of the various knowledge components of TPACK.

During the interviews, the teachers were requested to place an 'X' on the TPACK diagram to indicate where they believed their TPACK resides. Figure 24 below shows the semi-structured interview question 5.

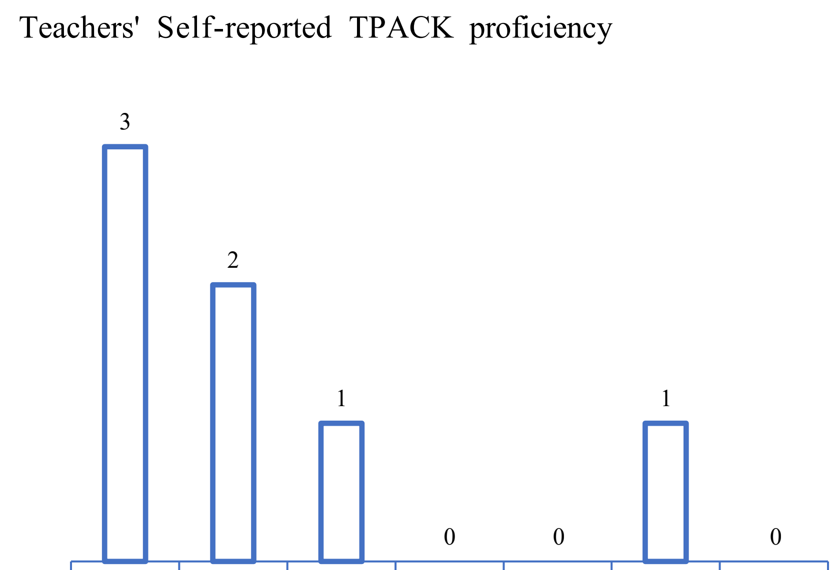
5. Please answer the following questions based on the TPACK diagram below.



5.1 Please place an 'X' on the diagram to identify where you believe your current TPACK resides with respect to your understanding of technology, pedagogy, and content knowledge for your teaching.

Figure 24: Extract of semi-structured question 5

The teachers' responses to the above question are presented in Figure 25 below.



	CK	PK	PCK	TK	TCK	TPK	TPACK
Teachers' Responses	3	2	1	0	0	1	0

Figure 25: Teachers' TPACK response

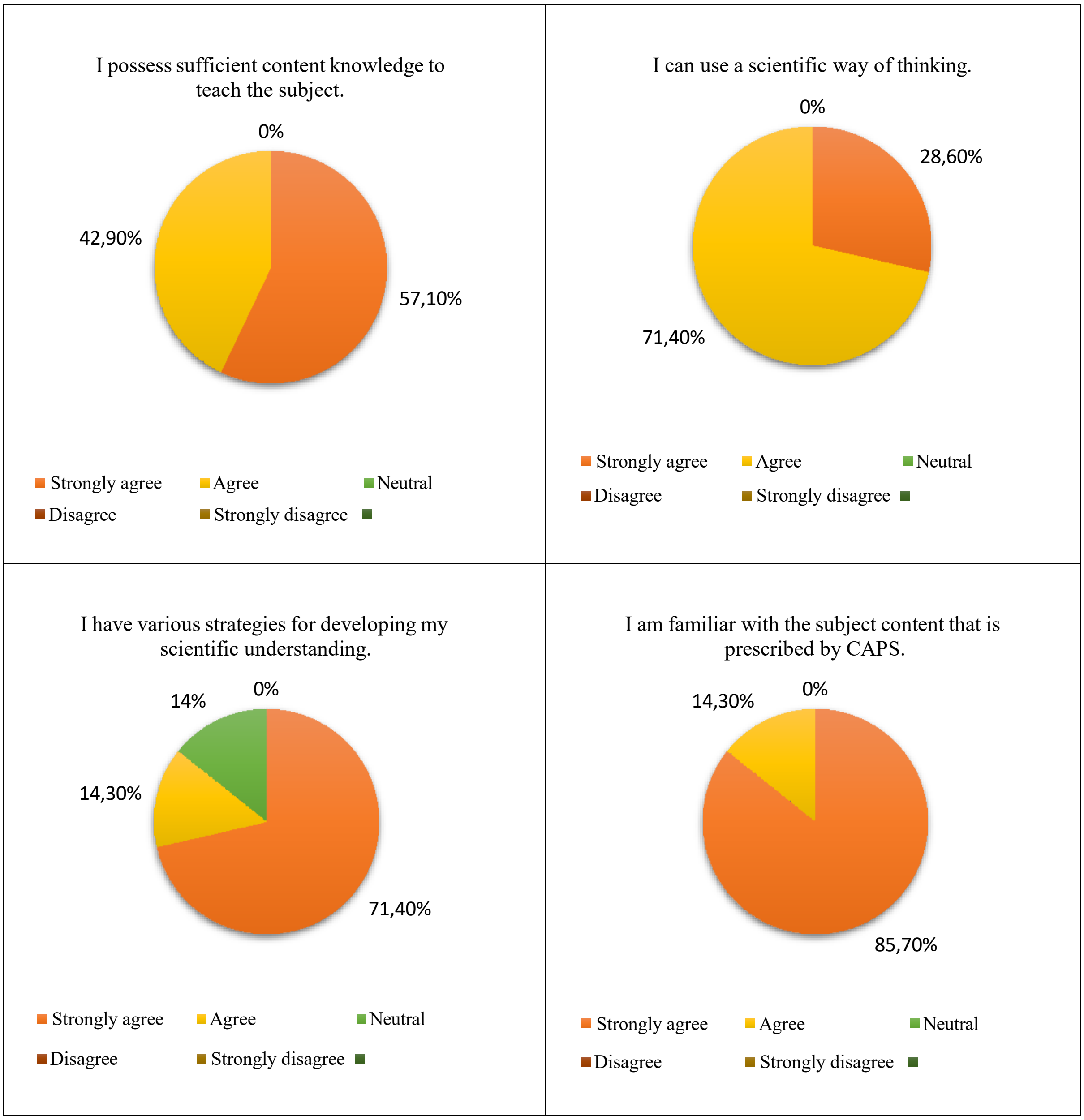
Figure 25 shows that most teachers (n = 3, 42.9%) placed their X on CK, followed by PK (n =2, 28.6%) and one teacher (n = 1, 14.3%) for both PCK and TPK. Moreover, no teacher (n = 0, 0%) placed X on TK, TCK, and TPACK. The above findings from the interview protocol confirm the TPACK questionnaire in that the most prominent TPACK domain is CK, followed by PK. However, there was some divergence in the findings between the TPACK questionnaire shown in Figure 24 and the interview responses in Figure 25. For example, no teacher placed an X on TK, TCK, and TPACK in the interview responses. In contrast, on the questionnaire responses, some teachers reported high levels of TK and TPACK (see Figure 25), indicating divergence between questionnaire and semi-structured interview findings. Even though researchers employ instrument triangulation, they typically strive to achieve convergence in their findings. This refers to the process of combining all their findings from the various research instruments in an organised manner to enhance the validity of their research (Hendren et al., 2023).

However, the lack of convergence of findings, as shown above, does not necessarily indicate a defect in the research. Non-convergence of results occurs for various reasons, such as differences in the sample size, sampling technique, or the research design or methodology (Hirose & Creswell, 2023). Furthermore, Mayoh and Onwuegbuzie (2015) argue that conflicting results can uncover new theories and insights, leading to a deeper understanding of the studied phenomenon. Likewise, Headley and Plano Clark (2020) suggest that divergence between results could offer a more comprehensive insight into the phenomenon, as researchers have an opportunity to explore and explain why the results are different.

According to Headley et al. (2023), one major cause of divergent results is the insufficient use of questionnaires. This study's divergence of results could be aligned with the fact that the questionnaire results were not obtained through questions that were explicit or tailored to each individual. On the other hand, the semi-structured interview protocol questions allowed teachers to express and elaborate on their TPACK more comprehensively. In other words, the questionnaire could not capture the depth and richness of the teachers' expressions regarding their TPACK as captured through the semi-structured interviews. As a result, the researcher suggests that the discrepancy between the questionnaire and interview results could be attributed to the limited ability of the questionnaire to capture the intricate experiences that were reported through interviews. Besides, methodological differences between the questionnaire and semi-structured interviews could have contributed to the observed divergence. Since the interviews were conducted after completing the questionnaires, there was a time lapse between data generation for the two instruments, which might have influenced the results. To fully comprehend the Life Sciences teachers' knowledge of technology, content, and pedagogy (TPACK), the researcher analysed each TPACK domain from the questionnaire and triangulated the findings with the semi-structured interview results. These are presented in the following sub-sections, beginning with content knowledge.

6.2.2.1 Content Knowledge

The questionnaire asked the participants to respond to the six question items concerning their content knowledge. Figure 26 displays the findings.



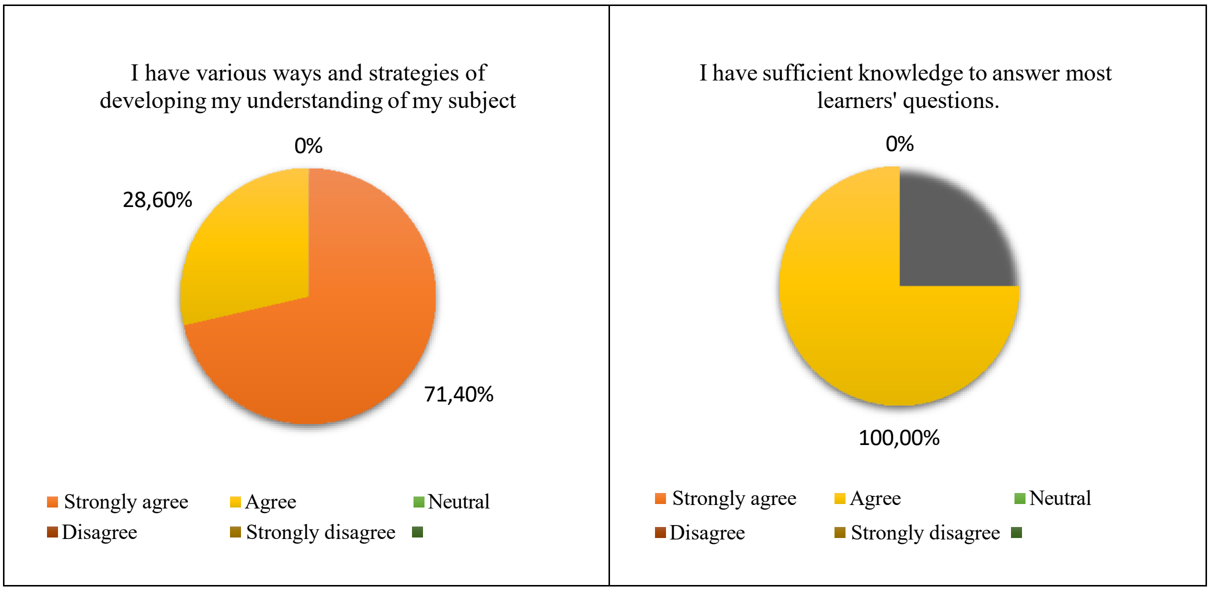


Figure 26: TPACK questionnaire findings – Content Knowledge (n = 7)

The computations in Figure 26 above show the Life Sciences teachers' responses regarding their self-reported content knowledge levels. All the teachers (n = 7, 100%) agreed to all the CK items. Notably, 85.7% (n = 6) of the teachers strongly agreed that they "are familiar with the Life Sciences content that CAPS prescribes", showing that the teachers are grounded in the subject content outlined in the CAPS. Following this, 71.4% (n = 5) of the teachers strongly agreed that they "have various ways and strategies of developing understanding of the subject". Furthermore, all the teachers (n = 7, 100%) agreed that they "have various ways and strategies of developing their own Life Sciences understanding." As discussed earlier, the computations in Figure 26 show a high agreement among teachers regarding their level of proficiency in all the CK statements. The results indicate that the Life Sciences teachers who participated in this study perceive themselves as highly knowledgeable in the subject content. This observation, while encouraging, is not unexpected considering that subject specialisation is a focus for Life Sciences teachers during their initial teacher training. In other words, for the teachers to have been awarded their teacher qualifications, one would have demonstrated competency at least in their subject specialisation, Life Sciences, in this case.

However, as discussed before, it is crucial to acknowledge that self-reported CK may not always align with actual competency. While teachers may perceive themselves as knowledgeable, their true mastery of the subject content requires an objective assessment. When the teachers' CK was examined through semi-structured interviews, the interview findings corroborated the questionnaire results. For instance, when the teachers were asked to mark with an X to indicate where they believed their TPACK resides, most marked on CK, followed by PK. This finding was also echoed through their individual interviews, where the teachers expressed confidence in their CK. For example, Mkoena stated as follows:

> *I have good Life Sciences content knowledge, enabling me to teach my classes without problems. Even my colleagues know that I am a guru in the subject.* (Mkoena)

In addition to Mkoena, Faku went into detail to describe how his self-reported CK proficiency in specific topics influenced his teaching. He described as follows:

> *When I teach, be it cell structure in Grade 10 or Evolution in Grade 12, I am always relaxed and can talk to them [learners] and check if everyone understands. I am always confident, and I make sure they follow properly.* (Faku)

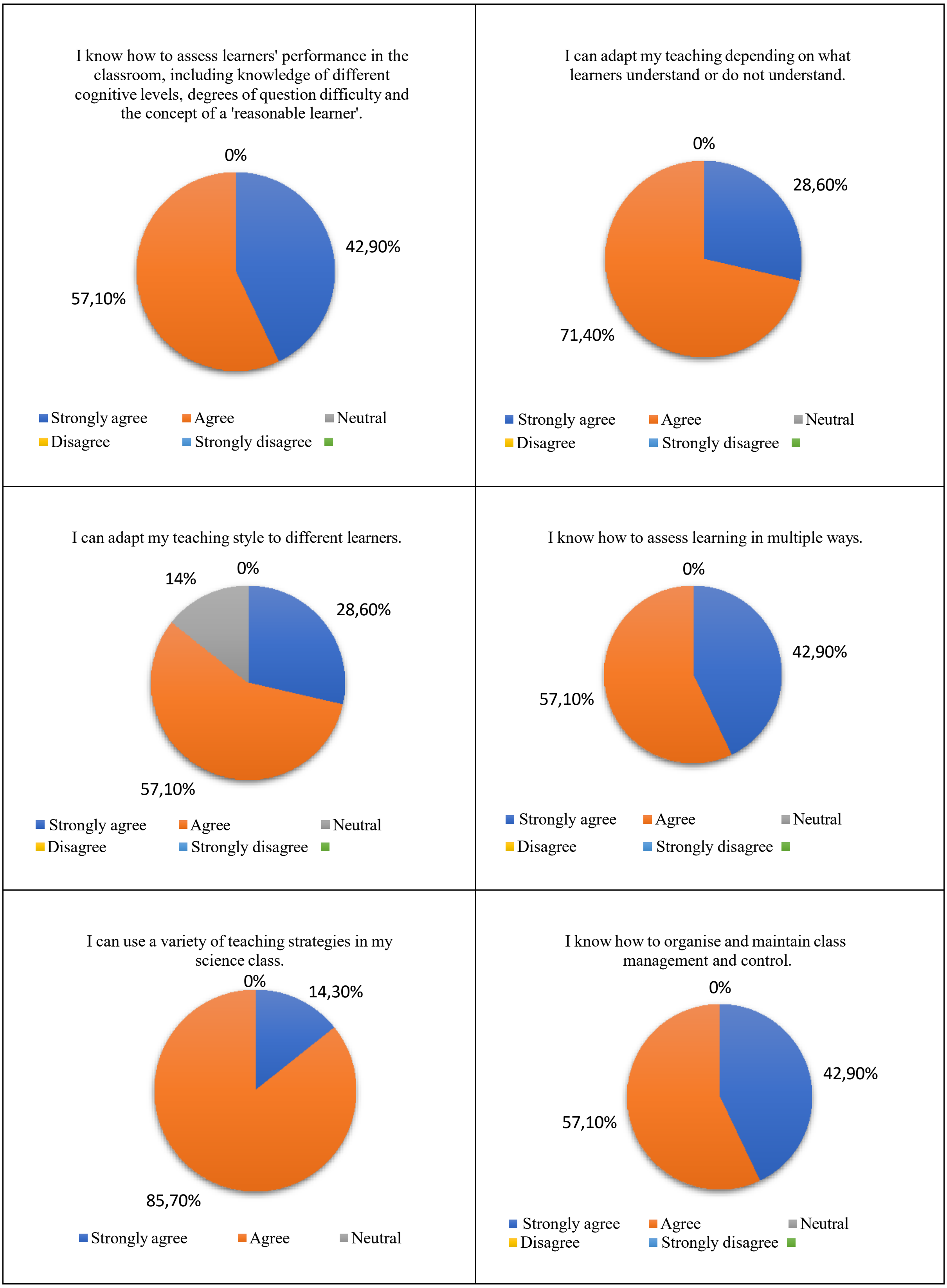
Along the same line, MaMbotho also explained how confident she is regarding her CK. She stated as follows:

> *I did a revision lesson on photosynthesis, so I made that very engaging because I am very confident with my knowledge.* (MaMbotho)

In sum, both the findings from the questionnaire and interviews indicate that Life Sciences teachers demonstrate mastery of content knowledge. Similar findings were reported by Yulisman et al. (2019) in their examination of 88 science teachers' TPACK development in Banda Aceh City in Indonesia. The researchers used inferential and descriptive statistics to analyse the data collected from multiple-choice test questions. Consistent with the present study, their results indicated that CK was the dominant component in the science teachers' TPACK. However, while having a solid understanding of the content is essential, being a competent teacher goes beyond content mastery and requires the ability to adapt teaching strategies to facilitate meaningful learning experiences. The following sub-section, therefore, explores the teachers' abilities to convey the content in ways that make it accessible to learners, i.e., pedagogical knowledge.

6.2.2.2 Pedagogical Knowledge

The questionnaire asked the participants to respond to the eight question items concerning their pedagogical knowledge, and Figure 27 displays the results.



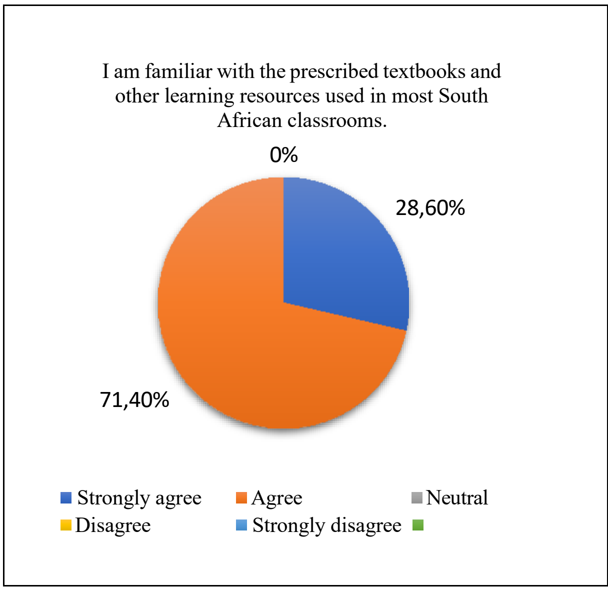


Figure 27: TPACK questionnaire findings – Pedagogical Knowledge (n = 7)

Figure 27 provides insight into the Life Sciences teachers' PK domain. The pie charts show that all the teachers (n = 7, 100%) agreed or strongly disagreed with all the PK items. This suggests that the teachers highly regarded their aptitude in adopting suitable learning approaches for meaningful learning. It was exciting to find that all the teachers who participated in this study (n = 7, 100%) reported that they "know how to organise and maintain class management and control." This finding was interesting because, as Chaipidech (2022) found, effective class management and control is a foundation for successful teaching and learning. Additionally, all the teachers (n = 7, 100%) strongly agreed that they "know how to assess learners' performance in the classroom, including knowledge of different cognitive levels, degrees of question difficulty and the concept of a 'reasonable learner'." The same can also be said for the item "I can adapt my teaching depending on what learners understand or do not understand," which was agreed to by all the teachers (n = 7, 100%).

Notably, there were only two items which one teacher (MaTshezi) (n = 1, 14.3%) neither agreed nor disagreed with, i.e., "I am familiar with common learners' understandings and misconceptions of science" and "I can adapt my teaching style to different learners." It is important to note that MaTshezi is the teacher who holds a BSc in Botany and lacks training as a teacher. Therefore, it was unsurprising that she remained neutral in some PK items. However, although one teacher chose to be neutral to the mentioned statements, most (n = 6, 85.7%) agreed to the statements, suggesting that most teachers believed they are familiar with common learners' understandings and misconceptions of science and that they can adapt their teaching style to different learners.

A closer look at the teachers' questionnaire responses indicates high confidence in their teaching capabilities and their confidence in creating engaging learning experiences for their learners. The teachers' strong PK levels are crucial as they significantly shape teaching practices and foster effective teaching and learning environments. Moreover, by possessing a solid foundation of PK, the Life Sciences teachers in rural schools could become better equipped to select appropriate teaching strategies, design meaningful learning experiences, and cater to their learners' diverse needs.

Furthermore, the results of the above questionnaire were triangulated with the interview findings. Like CK, when teachers were asked to mark with an X to indicate their TPACK proficiency during the interviews, most marked on CK, followed by PK. This finding suggests that the teachers believed that they possessed solid PK. It was particularly intriguing that most teachers recognised the importance of proficiency beyond merely possessing high CK; they acknowledged the significance of being competent in PK. This understanding is evident in Mkoena's response, where he asserted that knowing the content is just the starting point. Mkoena goes on to suggest that effective teaching requires not only a solid grasp of the content but also the ability to adapt teaching approaches to effectively meet the diverse needs of learners. This insight reinforces the teachers' awareness that teaching excellence involves more than just content expertise; it necessitates adeptness in pedagogy to ensure effective knowledge transmission tailored to the learners' requirements.

> *You got to adapt your strategies, you must know your learners, and you must know your content. But knowing the content is not teaching; it is just the basics. While you know your learners and how to teach the content so meaningfully that they get it, this is the art of teaching for me. Being smart does not mean to be a good teacher. You can be a genius and not be able to teach. Or you can be not too smart but an excellent teacher.* (Mkoena)

Mkoena's perspective on teaching is notable, as he views it as a dynamic and adaptable process that must be tailored to the needs of learners. To Mkoena, teaching should not be rigid but rather a flexible strategy that can be adjusted to meet the individual learning needs of learners.

More interesting to Mkoena's statement was his emphasis on the importance of the 'art' of teaching, which involves employing meaningful approaches that effectively engage learners and facilitate their understanding. By recognising the importance of being responsive to learners' needs, Mkoena highlights the significance of learner-centred teaching. This approach emphasises tailoring teaching methods, strategies, and activities to align with learners' interests, abilities, and preferred learning styles.

Like Mkoena, Manci, the least experienced teacher participant, also aligned himself with the notion that teaching is not solely about imparting knowledge but also about employing the best strategies that foster an engaging and meaningful learning experience. The teacher implied that successful teaching requires adaptability, creativity, and a deep understanding of learners' individual differences and learning preferences. From his perspective, Manci emphasises a teacher's ability to manage the class effectively to create a conducive learning environment. He stated as follows:

> *For me, a teacher must possess the ability to effectively manage learners, taking charge and ensuring that they remain focused on their work. There are different approaches to achieve this, some more effective than others. I adapt my methods based on the specific circumstances, but I consistently evaluate and monitor the situation. I always pay close attention to my learners' progress.* (Manci)

Manci's statement shows that the teacher expresses a confident approach to teaching, particularly in class management. Furthermore, Manci not only highlights the importance of managing learners and maintaining classroom control but also recognises that various management strategies can be employed. Notably, the teacher stresses the importance of continuously assessing and understanding the learners' needs and adjusting the teaching methods accordingly. Some interesting findings emerged when probed about which pedagogical practices Manci uses to maintain classroom control. For example, Manci expressed that he arranges his learners in different groups in his class:

> *I do a lot of the grouping, and that makes my learners work together. This also helps me a lot to manage the class and control discipline, as the learners in the group tend to reprimand each other when some of them misbehave.* (Manci)

In support, MaTshezi also indicated that she has since realised that grouping learners has been a strategy that enhanced her class management. She reported that she recognised that learners interact and that the class was a more collaborative and friendly environment:

> *I have implemented a group setting where the learners engage in more discussions among themselves. This change has fostered a friendly environment where learning takes place. Instead of solely relying on the teacher, my learners now actively collaborate and seek assistance from their peers. The classroom atmosphere has shifted from being quiet and focused solely on completing work to a more dynamic space where the learners engage and share information.* (MaTshezi)

MaTshezi mentioned again that being in the groups also helped learners learn from each other and identify other learners' strengths and skills:

> *Like I told you before, I made them create a DNA model, and I asked them to take each a role, I told them they must decide which role they want to do I am not going tight so there is thinking on their own now like, what am I good at? What is he good at? What is she good at? So, they are talking to each other.* (MaTshezi)

In MaTshezi's case, the satisfaction she derives from observing her learners engaging in conversations with each other indicates her aptitude for creating a learner-centred learning environment. From her statement, it can be inferred that she is a creative teacher who values and fosters collaborative learning experiences for her learners. Moreover, in another interview, MaZikhali highlighted a crucial aspect of effective teaching by emphasising the significance of considering learners' prior knowledge. According to MaZikhali, understanding the learners' existing knowledge allows the teacher to build upon their ideas, facilitating the assimilation and accommodation of new knowledge. This perspective underscores the importance of tailoring teaching methods to align with learners' prior knowledge, creating a foundation that enhances the absorption of new information. MaZikhali's explanation is encapsulated in the following statement:

> *When conducting a class, I pivot my teaching approach if I determine that the learners lack prior knowledge about the subject I am discussing. I redirect my focus towards topics that will guide them towards the desired outcome. It is futile to delve*

into areas where they lack understanding. Flexibility and adaptability are essential in this context. Assessing the situation and gauging the learners' gaps is crucial. It can be likened to playing football, where you constantly observe the defensive strategies. If the defence alters its approach, you must also adjust your own tactics accordingly. (MaZikhali)

Based on the above findings, the teachers' ability to assess learner understanding and adapt their teaching reflects their learner-centred approach. They acknowledge learners' diverse cognitive abilities and prior knowledge and tailor their teaching to address individual needs. This adaptability promotes meaningful learning experiences and supports learners' academic growth. Moreover, grouping learners within the classroom has positively impacted learner interaction, collaboration, and engagement. Teachers reported that this practice encourages learners to discuss concepts, share insights, and learn from one another.

Moreover, the teachers indicated that the collaborative environment fosters a sense of community and cooperation, enhancing learners' understanding and overall learning experience. Furthermore, the teachers' emphasis on being familiar with learners' common understandings and misconceptions of science demonstrates their commitment to addressing individual learner needs. They recognise the importance of bridging gaps in understanding and modifying their teaching styles to accommodate different learners. This awareness enables them to create inclusive learning environments where all learners actively participate and succeed. These teacher characteristics demonstrate their expression of mastery of PK. This finding supports Tanak's (2020) research in Thailand that examined the effect of TPACK-based courses on 15 science teachers' TPACK development. The results showed that PK is a dominant domain in the teachers' TPACK.

6.2.2.3 Pedagogical Content Knowledge

The questionnaire asked the participants to respond to the five PCK items, and Figure 28 below displays the results.

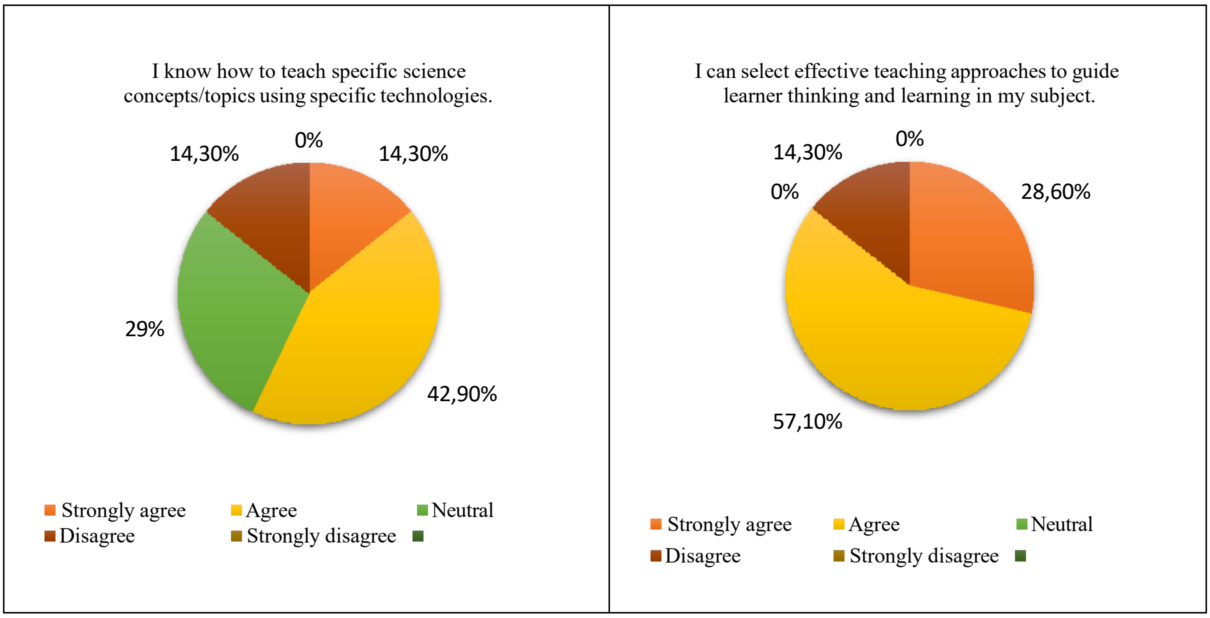


Figure 28: TPACK questionnaire findings – Pedagogical Content Knowledge (n = 7)

A closer examination of the individual PCK items revealed that although most teachers appeared to have high PCK levels, one teacher disagreed with both PCK items and two teachers neither agreed nor disagreed. Specifically, two teachers (n = 2, 28.6%) remained neutral, and one (n = 14.3%) disagreed with the statement "I know how to teach specific science concepts/topics using specific technologies." A different outcome, however, emerged where most teachers (n = 6, 85.7%) agreed to the statement, "I can select effective teaching approaches to guide learner thinking and learning in my subject."

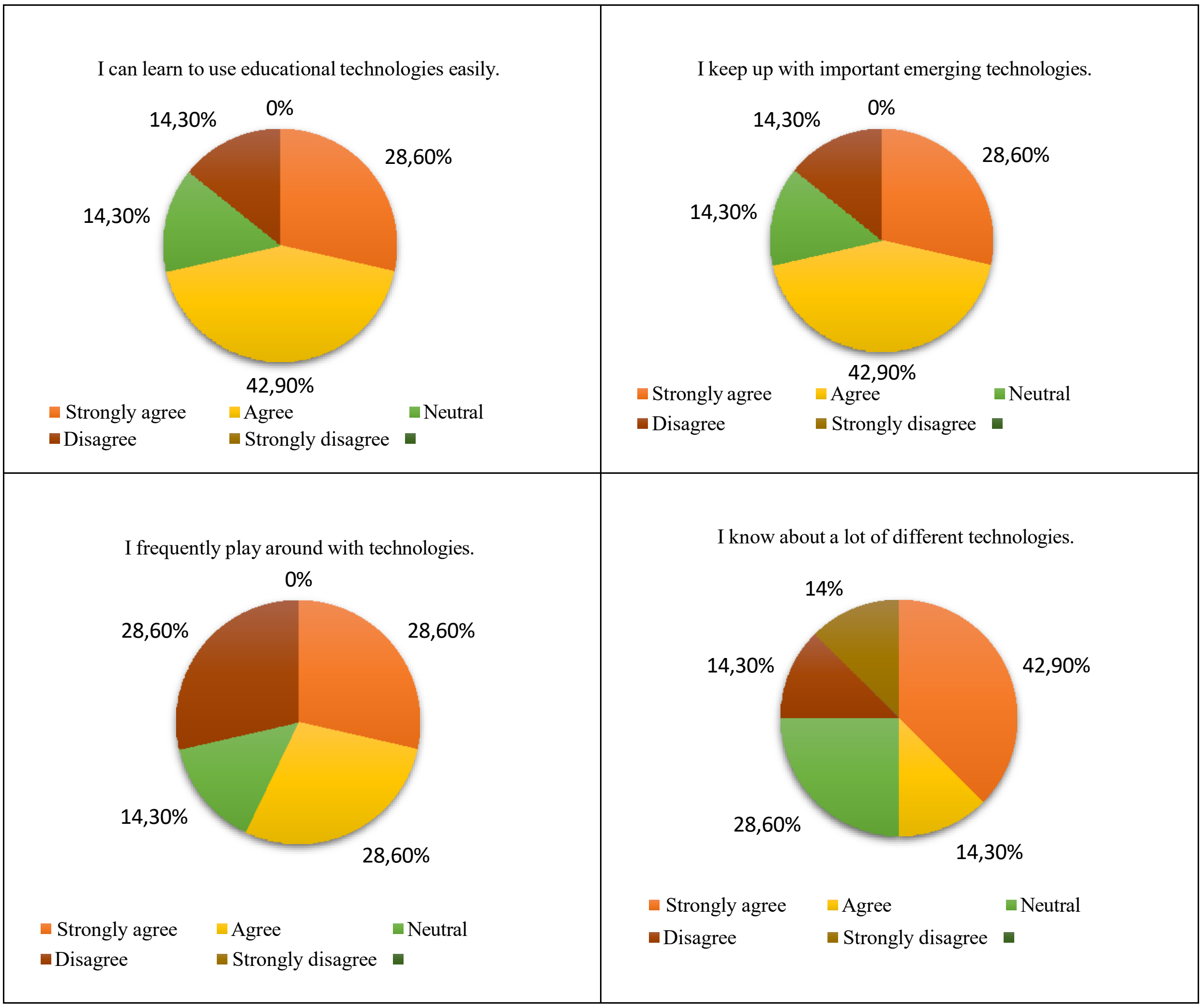
During the semi-structured interviews, a recurring theme among the teachers was their perceived lack of proficiency in utilising technology for teaching purposes. This was evident in comments by Mkoena, who expressed their limited ability to integrate technology into their teaching practices.

> *Despite recognising the potential of technology to enhance teaching, the main hurdle lies in the lack of familiarity among teachers. This unfamiliarity presents numerous complexities that need to be addressed. Therefore, we must invest time and effort in understanding how to effectively utilise technology in our teachings.* (Mkoena)

The above statement emphasises the importance of training teachers to use technology effectively for better learning outcomes. Overall, the average PCK score was quite high (M = 3.8796, SD = 0.6841). This indicates that Life Sciences teachers have the expertise to blend teaching methods with subject knowledge, giving learners various learning opportunities. The results suggest that rural Life Sciences teachers are well-informed about different teaching strategies and resources that enhance learners' achievements in this field. The study provides a comprehensive view of self-reported PCK levels among Life Sciences teachers, showing that most teachers strongly understand the subject. Despite a few inconsistencies where one teacher disagreed, and two teachers remained neutral about their PCK, most agreed that they were skilled in choosing practical teaching approaches to help learners learn the subject well.

6.2.2.4 Technological Knowledge

The questionnaire asked the participants to respond to the seven items for TK. The results are shown in Figure 29 below.



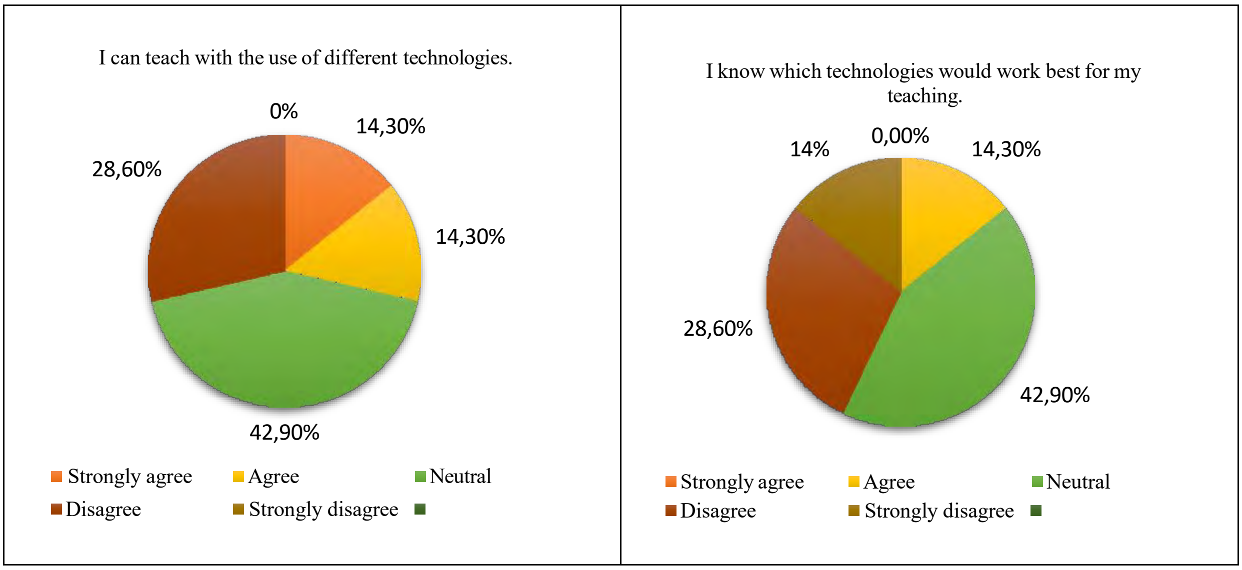


Figure 29: TPACK questionnaire findings – Technological Knowledge (n = 7)

According to the chats presented in Figure 29, most participants report high TK levels based on the percentages of all the individual TK items. Notably, two teachers strongly agreed (n = 2, 28.6%) and three agreed (n = 3, 42.9%) that they "can learn to use educational technologies easily". This result implies that most teachers (n = 5, 71.5%) possess a high level of adaptability and willingness to explore new technological tools in their classrooms. Similarly, most teachers (n = 5, 71.5%) reported that they "keep up with important emerging technologies", with only one (n = 1, 14%) disagreeing with the statement. This finding was corroborated by the semi-structured interviews in which teachers highlighted the necessity of staying current with technological advancements in education. MaMbotho stated as follows:

> *You know, it is amazing how many new educational technologies are popping up all the time these days, right? Just when you think you have a handle on one, bam! They introduce another game-changer! It can be quite challenging to keep up with the latest trends, so it is essential to ensure you are always staying updated.* (MaMbotho)

MaMbotho's statement indicates that the teachers know that TK is not static but an evolving knowledge form that must be updated to keep up with emerging technologies. As Harari (2018) points out in the epigraph of this study's abstract, the current era is marked by the proliferation of numerous novel educational technologies, an observation highlighting technology's dynamism in teaching. The introduction of these technological innovations is occurring at an astonishing pace, often leaving teachers and learners grappling with the task of keeping abreast of the latest trends. Consequently, it becomes imperative for teachers to update their knowledge and skills consistently (Harari, 2018). Adapting to this evolving landscape of educational technologies necessitates a commitment to ongoing professional development to effectively leverage the potential of these advancements and deliver enriched learning experiences. MaZikhali confirms the statement as follows:

> *Continuously updating my knowledge on the latest technological advancements is crucial as a teacher, enabling me to effectively leverage these tools and ensure that learning remains relevant for modern-day learners.* (MaZikhali)

MaMbotho and MaZikhali indicate that teachers recognise the importance of staying up to date through ongoing self-development of TK. Furthermore, the questionnaire findings indicate that over half of the Life Sciences teachers are comfortable using various technology tools, based on the item "I frequently play around with technologies" (n = 4, 57.2%). In addition, 57.2% (n = 4) of the teachers reported that they "know about a lot of different technologies." These results suggest that the teachers possess self-assurance in their technological capabilities and are well-equipped to use educational technologies in their pedagogical approaches.

However, only two out of seven (n = 2, 28.6%) indicated that "they can teach with the use of different technologies," suggesting that most teachers (n = 5, 71.5%) may lack confidence in their ability to teach with various technological tools. Even so, only one (n = 1, 14.3%) agreed that "he knows which technologies would work best for his teaching", with three (n = 3, 42%) neither agreeing nor disagreeing with the statement and another three (n = 3, 42%) in disagreement. This finding clarifies that most teachers did not know which technologies would enhance their teaching. The semi-structured interviews also captured the teachers' lack of "knowledge of a lot of different technologies" and "which technologies would work best for teaching". Some teachers indicated that they lacked basic technology skills to operate various technologies, as reflected by Mkoena's statements:

> *Teachers may encounter challenges in effectively utilising digital tools for teaching purposes, including implementing these tools and disseminating information through commonly accessible platforms.* (Mkoena)

Mkoena's statement underscores the importance of possessing a robust foundation in TK as a fundamental prerequisite for other knowledge domains related to technology, such as TPK and TPACK. This sentiment aligns with the findings of Tanak (2020), who demonstrated that science teachers with low TK levels struggled to establish the connection between pedagogy and technology, regardless of their high levels of CK and PK. This result suggests that even teachers who frequently use technology may need additional skills to stay abreast of emerging technologies and their applications in teaching and learning. Regrettably, the findings of this study indicate that the technology training provided to teachers is often insufficient. This inadequacy is attributed to training programmes that neglect to emphasise integrating content, pedagogy, and technological knowledge in teaching practices. Consequently, it becomes imperative for teachers to receive training that enhances their TK, enabling them to confidently utilise technology as a valuable tool to support effective learning.

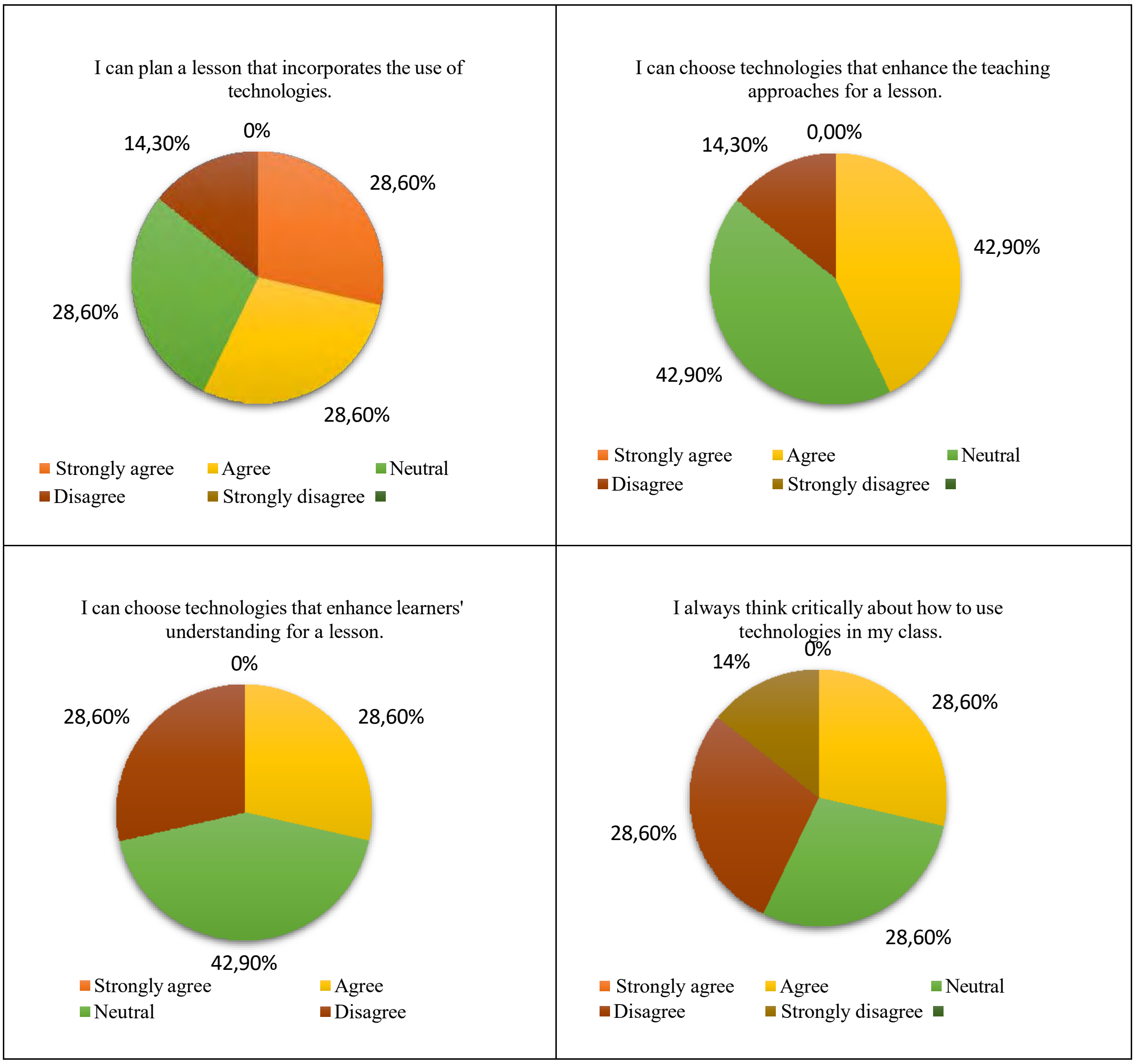
Similarly, the semi-structured interviews affirm that many Life Sciences teachers in rural schools strongly desire training programmes prioritising integrating technology into their teaching. Beyond acquiring knowledge about the latest technological tools, the teachers stressed the importance of understanding how to effectively incorporate these tools into the specific context of the Life Sciences subject area. This approach would empower them to create impactful and engaging technology-based teaching experiences for their learners. The emphasis placed by the Life Sciences teachers on the need for continuous professional development is evident in the following quotation:

> *Teachers need practical support and specialised training to effectively incorporate technology into their teaching alongside their existing pedagogical knowledge.* (Xaba)

The self-reported TK among Life Sciences teachers in rural schools highlight their competence and proficiency in working with diverse technologies. The teachers' expression of TK indicates that they are able to integrate technology effectively into their teaching with appropriate support and resources. These findings are encouraging as they underscore the potential for these teachers to leverage technology to enhance the teaching and learning experiences in Life Sciences. By harnessing their existing TK and providing them with further support, such as professional development opportunities, the teachers can further optimise their ability to incorporate technology seamlessly into their lessons.

6.2.2.5 Technological Pedagogical Knowledge

The questionnaire asked the participants to respond to the three TPK items, and Figure 30 below shows the results.



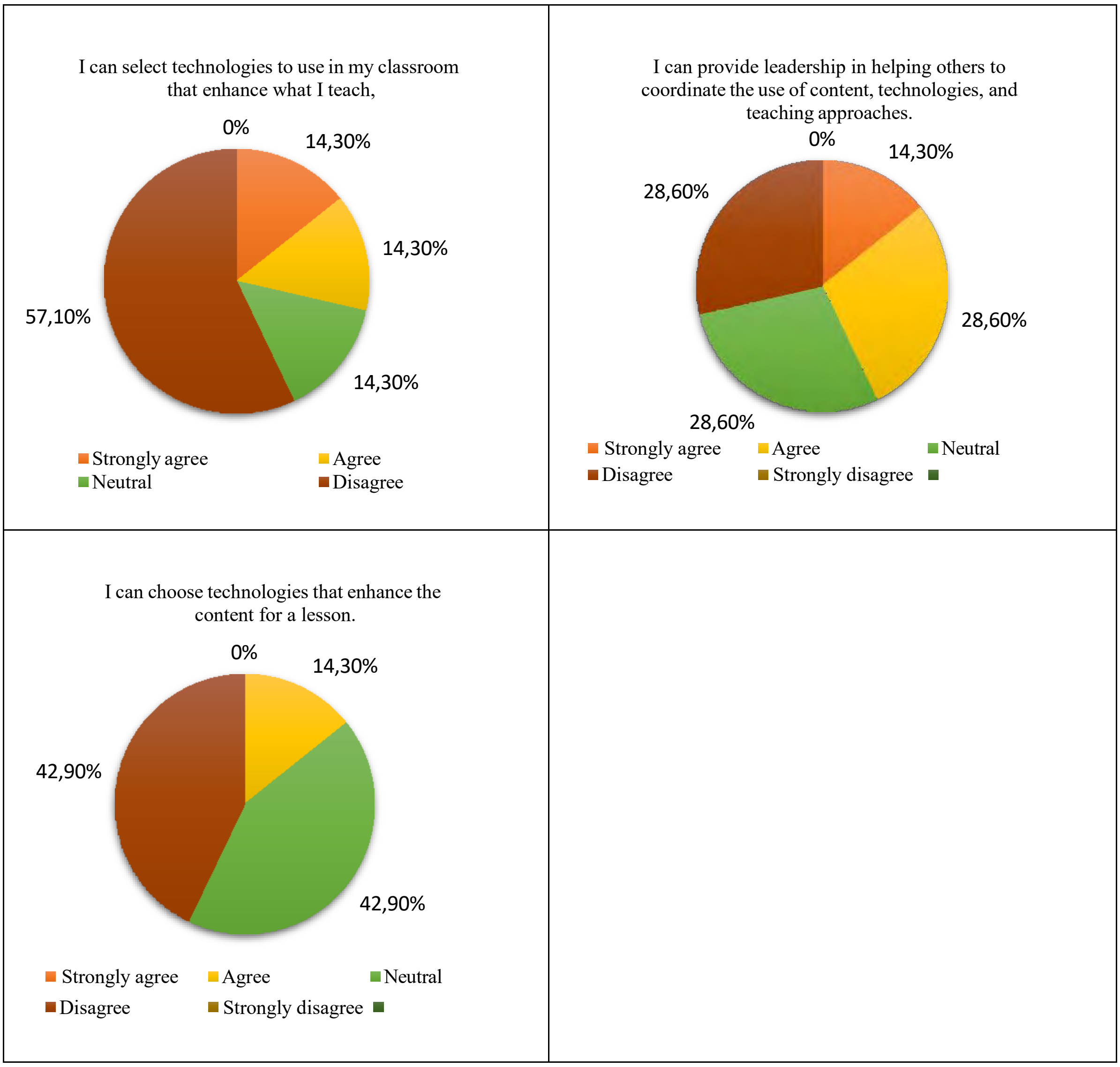


Figure 30: TPACK questionnaire findings – Pedagogical Content Knowledge (n = 7)

The computations of the mean scores of the six TPACK constructs in Figure 30 above revealed that the mean scores decreased when the technology component was added to the CK and PK. In this instance, TPK garnered the second-lowest mean score (M = 3.0816, SD = 0.67440). The mean score indicated that the Life Sciences teachers responded neutrally to disagree with the TPK items, suggesting teachers' poor TPK levels to use technologies as a pedagogical tool. To delve deeper into TPK, Figure 30 above displays the results of the eight individual TPK items. It can be seen from Figure 30 that the teachers displayed a broad range of responses. For example, for the item "I can plan a lesson that incorporates the use of technologies", the teachers responded as follows: strongly agree (n = 2, 28.6%), agree (n = 2, 28.6%), neutral (n = 2, 28.6%), disagree (n = 1, 14.3%) and strongly disagree (n =0, 0%). Furthermore, it can be noted that for most TPK items, the teachers' responses were clustered towards neutral and disagree. For example, four teachers (n = 4, 57.1%) disagreed with the item "I can select technologies to use in my classroom that enhance what I teach, how I teach and what learners learn." Lamentably, only one teacher (n = 1, 14.3%) reported that she "can choose technologies that enhance the content for a lesson", signifying that teachers' confidence in integrating technology into their pedagogy was low to moderate.

During the interviews, the question of the teachers' ability to select technologies that enhance learners' understanding was directly addressed. Most teachers acknowledged the potential of technology as a valuable tool in helping learners understand challenging topics. They expressed that incorporating technology in teaching can facilitate a better grasp of complex or abstract concepts. This sentiment was shared by MaMbotho and MaZikhali, as evidenced by their statements:

> *I have observed that when I incorporate technology into my teaching, learners seem better able to understand complex concepts such as the Geological timescale. Technology's visual and interactive elements engage them more effectively and enable them to comprehend difficult topics.* (MaMbotho)

> *Technology has been a game-changer in my classroom. I have noticed that when I use educational apps or multimedia resources, learners become more actively involved in learning. It helps them visualise abstract concepts and enhances their overall understanding.* (MaZikhali)

From these two statements, the teachers recognise technology's potential to support learners by providing visual and interactive experiences. These teachers demonstrated a forward-thinking mindset and a proactive approach to enhance the teaching of abstract or complex concepts. They acknowledge the potential of technology as a valuable tool for improving understanding and are open to exploring innovative strategies and incorporating them into their teaching methods. Their recognition of the value of educational apps, multimedia resources, and interactive elements reflects their dedication to creating engaging learning experiences that cater to the diverse needs of their learners. These teachers seemed to be aware of the challenges learners may encounter when grappling with abstract or complex topics, and they actively seek solutions to address these challenges by incorporating technology into their teaching.

Further scrutiny of the individual TPK statements from the questionnaire shows that the lowest mean rating (M = 2.790, SD = 1.1266) was recorded for the item "I always think critically about how to use technology in my Life Sciences class." This finding suggests that most rural Life Sciences teachers were either unsure or lacked confidence in their ability to "think critically about using technology in their teaching". Moreover, the high standard deviation (SD = 1.1266) suggests significant variation in teachers' responses. This high variability in the teachers' responses means that some are far from how the majority responded. During the semi-structured interviews, the teachers were asked about their perspectives regarding their TPK. Their responses indicated a clear understanding of the importance of technology training that goes beyond technical and operational aspects. Instead, they emphasised the need for professional development opportunities that focus on integrating technology into effective teaching practices. This result highlights their awareness that utilising technology effectively involves more than just knowing how to use specific tools; it requires understanding how technology can enhance pedagogy. The teachers' desire for training programmes prioritising integrating technology into pedagogy is crucial as it underscores their recognition of the interconnectedness between technology and effective teaching.

The teachers' interview responses emphasise the need to bridge the gap between technology skills and pedagogical knowledge, highlighting the importance of understanding how technology can be seamlessly incorporated into teaching strategies (TPK) to enhance learning experiences. These findings highlight the teachers' proactive stance towards their professional development that empowers them to harness technology's full potential in their pedagogical practices. The teachers' thinking can be summarised in Manci and Xaba's responses below:

> *The teacher workshop should focus on using technology to make science more accessible, interactive, and engaging. By incorporating technology into pedagogy, we [teachers] can enhance learning experiences by providing them greater access to scientific resources and information.* (Manci)

> *To ensure teachers are well-prepared to integrate technology into their teaching effectively, professional development programmes should prioritise improving technical competencies in using technology tools to enhance pedagogy.* (Xaba)

As mentioned earlier, the overall TPK mean score (M = 2.9875, SD = 1.0377) signifies the teachers' ability to choose which technologies can enhance their teaching. The results are not surprising considering that many participating teachers lacked formal training in technology integration into teaching. Therefore, it can be inferred that with increased technology adoption and usage, most Life Sciences teachers in rural schools will develop the TPK needed to utilise these teaching tools effectively. As technology becomes more prevalent in classrooms, professional development programmes should focus on training and supporting teachers to develop TPACK further.

6.2.2.6 Technological Pedagogical Content Knowledge

The questionnaire asked the participants to respond to the two TPACK items, and Figure 31 below shows the results.

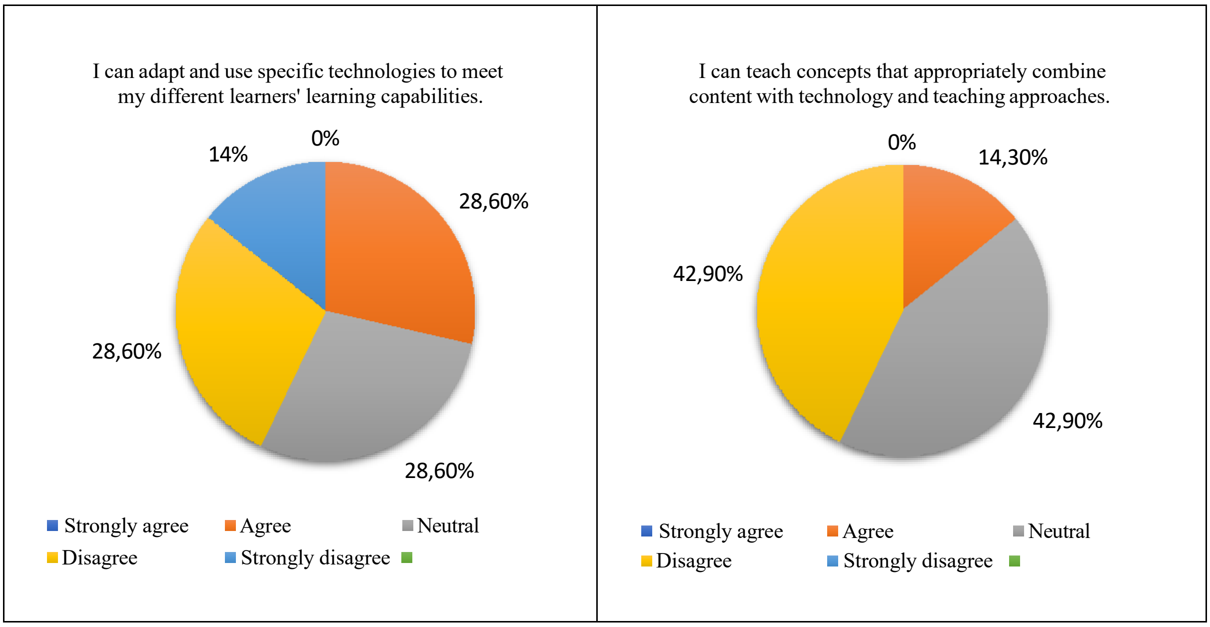


Figure 31: TPACK questionnaire findings – Technological Pedagogical Content Knowledge (n = 7)

The questionnaire findings reveal that the overall mean score for TPACK was the lowest (M = 2.7143, SD = 0.75593) among all the TPACK knowledge domains. This finding showed that most Life Sciences teachers (n = 5, 71.4%) were not confident in their ability to "adapt and use specific technologies to meet my different learners' learning capabilities." It also indicates that most teachers (n = 6, 85.7%) cannot "teach concepts/topics that appropriately combine the content with technology and teaching approaches." When explored through semi-structured interviews, the teachers were explicitly asked what informed their decision on which technologies to use and at what point they chose to do so. The teachers' responses included the following:

> *I can say I have a challenge to choose the technologies that can specifically help reinforce [learners'] understanding of a certain topic.* (Mkoena)

> *I think proper lesson planning is key to teaching well. So, before my lessons, I think about which technologies are right for my learners, but I am not yet good at that. I also check the CAPS document to see which activities can be taught with technology, and I do not quite get it.* (Manci)

The above statements highlight the teachers' confidence in their TPACK in teaching with technology. While this may be so, it was interesting that Manci's response reveals some pedagogical intent to use technology during the lesson planning stage. This aligns with Choi and Paik (2021), who describe lesson planning as the first stage of TPACK in practice. This shows the teacher's awareness of the need to contemplate how technology can support teaching at the lesson planning level, which on its own is an expression of some level of TPACK.

Moreover, the analysis of the questionnaire findings and the semi-structured interview responses indicate that less than half of the teacher participants (n = 3, 42.9%) agreed that they could "adapt and use particular technologies to meet their different learners' learning capabilities." This finding implies that most teachers in this study (n = 4, 57.1%) could not "adapt and use particular technologies to meet their different learners' learning capabilities." The challenge with this is that most technologies available were not specifically designed for teaching purposes or are not tailored for specific subjects or grades, which requires teachers to be able to adapt the technologies for teaching.

Therefore, a challenge arises when many teachers (n = 4, 57.1%) who participated in the study could not adapt and use particular technologies to meet their different learners' learning capabilities, suggesting a lack of TPACK. Notably, the overall TPACK domain has the lowest mean score (M = 2.7143, SD = 0.75593) when compared to the other technology-related domains, i.e., TK (M = 3.4048, SD = 0.77494) and TPK (M = 3.0816, SD = 0.67440). This is an important finding as it suggests that the Life Sciences teachers' confidence in integrating technology might be somewhat expressed by their lack of experience in using technologies in teaching. The interview response that corroborated this survey finding is as follows:

> *I really appreciate the flexibility of technology, especially the simulations, because they allow a teacher to modify and customize lessons to fit the needs and abilities of learners better. My issue is that I cannot select the simulations that align with my topic objectives.* (MaTshezi)

In addition to the semi-structured interview responses, the teachers also provided descriptions of their TPACK in the sharing circle discussions. The teachers were particularly responding to the question: 'Based on your experience of integrating technology in your classroom, how would you describe your own TPACK and what contributed to its development?' The teachers also had to respond to the question, 'Based on your experiences of teaching with technology, what noticeable TPACK component(s) were you able to identify in your teaching?' The teachers' responses made it apparent that while they appreciate their attempts to see the connections between various parts of TPACK, this is not easy for them. This finding confirms that TPACK is an emerging idea for most teachers, both as a concept and as something that they practice. This became evident from the following teacher responses:

> *TPACK is a concept that I have heard of, but I must admit that I find it quite challenging to grasp and explain it fully. My understanding is that TPACK involves technologies in teaching and knowing the subject content. My problem is understanding and articulating how these components interact and influence one another to enhance teaching with technology*. (MaTshezi)

> *To be honest, I find it challenging to provide a concise description of my TPACK. Although I may not fully understand the intricacies of TPACK, I appreciate that I have high CK and PCK levels.* (Mkoena)

> *I must admit that I am not entirely sure how to describe my TPACK. It is a concept that I only heard from this study. I can sense that TPACK involves the intersection of technology, pedagogy, and content knowledge. I believe that by understanding*

the connections between these elements and exploring how they interact, I can make more informed decisions regarding consciously integrating technology. (Faku)

In these responses, teachers MaTshezi, Mkoena, and Faku acknowledge their uncertainties in describing their TPACK knowledge but emphasise their belief in its transformative potential in teaching. These findings shed light on several important aspects of the teachers' TPACK and their challenges in integrating technology into their teaching practices. The key insights drawn from the above responses can be categorised as follows:

- **Competence and confidence in TPACK**: The statistical analysis indicated that the overall mean score for TPACK was the lowest among the technology-related domains. This observation suggests that while teachers may recognize the potential benefits of using technology, they lack the necessary skills, knowledge, and confidence to effectively incorporate it into their teaching. Specifically, they struggled with adapting technologies to meet the diverse learning capabilities of their learners and combining technology with content and teaching approaches.

- **Need for pedagogical intent:** One teacher's response in the semi-structured interview stands out, emphasising the importance of pedagogical intent during lesson planning when selecting and using technology. This suggests that teachers are becoming aware of the need to consider how technology can support teaching and learning during the lesson-planning stage. It indicates a shift from the traditional chalk and duster approaches to a more purposeful integration of technology aligned with pedagogical goals.

- **Decision-making challenges:** The semi-structured interviews provided valuable insights into teachers' decision-making process regarding technology use. The teachers expressed challenges in selecting appropriate technologies to reinforce learners' understanding of specific topics. They mentioned the importance of planning lessons properly but acknowledged their limited proficiency in doing so. The reference to the CAPS document highlights their attempts to seek guidance but also reveals confusion in understanding which activities can be effectively taught using technology.

- **A challenge in adaptation:** Since most available technologies were not explicitly designed for educational purposes or tailored to specific subjects or grades, it was a concern that teachers reported that they faced the challenge of adapting these technologies for teaching purposes. This requirement for adaptation created a gap in their ability to effectively integrate technology, as many teachers struggled to adapt and use particular technologies to meet their learners' diverse learning capabilities.

- **TPACK is an emerging and complex concept:** The teachers' descriptions of their TPACK knowledge indicate that TPACK is a complex and multifaceted concept that many teachers find challenging to articulate and fully grasp. They expressed uncertainties in describing their TPACK knowledge but recognised its potential to transform their teaching practices. However, their recognition of the potential transformative impact of TPACK on teaching practices is encouraging. It suggests a willingness to grow professionally and explore the connections between technology, pedagogy, and content knowledge.

Overall, the findings regarding the teachers' description of their TPACK reveal that Life Sciences teachers' expression of their non-technology-related domains (PK, CK and PCK) were higher than the technology-related constructs (TK, TPK and TPACK). Among the technology-related domains, the most robust proficiency was reported in the teachers' TK compared to TPK and TPACK, though lower than CK, PK and PCK. The strong TK imply that most Life Sciences teachers in rural schools regard their TK highly. However, the findings also reveal that introducing CK and PK domains to technology concepts further lowers their proficiency. This decline is demonstrated by the inclination towards reduced mean scores for the TPK and TPACK domains. As a result, most teachers have difficulty conceptualising TPACK holistically but often exhibit defragmented domains. Similar findings were reported by Tanak (2020), who found that science teachers in their study showed a mixture of pedagogy, content, and technology knowledge instead of integrating the three. The current study's findings, in line with Tanak's (2020) research, indicate that many science teachers do not effectively integrate pedagogy, content, and technology knowledge due to challenges in conceptualising TPACK. This finding can be read back to this chapter's epigraph, which states that TPACK, as an emergent knowledge form, is complex and elusive (Cox & Graham, 2009). This suggests a need for better teacher training and research into the underlying factors affecting TPACK integration. The next section explores how the teachers conceptualise TPACK.

6.3 PIECING TOGETHER TPACK

The findings from the questionnaire, semi-structured interviews, lesson observations, and sharing circle discussions consistently indicated that the teachers reported having the most substantial proficiency in the single components of CK, PK, and TK. This finding aligns with Neiss's (2011) model to understand how teachers develop TPACK, in which she explained that one of the first requirements is for the teachers to know the science (content) they teach (CK) and how to teach it (PK). The two knowledge kinds constitute PCK (Shulman, 1986). Beyond this, they must possess TK and, ultimately, how to teach science using technology (TPACK). While Neiss's (2011) model shows a linear development toward TPACK, the movement from one level or domain to another does not exhibit a systematic, steadily cumulative design. This observation implies that teachers may simultaneously draw on various TPACK domains as they develop TPACK. For example, at some point, teachers may demonstrate more CK, PK or TK than TPK in their teaching, as was found in this study.

Nonetheless, the teachers expressed notable difficulties in integrating and merging these individual knowledge components into the dual components, such as TPK, and ultimately forming a cohesive TPACK. The difficulty in 'piecing together' these knowledge components indicates that TPACK is not automatically strengthened through the development of its individual parts. In other words, simply mastering CK, PK, and TK does not guarantee a strong understanding of how to integrate technology into science teaching effectively. However, Warr and Mishra (2023) argue that TPACK is indefinable and elusive. The following teachers' responses point towards the teachers' challenges in 'piecing together' TPACK.

> *I have always considered myself proficient in CK, PK, and PCK. However, I now realise that I face significant challenges in effectively integrating these knowledge types to incorporate technology into my science teaching. I understand that TPACK requires a deeper level of comprehension and the ability to piece together these components strategically. I am willing to learn and seek guidance on how to improve my TPACK understanding and implementation.* (Mkoena)

The teachers' responses highlighted their recognition of the complexities of 'piecing together' TPACK. Mkoena, for example, acknowledged his initial belief in being proficient in CK, PK, and PCK but realised the significant challenges in integrating these knowledge types to incorporate technology in teaching effectively. He was willing to learn and seek guidance to improve his understanding and implementation of TPACK. Sharing the same view as Mkoena is Manci, who stated as follows:

> *Although I have a solid foundation in CK, PK, and TK, I struggle with integrating these areas to utilise technology in my class effectively. It is clear that acquiring high levels of CK, PK, and TK does not automatically result in a strong understanding of how to combine them for optimal teaching outcomes. I am interested in learning more about TPACK and gaining insights into effective integration strategies.* (Manci)

Sharing the same view as Mkoena, Manci expressed their struggles integrating their CK, PK, and TK to incorporate technology in teaching effectively. Despite having a solid foundation in these knowledge components, like Mkoena, Manci recognised that the amalgamation of CK, PK, and TK is not straightforward. They expressed that simply acquiring individual knowledge does not automatically lead to a comprehensive understanding of how to combine them synergistically for optimal teaching outcomes. The alignment between Mkoena and Manci's perspectives emphasises teachers' common challenges in integrating CK, PK, and TK into a cohesive TPACK framework. This challenge underscores that meaningful technology integration remains a pipe dream until teachers understand the transactional relationships between the individual TPACK domains. Along the same line, Choi and Paik (2021) posit that teachers need to develop fluency and cognitive flexibility in both critical domains, CK, PK and TK, and the manners in which these domains interrelate. This understanding allows the teachers to effect successful, differentiated, and contextually sensitive learning. These findings underline the importance of understanding how teachers develop TPACK and how teachers like Mkoena and Manci can be supported to enhance their TPACK understanding and implementation, leading to effective technology integration in teaching.

After the sharing circle discussions, the researcher conducted the last round of two lesson observations, which focused on the teachers' TPACK application in classroom practice. The observations were done for Mkoena and Faku. Both teachers reported that their initial teacher training programme did not provide opportunities for learning the use of technology in teaching Life Sciences. Consequently, the researcher assumed that the teachers lacked the TPACK for teaching Life Sciences. To analyse the teachers' TPACK development, the researcher first examined the teachers' lesson plans for the lessons to be observed. Mkoena's lesson plan was for the Grade 10 Life Sciences topic, Transport in Plants, and Faku's lesson plan was for the Grade 12 topic, Plant Responses to the Environment. Figures 32 and 33 show Mkoena's computer screenshots of the planned lesson presentations.

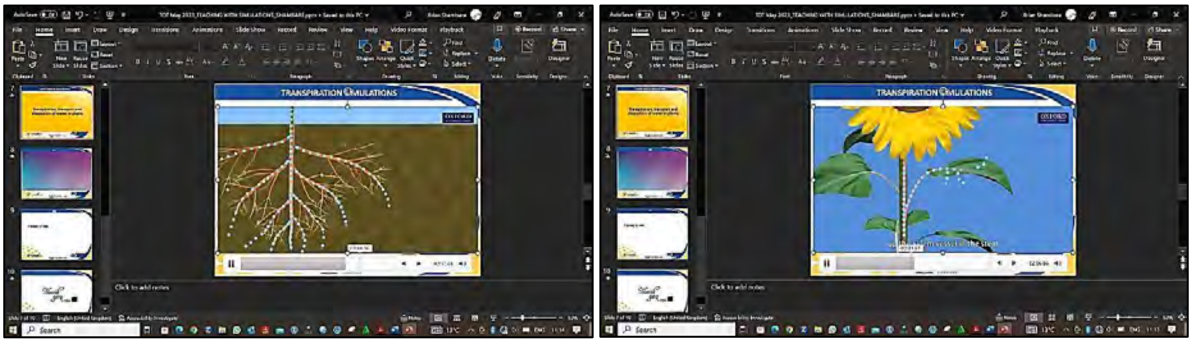


Figure 32: Mkoena's lesson computer screenshots

In Figure 32, Mkoena shows a simulation of water transport in plants, demonstrating how water moves from the soil into the inside of the root, stems and ultimately transpired out of the plant. Simulations like the one depicted in Figure 32, where Mkoena illustrates water transport in plants, hold immense significance for science learning. They provide a dynamic and visual way to comprehend complex scientific concepts that might otherwise be challenging to grasp through traditional methods. In Figure 33 below, Mkoena exemplifies the construction of a potometer using locally accessible materials, offering a method to measure the rate of transpiration in plants. This demonstration holds special significance in under-resourced schools, enabling learners to conduct essential experiments. By utilising readily available resources to create scientific tools, Mkoena addresses the challenges of limited materials and enhances learners' hands-on learning experiences. This practical approach promotes experimentation and critical thinking and empowers learners to engage actively in scientific exploration despite resource constraints.

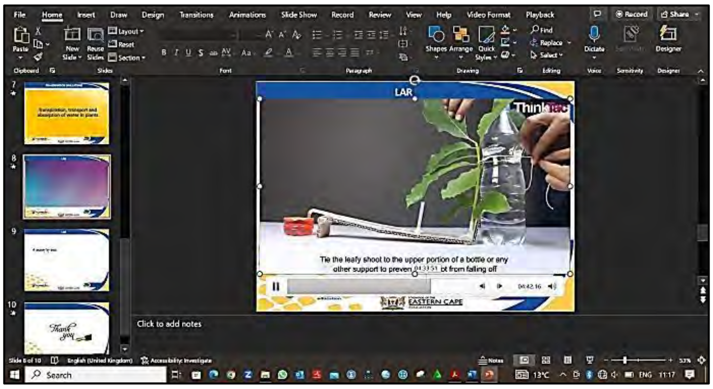


Figure 33: Mkoena’s lesson computer screenshot of a potometer made from locally available material

In their plans, both teachers had intended to use a video to introduce the topic to the class. However, the teachers did not plan to pause the video for questions or reflection, and the subsequent activity merely asked learners to watch the videos and write notes about them. This approach lacked inquiry tasks and explorations, and it appeared that technology was primarily used as a motivational tool. In addition, there were some shortcomings in the teachers’ use of technology. In her teaching, she provided a hyperlink to an age-inappropriate website that merely replicated the printed text.

Figure 34: Researcher conducting lesson observations

As already discussed, the purpose of the lesson observation was to assess the teacher’s understanding and application of TPACK. The observation aimed to identify specific instances where the teacher struggled to comprehend the different TPACK subdomains and how they should work together. The key observations are summarised below:

- **Limited integration of technology:** During the observation, it was noted that the teachers primarily used technology as separate tools rather than integrating them into science instruction. For instance, the teachers used technology to show videos of plants without explicitly connecting them to the learning objectives. The use of the videos was isolated and did not serve as an integral part of the lesson's content or pedagogy. As Gentles and Haynes-Brown (2021, p.6) observe, "Teaching with technology is an arduous and complex job given the multifaceted sources of knowledge which need to be contextualised and negotiated."

- **Lack of alignment between content, pedagogy, and technology:** The teacher demonstrated difficulties in aligning the lesson's content, pedagogy, and technology components. For example, Faku used a simulation on the smartboard to demonstrate the effect of light on plant growth. However, the simulation was not effectively integrated into the pedagogical approach. The teacher failed to guide learners in interpreting the simulation's results or facilitating meaningful discussions, which hindered the integration of TPACK.

- **Insufficient teaching strategies for technology integration:** Throughout the observation, the teachers relied primarily on traditional teaching methods, such as worksheets, without tapping into the capabilities of technology for interactive and engaging learning experiences. For instance, the teachers distributed paper-based worksheets instead of using Google Forms to administer questions. The missed opportunity to incorporate technology limited learner engagement and exploration of scientific concepts with the aid of technology.

6.4 CHAPTER SUMMARY

This chapter began by examining the teachers' understanding of TPACK both as a concept and a practice. The findings revealed that while most teachers correctly understood TPACK as a framework to describe the necessary knowledge for effective pedagogy in a technology-enhanced learning environment, many teachers lacked the correct understanding of TPACK. Despite this, the interview findings reflected their willingness to expand their TPACK and seek effective ways to integrate technology into their teaching. Interestingly, the teachers also demonstrated an awareness of the role of context in influencing technology integration in teaching. They sought to understand how TPACK could be applied within their own teaching context, displaying a proactive approach to improving their teaching methods. By expressing a need to learn more about the TPACK framework, the teachers acknowledged the value of translating theoretical knowledge into practical implementation in their specific classroom contexts. This finding highlighted that the teachers' pedagogical decisions and integration of technology were rooted in their specific contexts.

Furthermore, the questionnaire results showed that the overall mean score for TPACK was the lowest among the TPACK domains. There was a convergence between the questionnaire and semi-structured interview responses, illuminating a consistent pattern of high self-reported CK and PK proficiency and limited knowledge and understanding of TPACK. Specifically, the teachers reported high confidence levels for the single knowledge components such as CK, PK and TK. However, they reported low levels when amalgamated into dual components such as TPK and TPACK. These findings suggested that there is still much to be explored and understood regarding TPACK understanding and its application by Life Sciences teachers in rural schools. Consequently, it can be concluded that until teachers understand how TPACK influences and supports meaningful technology integration in teaching, the full potential of technology in rural classrooms remains untapped. The following chapter addresses Research Question 3: 'What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?' Specifically, the next chapter explores the factors, practices, experiences, and contexts that shape the teachers' TPACK development in rural schools.

CHAPTER SEVEN: PRESENTATION AND ANALYSIS OF RESULTS

> Vygotsky's (1978) notion of mediation of knowledge suggests that human knowledge is mediated and developed using cognitive artefacts or 'tools.' The discerning use of such cognitive artefacts assumes paramount significance in the intricate tapestry of knowledge construction and its concomitant and ongoing cycle of learning and developmental growth. (Vygotsky, 1978, p.37)

7.1 INTRODUCTION

The epigraph above emphasises Vygotsky's (1978) concept of the mediation of knowledge, which proposes that human knowledge is shaped and advanced through the utilisation of 'tools.' This perspective assumes that how these tools are leveraged is essential for developing knowledge and continuous learning. Through their individual and collective voices and self-reported practices, the Life Sciences teachers in rural secondary schools, who lack formal training in technology integration and without guidelines, facilitated a better understanding of the sources of TPACK from which they draw in their teaching. Specifically, this chapter is premised on the research question: 'What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers commonly draw upon in their teaching?' Findings related to this question are the results of the analysis of semi-structured interview data, lesson observations and sharing circle discussions.

This inquiry to understand the sources of the teachers' TPACK is paramount as the researcher sought to delve into the underlying factors, contexts, and experiences that shape the teachers' TPACK development in rural schools. This knowledge holds the potential to maximise the effective use of technology in the classroom. By embracing and leveraging these insights, the teachers in rural schools could be supported and equipped with the skills, knowledge of teaching, and adaptability needed to thrive in rapidly evolving technology-infused classroom environments. This chapter presents the semi-structured interviews and sharing circle discussion results thematically in a narrative form using excerpts or verbatim statements from the participants. These findings are triangulated with the lesson observation findings during the interpretation and discussion stages. This chapter is divided into two main sections. The first section, Section 7.2, along with its sub-sections, is dedicated to presenting the findings related to the sources of the teachers' TPACK. The second section, Section 7.3, serves as a summary of the chapter.

7.2 RESEARCH QUESTION 3

Data for this section was generated to answer the following question:

> What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?

Research Question 3 is premised on the realisation that most studies on TPACK development focused on preservice teachers. This research took a shift from the main line of inquiry on preservice teachers and turned its attention to understanding how TPACK develops among in-service and experienced teachers. Due to the experienced teachers' familiarity with teaching and curriculum, the nature and acquisition of their TPACK differs from those of their preservice teachers. Furthermore, previous investigations into in-service teachers' TPACK development have often failed to differentiate between the various TPACK subdomains explicitly. In contrast, this study looks at these interconnected yet distinct aspects to identify their specific sources and understand their individual contributions to TPACK development. It is worth noting that most TPACK research has been conducted in the Global North, with few studies representing the Global South. Thus, Research Question 3 seeks to address the remaining uncertainties in the field by specifically exploring aspects that have not been adequately clarified thus far. By doing so, this study aims to provide valuable insights into TPACK development among in-service teachers, filling a significant research gap and contributing to a more comprehensive understanding of this topic.

In presenting the findings for Research Question 3, the researcher drew on the SCT and TPACK principles as lenses to analyse and offer a more rounded grasp of the Life Sciences teachers' TPACK development in rural secondary school contexts. As indicated in section 3, the TPACK framework provided the analytical framework to examine teacher knowledge to integrate technology in the classroom. On the other hand, the researcher used the SCT to explore how rural Life Sciences teachers' interaction with technology tools mediates (or not) their self-reported TPACK development. The findings for Research Question 3 are presented as themes and sub-themes which are summarised in Table 9 below.

Table 9. Major sources of teachers' TPACK

Theme (TPACK Component)	Sub-theme (TPACK Source)
Pedagogical Knowledge	• Initial teacher training and teaching practice • Self-directed learning and teaching experience
Content Knowledge	• Teacher development workshops and secondary schooling experience • Collaboration with Peers
Pedagogical Content Knowledge	• Teaching practice during initial teacher training • Teaching experience and mentoring by more experienced teachers
Technological Knowledge	• Technology-related training workshops • Self-directed learning • Interaction with colleagues
Technological Pedagogical Knowledge	• Teacher development workshops and teaching experience
Technological Pedagogical Content Knowledge	• Self-directed learning • Peer learning through social interaction • Learning from learners

7.2.1 Pedagogical Knowledge

This section delves into the origins of PK, as illuminated through insights gleaned from semi-structured interviews with the Life Sciences teachers. Specifically, the spotlight is on two noteworthy PK sources: initial teacher training and teaching practice and self-directed learning and teaching experience. These dual sources offer valuable insights into how Life Sciences teachers acquire the knowledge and skills essential for teaching in rural schools.

7.2.1.1 Initial teacher training and teaching practice

During the semi-structured interviews, most teachers indicated that the major source of their PK was the initial teacher education. Tied to the teacher education context was their teaching practicals in schools as part of their initial training. Most teachers focused on classroom management as part of the PK they developed at university. Specifically, the teachers reported developing effective behaviour classroom management strategies from their initial teacher training. This was captured in the following interview responses:

I obtained most of my PK from my initial teacher training programme at the university. During that period, I had chances to conduct teaching practicals at various schools, where I developed my knowledge of classroom management. This helps me now to create and maintain a conducive environment for learning. (Faku)

I credit a substantial portion of my PK to my university years. The hands-on experience I acquired by teaching in schools as part of that programme played a big role in learning how to manage a class and strategies on how to teach. (MaMbotho)

As a practising teacher, I consistently draw upon the PK I gained during my initial teacher preparation programme at the university. The experiential aspect of that programme, where I taught in actual school settings, reinforced my understanding of classroom management. (Mkoena)

The teachers' responses are not unexpected because, throughout teacher training, PK is strongly emphasised in the teacher education programme and teaching practice in schools. The teachers mentioned that assessing prior knowledge was also a critical practice they incorporated into their teaching. When asked about what informs their rationale for assessing prior knowledge, the teachers indicated that they were drilled to do so during their initial teacher training. For example, Xaba recollected:

In university, we were often told that it is crucial to find out what they already know before teaching someone. It would not make sense to teach them something new if we are not sure they will understand it. (Xaba)

The responses from the teachers in the study shed light on the significant influence of initial teacher training programs as a source of teachers' PK. The teachers' recognition of the enduring impact of their teacher education training on their current practice underscores the effectiveness and long-term benefits of comprehensive initial teacher preparation programmes. Furthermore, the experiential aspect of their training, including the opportunity to teach in actual school settings, deepened their PK, particularly the understanding of effective classroom management and teaching strategies. This finding suggests that teaching practical experiences are instrumental in bridging the gap between theory and practice, equipping the would-be teachers with the skills and knowledge necessary for successful teaching careers. More so, the teachers emphasised assessing prior knowledge, demonstrating their understanding of the importance of recognising and building upon learners' existing knowledge. This practice aligns with learner-centred and differentiated teaching principles, allowing teachers to tailor their teaching approaches to meet their learners' individual needs and abilities.

7.2.1.2 Self-directed learning and teaching experience

In addition to the initial teacher training programme as a major source of PK, another noteworthy response emerged from MaTshezi, who holds a BSc degree. Contrary to the rest of the participants, it is essential to note that MaTshezi is the only one who did not undergo initial teacher training for her first degree. Furthermore, she lacks a PGCE, which could have allowed her to develop her PK. MaTshezi responded as follows:

> *I have learned science in my BSc degree, but I have not learned how to teach science. I did a BSc degree, and we had no 'How to teach science' modules. I have not really been taught how to teach science. So yeah, the university did not teach me pedagogical knowledge.* (MaTshezi)

From the above response, the researcher became interested in understanding where MaTshezi draws her PK in teaching, considering that she was never initially trained as a teacher. In her response, the teacher indicated that she develops PK through self-directed learning and her teaching experience. She explained as follows:

> *I believe that teaching is not solely limited to the knowledge gained from traditional teacher training programmes. While those programmes provide a solid foundation, I have found that hands-on experience and reflection significantly shape my PK. I have refined my teaching strategies over time by actively engaging with learners and adapting my teaching methods based on their needs.* (MaTshezi)

MaTshezi also explained that she has been proactive in developing herself as a teacher through self-directed learning, which she believed was a source of her PK. She added as follows:

> *Additionally, I have taken the initiative to seek out educational books and online resources to supplement my understanding of effective teaching practices. In my view, this self-development has allowed me to improve my PK.* (MaTshezi)

In sum, the interview responses above highlight the role of initial teacher training programmes at universities as a major source of PK for most teachers. The teachers acknowledged the invaluable opportunities provided by these programmes, including practical teaching experiences in actual schools, which significantly contributed to their development as teachers. A particular focus of their PK development was classroom management, with the teachers reporting that they learned effective behaviour management strategies during their university experiences. These strategies have been instrumental in creating positive and supportive learning environments in their classrooms. The emphasis on PK in initial teacher training programmes aligns with expectations, as most initial teacher education programmes typically prioritise the development of PK in their teacher education programs.

However, one teacher (MaTshezi) mentioned that her initial university degree curriculum did not include specific training on teaching. This led her to develop her PK through self-directed learning and teaching experience. This finding highlights the value of hands-on experience, reflection, and active engagement with learners in shaping a teacher's PK. Additionally, like MaTshezi, most teachers with no training can develop PK by seeking resources such as educational books and online courses to enhance their understanding of effective teaching practices, demonstrating the importance of self-directed learning in their professional growth. Ironically, MaTshezi's story aligns with the researcher's own teaching experience. The researcher taught for four years with a BSc (not a teaching qualification) and learned how to teach similarly to MaTshezi.

7.2.2 Content Knowledge

Drawing from the teachers' self-reported experiences, teacher development (TD) workshops and their formative experiences as secondary school learners, coupled with peer collaboration's transformative influence, emerged as the pillars of CK development.

7.2.2.1 Teacher development workshops and secondary school experience

While it might be assumed that the initial teacher training would have been the most significant source of CK, analysis of the interview findings indicates otherwise. The interview narratives revealed that the teachers rely more on CK from TD workshops and their own school experience as learners. This finding flows from the following teachers' responses:

> *Reflecting on my teaching journey, I realise that the workshops I have attended and the practical insights gained from my school experience have played a more significant role. These experiences have allowed me to develop my knowledge of Life Sciences content.* (MaZikhali)

> *I have found that attending the Life Sciences content-gap workshops has helped deepen my understanding of the subject content. Furthermore, reflecting on my own experiences as a learner in school has allowed me to understand my learners and address their needs more effectively.* (Xaba)

> *In my case, I was never taught Life Sciences content at university. No topics on genetics or evolution were taught. I learned the Life Sciences content I have is one I learned from my secondary school and the teacher development workshops.* (Manci)

As indicated by the teachers' statements above, most teachers draw their CK from the continuous TD teacher development training. These training workshops are facilitated mainly by the Subject Advisor under the ECDoE to capacitate the teachers continuously. In this instance, it should be noted that the researcher is the Subject Advisor who facilitates some of the workshops (see Figure 35 below).

Figure 35: Researcher conducting content workshops (Mthatha)

7.2.2.2 Collaboration with peers

During the interviews, the teachers also reported drawing CK through peer collaboration. The teachers specifically mentioned collaborating with their colleagues within their school and neighbouring schools to share best practices, exchange ideas, and learn from each other. The teachers further revealed that the collaborations help them broaden their CK and benefit from the expertise of the more knowledgeable peers in some aspects of the content areas. Below are the teachers' responses:

> *My school has set up a subject committee led by our Departmental head. Every Friday, we meet and plan our lessons for the following week. In these meetings, we clarify those content areas that we are not too sure about. We actively share best practices, exchange ideas, and learn from each other. This helps me broaden my content knowledge and improve my teaching.* (MaZikhali)

> *We have a structure for sharing best practices and tapping into each other's expertise. This leads to a supportive learning community within the school.* (Faku)

> *At my school, we regularly share best practices, discuss strategies, and learn from each other in terms of content.* (Mkoena)

From the above responses, the subject committees that the teachers have at their schools are helping them to develop their CK. These subject committees are, in fact, Professional Learning Communities (PLC), although the teachers did not identify them as such. Therefore, these PLCs provide opportunities for the teachers to develop various aspects of teacher knowledge. This finding contradicts Fullan and Hargreaves (1991), Leonard and Leonard (2003), and Ni et al. (2023), who found that teachers often do not work together. Specifically, the findings from the interviews shed light on the sources of CK for the teachers interviewed.

Furthermore, contrary to the assumption that the university would be the primary source of CK due to their teacher preparation programmes, the teachers revealed that they rely more on CK acquired through TD workshops. Additionally, reflecting on their experiences as learners during secondary school allows them to connect with their learners and address their needs more effectively. The teachers mentioned that their university training did not cover specific content topics adequately. Instead, they relied on the content knowledge they had acquired during their secondary school education. This finding highlights the importance of their prior educational experiences as a foundational source of CK. In addition, collaboration with peers also emerged as a significant source of developing CK for the teachers. They emphasised the value of working with colleagues in their schools and participating in professional networks. By sharing best practices, exchanging ideas, and learning from each other's expertise, teachers reported that they were able to broaden their CK and enhance their teaching approaches.

7.2.3 Pedagogical Content Knowledge

This study discovered that teaching practice during initial teacher training forms the bedrock for teachers, giving them their first insights into PCK. Notably, the present research revealed that PCK's development continues beyond training and is shaped by two core sources: teaching experience and mentorship by more experienced teachers.

7.2.3.1 Teaching practice during initial teacher training

Regarding PCK, most teachers indicated that they draw this knowledge from their teaching practicum during initial teacher training and teaching experience. This narrative is evident from the following responses:

> *During my teaching practice as a learner teacher, I received a foundation of PCK that provided me with essential teaching strategies. However, I have found that my PCK is significantly evolving through my teaching experience. As I become more experienced, I become more aware of how to teach the content effectively.* (MaZikhali)

> *I can say that I first had a grasp of PCK during my teaching practice, where I was introduced to various ways of teaching. As time passes by now, as I teach, I can see that my understanding of PCK is becoming clearer by the year as I deal with different learners and challenges, which forces me to adjust my strategies and develop a deeper understanding of how to present content in ways that engage and support learning.* (Faku)

From the above responses, one can see that regarding PCK, teachers began learning how to be "good teachers" from their teaching practice.

7.2.3.2 Teaching experience and mentoring by more experienced teachers

Furthermore, mentoring by more experienced teachers, who are knowledgeable others, during teaching practice was also highlighted as a source of PCK. The teachers also indicated that mentoring has remained a source of PCK even as they become more experienced teachers. They suggested that they learn PCK along the way as they teach. For example, the following teachers stated as follows:

> *I believe that my PCK is something that develops and grows over time as I gain more teaching experience. I learn and refine my PCK along the way as I teach. Each interaction with my learners presents an opportunity for me to adapt and adjust my teaching strategies. Also, through ongoing reflection, collaboration with colleagues, and seeking professional development opportunities, I continuously learn and enhance my PCK to better support my learners' learning.* (MaTshezi)

> *Developing my PCK has been an ongoing process throughout my teaching career. True development of my PCK has occurred as I engage with learners in the classroom. By constantly evaluating the effectiveness of my teaching, I continue to learn and improve my PCK.* (MaMbotho)

> *Teaching is a dynamic profession, and my PCK evolves alongside my learners' needs. I reflect on my teaching experiences, and seeking feedback from colleagues and mentors has been invaluable in developing my PCK over time.* (MaTshezi)

The above teachers' responses, which show how they develop their PCK, align with constructivism. Through this lens, constructivism argues that learning is a dynamic process through which the experiences of the individual and their interaction with their environment allow them to build knowledge (Amineh & Asl, 2015). The teachers in this study reported drawing PCK from their teaching experiences and interactions with their peers that represent their environment. The teachers recognise that while initial teacher training provides a foundation, practical experience in the classroom is essential for deepening their understanding and application of PCK. Through teaching practicals and interactions with diverse learners and challenges, teachers refine their strategies and better understand effective content presentation. Even as teachers gain more experience, they benefit from mentoring relationships with knowledgeable colleagues. This finding aligns with Lortie's (1975, p. 54) "apprenticeship of observation" that teaching is an endeavour that involves gradually accumulating knowledge and expertise over time, which he referred to as the process of incremental growth.

Furthermore, the teachers expressed a desire to engage and support their learners by aiming to design teaching methods that actively engage learners and meet their individual needs, fostering a more inclusive and effective learning environment. Notably, reflective practice emerged as a crucial aspect of their teaching experience, driving self-directed learning and growth in PCK. Through reflection, teachers adjust their strategies and deepen their understanding of effective teaching techniques as they gain more experience. Therefore, teaching practicum and ongoing in-service teaching become a source of the teachers' PCK, ultimately contributing to their overall TPACK. Jang and Tsai (2013) reported similar findings when examining 1 292 Taiwanese secondary school science teachers TPACK. They found that experienced science teachers' PCK and CK were significantly higher than those of less experienced teachers. The findings emphasise the importance of experience and the continual improvement of teaching skills. Overall, teaching practice during initial teacher training provides a foundation. However, through teaching experience and reflective practice, teachers refine and enhance their PCK to meet the evolving needs of their contexts.

7.2.4 Technological Knowledge

According to the teachers, the most significant sources of TK are the technology-related teacher development workshops, self-directed learning, and interaction with colleagues. It was also noteworthy that none of the teachers cited the initial teacher education as a source of their TK. This finding could imply that the teacher's initial training did not address technology integration in teaching or that the teachers did not attend the technology courses during the university training.

7.2.4.1 Technology-related training workshops

An analysis of the teachers' responses regarding technology-related training workshops as their source of TPACK yielded divergent perspectives. While some teachers reported the positive contribution of the workshops to their TK development, this could not be said for others. For example, MaTshezi and Xaba reported that technology workshops offered them opportunities to develop TK. The teachers explained as follows:

Technology training workshops have been important in developing my technological knowledge. These workshops provide hands-on experience and practical guidance on using various technologies. I learned new tools and software applications. (MaTshezi)

The workshops on technology training have helped me improve my knowledge of how to use various technology tools, which I would not have been able to use without the training. (Xaba)

While the above teachers indicated that the in-service teacher technology workshops developed their TK, there were differing views regarding the usefulness of the technology workshops as a source of TK. This was reflected in the following statements:

While technology training workshops can potentially develop TK, my experience with most of these workshops has been disappointing. In most cases, the workshops lacked depth and in-depth training on specific tools or applications. (Mkoena)

Mkoena went as far as to add the following statement suggesting that the workshops did not address the actual teaching applications of the technology tools:

Additionally, the pace of the workshops was often too fast, leaving little time for practice and reflection. As a result, my understanding of the technology was limited, and I struggled to implement it in my classroom effectively. It would be beneficial if these workshops offered more comprehensive and tailored training, allowing teachers to better understand the technologies and their practical application in teaching. (Mkoena)

Like Mkoena, MaTshezi also reported that the technology training workshops have not been very active in developing her TK. She stated as follows:

In my experience, technology training workshops have been somewhat ineffective in developing my TK. While these workshops introduce new tools and techniques, they often lack practical application and fail to address the specific challenges faced *in the classroom. The content is often too generic and does not align with the needs of diverse content areas or grades.* (MaTshezi)

The teachers' responses above indicate divergent views regarding the contribution of technology training workshops as a source of TK. Indeed, as part of his job description, the researcher is cognisant of the teacher participants' experiences as he often facilitates the training workshops. For example, in the pictures below, the researcher conducted a four-day workshop on teaching Life Sciences using simulations. The workshop was conducted in Port Elizabeth (Gqeberha) from 12/05/2023 to 15/05/2023 (see Figure 36 below).

Figure 36: Researcher conducting Technology (Teaching with Simulations) Workshop in Port Elizabeth

Analysing teachers' responses regarding technology-related training workshops as a source of TK reveals divergent perspectives. Some teachers reported positive experiences, emphasising the workshops' importance in developing their TK. They appreciated the hands-on experience, practical guidance, and learning new tools and software applications. However, contrasting views emerged, with some teachers expressing disappointment in the workshops' effectiveness. They found the sessions lacked depth and failed to provide in-depth training on specific tools or applications. The fast pace of the workshops left little time for practice and reflection, hindering their understanding and implementation of technology in the classroom. These teachers suggested that more comprehensive and tailored training was needed, focusing on the practical application of technologies in teaching.

7.2.4.2 Self-directed learning

In addition to the technology-related training workshops, it was interesting to discover that most teachers also cited self-directed learning as a source of their TK. This finding was captured in the following statement:

> *When it comes to my TK, I am learning much of it by teaching myself. I explore a wide range of online resources, tutorials especially from YouTube. This enables me to delve deeper into learning new technologies, experiment with new tools and by doing so, software and acquire some TK.* (Faku)

However, MaZikhali further indicated that while self-directed learning offers numerous opportunities, it does come with certain challenges. One challenge she put forward was:

> *One challenge I encounter is the overwhelming amount of information available online. It can be difficult to discern credible sources and identify relevant resources. Without proper guidance, I sometimes waste time finding reliable and high-quality materials.* (MaZikhali)

As part of the challenges of self-learning, Xaba also indicated that the method demands a high level of discipline, without which one cannot effectively acquire knowledge. He stated as follows:

> *Teaching oneself requires self-discipline and motivation to set and achieve learning goals. Without external deadlines or guidance, I often lose focus and become confused by too much available information.* (Xaba)

After hearing how the teachers use self-learning to develop their TK, the researcher became more curious about specific examples of how the teachers taught themselves as they developed TK. The teachers explained as follows:

> *I taught myself how to use Adobe Photoshop. I explored online tutorials, watched videos, and experimented with the software. Through practice and trial and error, I learned various image editing, retouching, and graphic design techniques. This*

> *self-learning allowed me to create great-looking visuals to support my teaching materials.* (Xaba)

> *No one sat me down and taught me how to use data visualisation tools like Microsoft Power BI. I searched online tutorials and practised creating visual representations of data sets. I gained the skills to convert numbers into good-looking charts and graphs. This allowed me to analyse learners' marks with more insights.* (MaZikhali)

The above teacher responses underscore the role played by self-directed learning on their TK development. They mentioned exploring online resources, tutorials (especially on platforms like YouTube) and experimenting with new technologies and tools as agents of self-directed learning. However, challenges such as discerning credible sources, identifying relevant materials, and maintaining self-discipline were noted. The teachers' abilities to learn the technologies on their own can be understood through this study's constructivist lenses (Piaget, 1981). He clarifies that having assimilated using the technologies from their experiences, the teachers become more experienced in various technologies (TK), assessing which technologies are most appropriate to represent certain content, leading to TPACK.

7.2.4.3 Interaction with colleagues

Further analysis of the teachers' responses revealed another interesting finding: they also draw TK from interactions with their colleagues. According to the teachers, these interactions occur in various forms, from formal workshops to PLCs to informal discussions. Reduced to their simplest elements, these interactions provide teachers with opportunities for collaboration and knowledge-sharing. This allows the teachers to exchange ideas, discuss best practices, and explore innovative ways to incorporate technology in the classroom. This was captured in the following teachers' responses:

> *The collaborative nature of the workshops promotes networking and knowledge-sharing with fellow teachers. This allows us to learn from each other's experiences and discover other ways to use technology for teaching. Interacting with other teachers helps me learn from their successes and challenges to use technology effectively in the classroom.* (MaTshezi)

As part of interacting with each other, MaMbotho indicated that one advantage he draws from such interactions is what he referred to as collaborative problem-solving. She explained as follows:

> *Whenever I encounter technological challenges or need assistance with troubleshooting, my colleagues provide invaluable support and guidance. We discuss problems, brainstorm solutions, and find innovative approaches. This collaborative problem-solving approach helps me overcome technical difficulties and encourages me to address technology-related issues proactively*. (MaMbotho)

Furthermore, from the teachers' responses, it could be seen that their interactions also serve as platforms to work together on specific projects. Mkoena identified this as a collaborative project. He stated as follows:

> *I collaborated with a colleague on a project that involved creating interactive multimedia presentations for our learners. Through our discussions and brainstorming sessions, my colleague shared their expertise in using presentation software and recommended advanced features I was unaware of. Their insights and guidance helped me explore new techniques, such as incorporating interactive quizzes and multimedia elements, which significantly enhanced the engagement and interactivity of my presentations.* (Mkoena)

It can be seen from Mkoena's response above that he learned some advanced features he was not aware of from his colleague. The researcher identified this as peer learning and mentorship. When probed to explain further what learning from his more knowledgeable colleagues meant, Mkoena elaborated as follows:

> *Some of my colleagues possess advanced technological skills and expertise. They have become mentors for me, guiding and inspiring me to expand my TK. Observing their practices and seeking their advice has taught me valuable insights about educational technologies.* (Mkoena)

The teachers also made it clear that the interactions they have amongst themselves are not only limited to formal settings such as workshops. They indicated that they often draw their TK from informal discussions. For example, Manci stated as follows:

> *During informal discussions with colleagues, we often share our experiences and challenges related to various technologies. In one instance, a colleague shared their success using a specific educational app to enhance learner collaboration and critical thinking skills. Intrigued by their approach, I explored the app further, implemented it in my classroom, and observed positive results. This interaction with my colleague introduced me to a valuable tool and inspired me to seek out more innovative applications to improve learner learning.* (Manci)

From the above responses, the teachers identified technology-related teacher development workshops, self-directed learning, and interactions with colleagues as the main sources of their TK. Notably, none of the teachers mentioned the university as a source of TK, suggesting a potential gap in technology integration during initial teacher training. The question that arises from this finding is whether the initial teacher training programme does not offer technology integration training or perhaps the teachers who participated in this study did not attend the technology integration courses. Moreover, another finding regarding technology-related training workshops is that the teachers had divergent perspectives. Some reported positive experiences, highlighting the hands-on experience, practical guidance, and exposure to various technologies and software applications. However, others expressed disappointment, noting a lack of depth, insufficient training on specific tools or applications, and a failure to address the practical application of technology in teaching. The fast-paced nature of the workshops and generic content were also cited as concerns.

In addition to the technology training workshops, the teachers identified interaction with colleagues as an essential source of their TK. The teachers highlighted formal workshops, PLCs, and informal discussions as opportunities for collaboration, knowledge-sharing, and problem-solving that served as the sources of their TK. This can be viewed from the constructivist perspective, which posits that learning is an active process through which the experiences of an individual and their interaction with their environment allow them to build knowledge (Ajzen, 1991; Piaget, 1981; Valente & Blikstein, 2019). In this study, it was the interaction of the teachers with various educational technologies and colleagues in the workshops that the researcher assumed offered them opportunities to develop TK. The teachers learned from their colleagues' experiences, discussed best practices, and worked together on projects, benefiting from peer learning and mentorship in line with the epigraph above. The responses indicate the teachers' reliance on formal and informal learning opportunities to develop their TK. The workshops, although having mixed effectiveness, still provided valuable insights and exposure to new tools. Self-directed learning allowed for in-depth exploration and experimentation, while interactions with colleagues fostered collaboration, problem-solving, and the acquisition of advanced skills through peer learning and mentorship.

7.2.5 Technological Pedagogical Knowledge

This study's participants reported crucial findings on the sources of their TPK: teacher development (TD) workshops and teaching experience.

7.2.5.1 Teacher development workshops and teaching experience

Regarding TPK, the teachers reported drawing this knowledge from the teacher development (TD) workshop and teaching experience. The teachers indicated that the TD workshops help inform and motivate them to inquire about adapting technologies into their classrooms. According to the teachers, the TD workshops provide them with opportunities to consider how technology can enhance their lesson delivery. In addition, it was interesting to find out that the teachers were aware that the decision of how technology can be used to support pedagogy should be taken individually. Related to that, it was also interesting to realise that the teachers were conscious that each teacher should decide if technology is useful and find the best ways of integrating it into their lessons depending on their contexts. This understanding was evident from MaMbotho's response:

> *How else could I have enhanced the classroom with technology? Initially, I attended a workshop. However, a couple of hours of workshop were not enough to teach me how to use it. It did spark my interest, though, and I had to decide whether to try it in the classrooms. I had to put in the effort to learn it well enough to give it a try.* (MaMbotho)

Furthermore, MaMbotho, who attended workshops, reported that he could adjust technologies for his classes through the experience of using them in class. She mentioned as follows:

As a teacher with some experience under my belt, attending the workshops was a real eye-opener for me. It gave me some great ideas on how to use technology in my teaching. I learned new strategies and techniques that made my lessons more engaging and helped my learners learn better. (MaMbotho)

Along the same line, Manci also reflected on the role of TD workshops as a source of their TPK. This was captured in his response as follows:

Using my teaching experience as a foundation, the workshop completely changed the way I thought about technology in the classroom. It motivated me to learn new ways of teaching by combining technology with what I already knew. (Manci)

From the above excerpts, it can be concluded that attending the TD workshop proved to be a transformative experience for the teachers, as it enhanced their existing PK by incorporating technology (TPK). The teachers indicated that they were aware that the TD workshops serve as a starting point, providing the teachers with insights and motivation to explore technology integration in their classrooms. Moreover, from the teachers' perspectives, the TD workshops allowed them to consider how technology can enhance their lesson delivery and sparked their interest in incorporating technology. The importance of TD workshops in improving TPK was also reported by Dursun (2019) in Turkey, where they measured four secondary school science teachers' TPACK development through technology teacher development training. Data was gathered through lesson plans, questionnaires, observations, and interviews. The researchers found that teacher development programmes helped the teachers' TPACK development. However, the teachers in this study recognised that simply attending a workshop is insufficient to understand and effectively use technology in the classroom. They emphasised the importance of individual decision-making and the need to determine if a particular technology is useful and find the best ways to integrate it into their lessons. This understanding reflects the teachers' awareness that technology should support their pedagogy and that teachers must take the initiative to learn and master the technology before implementing it.

In addition to the significant role played by the TD workshops, the teachers in this study also highlighted their teaching experience as a valuable source of TPK. This observation is underscored by Piaget (2003), who elucidates how teaching experience can serve as a wellspring of knowledge. To Piaget, accommodation, a fundamental aspect of constructivism, asserts that learning often emerges from failures. This means that when attempting to use new technology in teaching, initial failures can become valuable learning experiences that contribute to understanding and knowledge construction (Piaget, 2003). In the context of this study, the rural Life Sciences teachers may have encountered situations where adopting new technology did not yield immediate success for them personally, even though it proved effective for other teachers in their field. Consequently, effectively learning to teach with the new technology may have pushed these teachers to overcome challenges, acquiring previously unexplored teaching abilities. This transformative experience could have compelled the teachers to modify their preconceived notions and adjust their understanding to accommodate this newfound information.

Thus, teaching experience, coupled with the acknowledgement and embrace of failure as a catalyst for learning, played a crucial role in the TPK development of the rural Life Sciences teachers in this study. It highlights the significance of experiential learning and the willingness to adapt teaching practices in the face of technological challenges.

7.2.6 Technological Pedagogical Content Knowledge

The researcher drew upon the sharing circle discussions and lesson observations to explore the sources of the teachers' TPACK. When asked how they are accumulating knowledge of integrating technology in the classrooms, it became apparent that the teachers' teaching experience is the most significant source of TPACK. While this may be so, it is essential to note that it is not the greatest source of all the individual TPACK-related knowledge types. For example, the most significant source of knowledge of how to teach Life Sciences (i.e., PCK) for participants in this study is their experience as in-service teachers. Reports of CK-related experiences also point to secondary school experience as a critical source of CK. Regarding PK, most teachers cited university experience as the major source, followed by teaching experience. During the sharing circle discussions, exciting sources of TPACK emerged, which can all be tied to their teaching experience. These were categorised into practices and experiences from self-directed learning, peer learning, guided practice, consultation, and learning from learners.

7.2.6.1 In-service Teaching Experience

The teachers' responses illuminated the teaching experience as a major source of TPACK. Through years of classroom practice, teachers acquire a deep understanding of content knowledge, refine their pedagogical skills, gain practical insights into technology integration, and develop an acute awareness of learner needs. This accumulated experience enables them to effectively leverage technology to enhance teaching and learning, making them more proficient in TPACK. The following responses highlighted how teaching experience shaped the teachers' TPACK development:

> *My teaching experience has taught me the importance of adopting a learner-centred approach when developing TPACK. By recognising the unique abilities of my learners, I have tried to use technology to create meaningful learning experiences. For instance, I have witnessed deeper understanding by integrating technology tools that align with their interests, such as videos. This has shaped my TPACK over time and transformed the way I teach.* (MaMbotho)

> *I have been teaching for quite some time now, and through trial and error, I have tried to use technologies, ensuring that technology supports rather than replaces my teaching. However, I still have moments of doubt regarding my TPACK development. Sometimes, I wonder if I am effectively aligning my content with relevant technological tools to create meaningful learning experiences. I often question if there are better ways to use technology or if I am underutilising certain resources. It is a continuous journey of reflection and improvement.* (Faku)

> *The more I become experienced as a teacher, the more I appreciate how technology can support my teaching. I have learned a lot about how to teach with technology, and I believe I will improve my teaching knowledge over more years. I am not always confident if I select the most appropriate technology for a particular concept or if I am truly integrating it pedagogically soundly. I strive to keep learning*. (Xaba)

Based on the above statements, it becomes clear that the teachers acknowledge that their experience as teachers has increased their appreciation for how technology can support their teaching. They have learned a lot about teaching with technology but still feel the need to improve and expand their knowledge further. This highlights their commitment to lifelong learning and a growth mindset. In addition, the teachers also acknowledge that their TPACK development is an ongoing process that is shaped by teaching experience. As they learn through experience, the teachers mentioned moments of doubt and questioning, indicating a reflective mindset regarding the effectiveness of their content-technology alignment. This demonstrates a willingness to continuously improve their teaching practices and explore better ways to utilise technology resources.

Moreover, the teacher's reflection on whether they are selecting the most appropriate technology for specific concepts and pedagogically integrating it indicates a desire to ensure meaningful integration rather than mere technological substitution. It is worth noting that the present study is consistent with many others that identified teaching experience as a significant source of TPACK (Firdaus & Robandi, 2022; Niess & Gillow-Wiles, 2017; Malikova, 2019). Specifically, Bingimlas' (2018) quantitative research investigated 243 teachers' TPACK in Saudi Arabia. The findings showed a significant difference between teaching experience and TPACK.

The development of teachers' TPACK through teaching experience can be understood by examining the epigraph at the beginning of this chapter. The epigraph emphasises Vygotsky's (1978) concept of the mediation of human knowledge, which suggests that knowledge is mainly developed and mediated through the use of 'tools.' These tools can be human mediation or "technical tools," such as physical objects or artefacts, including technological tools. Vygotsky (1978) highlights that the specific utilisation of these tools is crucial in developing and learning knowledge. Recent studies have demonstrated the influential role of technology tools in facilitating changes in technological knowledge levels (Bohn, 2009; Raschka et al., 2020; Säljö, 2002). The present study's findings align with previous research, which suggests that novice teachers have a limited approach to integrating technology into their teaching, unlike experienced teachers (Conole, 2009; Impedovo et al., 2017; Subero et al., 2018). However, when novices are immersed in an environment that encourages the use of technology tools, they can adopt teaching patterns similar to those of experienced teachers (Subero et al., 2018).

Therefore, this study argues that Life Sciences teachers in rural secondary schools, who possess a solid pedagogical foundation from their initial teacher preparation but lack formal training in technology integration, are immersed in teaching contexts where technology plays a significant role. Through their interactions with technology tools, the teachers in this study learned to align technology with the subject matter and employ effective pedagogical strategies (Mishra & Koehler, 2006). As Vygotsky (1978, p.55) observed, "tool mediation contributes to changing, broadening, or developing human knowledge". Thus, this study found that teaching experience enabled the teachers to negotiate and develop their TPACK effectively.

7.2.6.2 Self-directed Learning

During the sharing circle discussions, the teachers were asked, 'In your view, how do access to and your interaction with various technology tools create opportunities for you to TPACK?' Most teachers revealed that they are learning for themselves. This was evident in the following statements:

> *My university training as a teacher did not teach me how to integrate technology into my teaching. The little knowledge I have so far on teaching with technology was learned alone from my desire to be a better teacher.* (Xaba)

A similar sentiment was made by Mkoena and MaMbotho, who also indicated that they have learned how to integrate technology out of their own effort and dedication:

> *As a teacher, I believe in lifelong learning. I engage in self-learning. I allocate time to explore and experiment with new educational technologies in my classroom. I take advantage of online tutorials and video guides to familiarise myself with various tools, software, and platforms. Through trial and error, I discovered innovative ways to integrate technology effectively while aligning it with the curriculum and the specific needs of my learners*. (Mkoena)

> *Reflection plays a vital role in my journey to develop TPACK. After incorporating technology into my lessons, I take time to reflect on its effectiveness. I consider my learners' engagement and learning outcomes and identify areas for improvement. Reflective practice helps me refine my pedagogical strategies, make informed decisions about technology integration, and adapt my approach to meet the unique needs of my learners.* (MaMbotho)

For MaMbotho, it was interesting when she said that:

> *I used to be in the PCK circle, and my TPACK circle is becoming slightly bigger.* (MaMbotho)

When probed further to explain how her TPACK is developing, MaMbotho explained:

> *I take the initiative to explore new educational technologies, apps, and software relevant to Life Sciences. By experimenting with these tools and platforms, I try to identify their strengths and limitations and determine how they align with the content I teach. This helps me gain confidence in using technology and develop a deeper understanding of how it can support teaching and learning in my classroom.* (MaMbotho)

In addition to self-learning as a source of TPACK for teaching purposes, it was intriguing to find that some teachers extend the application of TPACK beyond their classroom boundaries. Faku was responding to Question 5.5 of the semi-structured interview protocol: 'How has teaching with technology factored in your work outside of the classroom?' He answered as follows:

> *I have realised that some of my experiences with technology in my classroom as a teacher helped me as a postgraduate learner for my Honours. I learnt through YouTube how to design self-marking Google forms, which I give my learners for informal assessment. Interestingly, I used the same skills to develop an online questionnaire that I used for my studies.* (Faku)

From the above response, Faku recognised the potential for incorporating technologies into his studies for his Honours degree. He indicated that through self-directed learning, Faku devised teacher surveys as part of research for his studies to find out how teachers deal with learner indiscipline in their classrooms. These surveys were administered through an online questionnaire on Google Forms, not only within his circuit but also openly shared with other colleagues in the district. The data collected through these surveys proved invaluable for his research report. By extending his technological knowledge beyond the confines of his classrooms, Faku assumed the multifaceted role of a researcher and scholar. His attempt to amalgamate his TK, PK, and CK, along with their intricate interplay, can become evident as he actively explored these domains in non-teaching capacities. Through meaningful experiences transcending the disciplinary boundaries and contextual constraints, this could be seen as an enhancement of Faku's TPACK. Xaba believes that as he builds his knowledge of different tools and ways to use those tools in his teaching, his enthusiasm about the role of technology in his work as a teacher increases. This enthusiasm, unexpectedly, appeared to be extending his TPACK beyond his classroom teaching into his other personal activities, such as studies.

Overall, the above responses highlight the teacher's dedication to lifelong learning and proactive approach to integrating technology into their teaching. They allocate time to explore new educational technologies, experiment with them in the classroom, and seek online tutorials and guides for familiarisation. Through trial and error, they discover innovative ways to effectively integrate technology while aligning it with the curriculum and the needs of their learners. This observation is consistent with constructivism, as explained in Chapter 3, which is a 'theory of knowing' and a theory about 'coming to know' (O'Connor, 2022) and how individuals construct knowledge through processes of discovery and exploration. This notion of 'coming to know' was particularly central in this research because the intention was to seek to comprehend how Life Sciences teachers in rural secondary schools 'are coming to know' how to integrate technology into teaching. In other words, this is how Life Sciences teachers, who lack formal training in teaching with technology, develop TPACK as they leverage technology for teaching.

Furthermore, the responses emphasise the importance of reflection in the teacher's journey of developing TPACK. After integrating technology into their lessons, they reflect on its impact, considering learner engagement and learning outcomes. This reflective practice helps them refine pedagogical strategies, make informed decisions about technology integration, and adapt their approach to meet learners' unique needs. Their commitment to evaluating their practices and using reflection as a tool for growth is evident in their teaching philosophy. The TPACK development by reflection trajectory of the teachers who participated in this study supported McCrory (2008, p.78), who points out that "learning to teach with technology can be a newfound, iterative experience that requires reflection and particular knowledge bases." This often involves constructing scenarios to teach with technologies followed by reflections on what would have transpired after the class; then, the teachers develop knowledge that they would use in subsequent teaching with the technologies. This knowledge is content- and context-specific and depends on the available technologies, the subject content, and the learners. These reflections on TPACK would allow teachers to understand further how TPACK can support effective instruction.

7.2.6.3 Peer-learning through social interaction

The teachers were explicitly asked the following question: 'Explain how you socially interact with your colleagues as you integrate technology in your classroom.' In addition to this question, the teachers were asked, 'Do you think the interaction assisted in developing your TPACK?' The teachers' responses revealed that peer learning through social interactions has supported their TPACK development. The teachers indicated that these interactions could occur one-on-one or in group discussions. It was interesting to note that one teacher, MaTshezi, cited the sharing circle discussions of this study as having shaped his TPACK development. MaTshezi stated as follows about this study's sharing circles:

> *Participating in the sharing circles here and hearing the experiences of other teachers have played instrumental roles in developing my TPACK. My goal has always been to find the best ways to integrate technologies into my classroom. I have heard how my fellow teachers are attempting to use different tools and strategies in their teaching, and I believe I have learned various ways that could suit my context.* (MaTshezi)

The above response by MaTshezi shows how crucial peer learning is to aid teachers in developing their TPACK. During the sharing circles, the teachers shared many suggestions and strategies they had found successful in their schools regarding technology integration. In addition, the teachers were also able to ask each other questions about specific examples from their teaching contexts, with the view of learning from their peers. This modelled the excellent practice of sharing knowledge and reinforced their TPACK as the teachers learned from each other about methods they tried with different tools, which seemed successful for them.

Furthermore, during the sharing circle discussion, one teacher, MaMbotho, indicated that she had become an exemplar of teaching with technology in her school. She noted that many of her peers regularly follow her suggestions and demonstrations of strategies for integrating technology and their pedagogy. She stated as follows:

> *I have become a model of teaching with technology in my school. My colleagues regularly seek my advice on integrating technology into teaching. It is humbling to inspire and empower people*. (MaMbotho)

Indeed, MaMbotho appeared enthusiastic about being a model to her colleagues at school and her peers during the sharing circle discussions. In Figure 37 below, MaMbotho demonstrated to other participants how she teaches the topic of Genetics before the circle discussions.

Figure 37: Researcher conducting reflective space with teacher participants

MaMbotho believes her TPACK is driven more by her thinking of how best to integrate technology into her teaching. She described her thinking about technology as follows:

> *I think about the way I integrate technologies, particularly video clips or other forms of multimedia, into my work as it enhances the learning experience in my classroom. It is painful that some technologies have long been with us but never really utilised. However, I have yet to reach the point where I can be so confident with my TPACK, but I will continue to learn.* (MaMbotho)

Despite not feeling so secure in her TPACK, MaMbotho understands TPACK during the sharing circle discussions. Here, she not only shows knowledge of different tools and their functions but also how these tools might support learning in her classes. This suggests a deep thoughtfulness in how TPACK guides her thinking and decision-making as a teacher.

It can be seen from the teachers' responses above that peer learning, including participating in sharing circles and hearing about other teachers' experiences in this study, contributed to her TPACK development. Through these interactions, teachers exchanged successful strategies, learned from each other's methods, and discovered ways to integrate technology effectively in their classrooms. For example, MaMbotho indicated that she became an exemplar of teaching with technology, where her peers regularly sought her advice and looked up to their demonstrations of technology integration strategies. In summary, social interactions and peer learning proved to play a crucial role in the teachers' TPACK development. Through sharing circles, which unexpectedly became PLCs, teachers exchanged ideas, learned from successful strategies, and gained insights into integrating technology effectively from each other. This is where this study drew on the socio-cultural theory to shed light on the importance of social interactions in an individual's knowledge development (Valente & Blikstein, 2019; Vygotsky, 1978). As evident from the teachers' responses, their social interactions through workshops and this study's sharing circles became the sources of their TPACK.

7.2.6.4 Learning from Learners

During the sharing circle discussions, some exciting and unexpected discoveries surfaced regarding the role of learners as a valuable source of TPACK for teachers. This intriguing dynamic where learners actively contribute to the teachers' TPACK is a new contribution to knowledge on how teachers develop TPACK in rural schools. This finding challenges conventional wisdom, where teachers have predominantly been considered to be the More Knowledgeable Others (MKOs). This revelation became apparent through the responses provided by two specific teachers, MaTshezi and MaMbotho, which are outlined below:

> *One instance that comes to mind is when I introduced Anatomy 4D, an app that allows learners to view detailed 3D models and learn about the structures and functions of organs and tissues. While I initially thought I understood the tool well and how it could enhance their learning, the learners surprised me with their creativity and innovative usage. They explored features that I had not even considered. Their insights and experimentation taught me valuable lessons about the app's potential and how it could be effectively integrated into future lessons.* (MaTshezi)

MaTshezi's statement revolves around introducing the Anatomy 4D app to the learners. Initially, she expected the app to enhance her teaching by showing learners detailed 3D models and information on organ and tissue structures. However, the learners surprised the teacher with their creative and innovative app use. They explored features the teacher had not even considered, showcasing their unique perspectives. This unexpected outcome taught the teacher valuable lessons about the app's potential and how to integrate it into future lessons effectively. This finding emphasises the significance of embracing learners' perspectives and allowing them the freedom to explore and experiment with educational tools. Importantly, it demonstrates that learners often possess unique insights and can discover new ways to use technologies. Thus, teachers can foster a more collaborative and engaging learning environment by embracing and valuing their contributions.

> *During a food webs lesson, I prepared a set of pre-selected online resources for my learners to explore. So, as the lesson progressed, I noticed that some learners were disengaged and did not find the content relevant. I decided to discuss openly with the class to understand their perspectives. To my surprise, many shared their interest in a specific tool, 'iNaturalist.' This app allows learners to identify different species of plants, animals, and insects by uploading photos and sharing observations. I had not known about this app. Realising their interest in the technology, I researched the app further and adjusted my next lesson plan to incorporate their suggested technology. The learners became more engaged and took ownership of their learning, and their enthusiasm inspired me to be more flexible and learner-centred in designing future lessons.* (MaMbotho)

Like MaTshezi, MaMbotho's experience relates to a lesson on food webs where the teacher had prepared some digital resources for the learners. However, some learners appeared uninterested. Recognising this, the teacher initiated an open discussion to understand their viewpoints. To the teacher's surprise, many learners expressed interest in a tool called 'iNaturalist.' This app lets learners identify various species by uploading photos and sharing observations. Listening to the learners, the teacher incorporated the app in the next lesson, and the learners were more engaged and interested. This finding underscores the importance of listening to learners and realising that 21st-century learners possess valuable knowledge of technologies and how they can be used in their learning. This observation finds resonance with Prensky (2001, p.54), who recognises modern learners as "the digital natives" because they are born during the digital era, which makes them 'inherent speakers' of the digital language.

Moreover, Oriji and Torunarigha (2020) went so far as to argue that today's learners are no longer the same as the past generation because they are technologically advanced. These learners' attributes, therefore, make teaching and learning a two-way enterprise in which the teacher also learns from the learners. As was found in the above teachers' experiences, their willingness to adapt and incorporate the suggested technology increased learners' engagement and empowered their teaching approach with technology. Therefore, it could be argued that the teacher's experience in this situation would have contributed to his TPACK development. These findings could remind teachers about the potential that lies in learning from learners in developing teachers' TPACK in rural secondary schools. The next section examines how teachers conceptualise and integrate the different TPACK sub-domains to enhance their overall understanding of TPACK.

7.3 CHAPTER SUMMARY

This chapter investigated the diverse sources contributing to teachers' TPACK. The findings revealed a range of interconnected sources that shape teachers' TPACK. The results provided insights into the dominant sources of TPACK and highlighted the significance of various experiences and contexts in teachers' TPACK development. For example, the analysis of the teachers' responses revealed that the different TPACK domains were drawn from multiple sources and developed differently. As a result, certain domains emerged as more dominant than others, depending on the teachers' exposure to different experiences and contexts.

The teachers' responses indicated that TPACK domains originated from multiple stages of their professional journey. These stages included secondary schooling, initial teacher training at university, teaching practice, self-directed learning for technology integration (informal learning), teaching experience, teacher development (TD) workshops, and interactions with colleagues. Specifically, the TD workshops served as a significant source for CK and PK. These workshops gave teachers valuable insights and the necessary skills to enhance their TPACK. Additionally, self-directed learning was crucial in empowering teachers to improve their overall TPACK. By exploring innovative teaching methods and staying abreast of technological advancements, teachers were able to enhance their teaching practices.

Furthermore, initial teacher education and the practical experiences gained during teaching practice, combined with mentorship from more experienced teachers, contributed to the development of PK, PCK, and TPK. In addition, teaching experience emerged as a pivotal factor in shaping all the TPACK knowledge components. Furthermore, it was found that collaboration with peers is an influential TPACK source, allowing teachers to develop their overall TPACK through engaging in professional discussions and resource-sharing within a supportive community. The findings also emphasised the importance of interaction with colleagues. Informal discussions and collaboration provided opportunities for teachers to learn from each other's experiences, discover new technological tools, and stay updated on technological trends.

Related to this are the technology-related training workshops that specifically targeted the development of TK, enabling teachers to integrate technology effectively into their teaching practices. Interestingly, teachers' experiences as secondary school learners gave them a deeper understanding of the subjects they teach, enhancing their CK. Additionally, teachers' interactions with their learners proved invaluable in developing their TPACK. These interactions offered insights into learners' preferences, challenges, and perspectives, enabling teachers to tailor their teaching approaches to meet the diverse needs of their learners. In conclusion, this chapter's findings shed light on the diverse sources contributing to teachers' TPACK development. These findings contribute to understanding how teachers acquire and enhance their TPACK. They provide insights that can inform professional development programmes and support effective technology integration in rural secondary schools.

CHAPTER EIGHT: DISCUSSION OF FINDINGS

> It is important to note that there is no one-size-fits-all approach to TPACK development. (Mishra & Koehler, 2006, p.1023)

8.1 INTRODUCTION

This chapter provides a concise summary of the research process and a discussion of the findings. Notably, the current study has set a precedent for future research and opened new avenues for examining TPACK in rural educational contexts. Specifically, the present research stands as the sole study in South Africa to explore TPACK development within the context of rural secondary schooling. Therefore, the present study's methodological approach is of utmost significance and deserves highlighting to facilitate other researchers conducting similar investigations by utilising and building upon the methodologies employed.

Throughout this chapter, the interpretation and discussion of the findings are closely tied to the literature review presented in Chapter 2, the theoretical framework discussed in Chapter 3, and the methodology detailed in Chapter 4. Through a thoughtful examination of these findings, the chapter contributes to a deeper understanding of the research topic and its broader implications. Moreover, the discussion of findings sets the stage for formulating meaningful recommendations and conclusions, positioning the research within the context of the larger academic discourse. The chapter follows a structured format, starting with an overview of the research. It proceeds with a presentation of the main findings and their implications. Building on these findings, the chapter introduces a novel TPACK model explicitly designed for rural Life Sciences teachers. The chapter concludes with a summary of its key points. The next section presents the summary of the study.

8.2. SUMMARY OF THE RESEARCH

The current study was conducted in South Africa when there was a growing global call to utilise technology in education, prompted by experiences during the COVID-19 pandemic. Despite this international call, many teachers in rural schools lack formal training in integrating technology, yet they can adapt and incorporate technology into their teaching practices. Hence, it became imperative to examine the processes, factors, and experiences through which teachers who lack formal technology integration training develop TPACK to leverage technology into teaching effectively. A review of existing literature revealed a limited number of studies investigating the development of TPACK in the Global South context, particularly in South Africa. These studies include works by Tunjera and Chigona (2020), Bernardesa and de Andrade Neto (2020), Major and McDonald (2021), Ramnarain et al. (2021), and Adedayo et al. (2022). Notably, the present study stands apart from these prior investigations due to its exclusive focus on the population of secondary school teachers in rural settings instead of university contexts involving lecturers and learners. Consequently, this study holds a unique significance as it marks the first exploration of the development of TPACK among Life Sciences teachers in rural secondary schools within South Africa. As a result, it serves as a bridge to address the gap in existing research and supplements earlier findings by introducing novel insights into the development of TPACK among secondary Life Sciences teachers in the distinct context of rural schools in South Africa.

This qualitative study examined how teachers' self-reported practices, factors, and experiences influence their TPACK development in rural secondary schools. Using a qualitative approach in this investigation represented a methodological innovation in TPACK research, as most studies in this area have been quantitative. Through a qualitative methodology, the present research delved into the rich and nuanced aspects of teachers' experiences, ways, and purposes for which they integrate various technology tools, providing valuable insights into the intricate process of TPACK development within the specific context of rural secondary schools.

The study commenced with five fundamental premises to which it aimed to contribute valuable insights:

a) **First, The in-service teachers' perspective.** The existing body of knowledge on TPACK has predominantly focused on research concerning pre-service teachers. Consequently, the current understanding of TPACK mainly revolves around the viewpoints of pre-service teachers, with limited insights from in-service teachers, particularly those in rural secondary schools. To address this gap, the present study aimed to expand the boundaries of TPACK development knowledge by examining how this specialised, intricate, and context-dependent knowledge evolves. The study also sought to identify the practices and factors that influence TPACK development, as perceived by Life Sciences teachers in rural secondary schools.

b) **Second, The Global South perspective**. Most TPACK studies have been conducted in the Global North, with only a few in the Global South, including African countries like South Africa. Since TPACK is recognised as context-specific and situated (Kohler & Mishra, 2007), the current body of knowledge largely relies on the developed world's context, which might differ from that of the developing world. Therefore, there is a limited understanding of TPACK development in Global South contexts. The present research was conducted in a rural context to address this gap.

c) **Third, The Rural Context perspective**. Upon reviewing studies on TPACK from 2005 to 2023 (as presented in Table 2.2), only one recent study from the USA (Hill & Uribe-Florez, 2020) has primarily focused on the rural school context. This observation indicates that, globally, the rural school context has not received sufficient exploration throughout the evolution of research on teachers' TPACK development. Once again, this study aimed to contribute to the TPACK development literature, specifically focusing on the rural context.

d) **Fourth, The teacher's voice matters too**. Most studies concerning teachers' TPACK development have focused on assessing or measuring teachers' TPACK before, during, or after technology training workshops or courses. These studies have primarily relied on pre-and post-test scores to determine the development of teachers' TPACK. However, few have directly sought the teacher participants' perspectives, opinions, experiences, and understanding regarding their TPACK and its development. This study, therefore, placed the teacher at the core and solicited their self-reported TPACK development practices (see research objectives, Section 1.6). Moreover, unlike some studies, this research considered the seven-component architecture of TPACK (TK, CK, PK, PCK, TCK, TPK, and TPACK).

e) **Fifth, Qualitative approach and comprehensive context.** Most TPACK studies (see Table 2.1) have adopted a quantitative approach, limiting the depth of factors explored that shape teachers' TPACK development. Departing from the prevalent quantitative methods, the present study opted for a qualitative approach to delve into the practices and experiences shaping TPACK development with more depth and richness and contribute methodologically to the overall TPACK research. Furthermore, many previous research works have lacked contextual information, making it challenging to extrapolate their implications to other settings. To address this limitation, the present research comprehensively describes rurality, the rural secondary schooling context (see Sections 2.2 and 2.3), and the teacher participants' educational backgrounds and teaching experiences.

The findings obtained from the data analysis are in the subsequent section. The section explores the theoretical significance of these findings, considering how they contribute to the existing body of knowledge on TPACK development among science teachers in rural secondary schools. The section also examines the implications of the findings for educational policy and practice.

8.3. KEY FINDINGS AND THEIR SIGNIFICANCE

Teaching Life Sciences in rural schools presents significant challenges, exacerbated by the additional complexity of integrating technology into the educational process. While some teachers, at their discretion, integrate technology to address the diverse learning needs of prospective learners, the impediments to technology integration outweigh the strengths. This concern stems from a prevalent lack of TPACK among most science teachers, hindering their ability to seamlessly integrate technology into teaching practices. The present study presupposes that certain science teachers, particularly those in rural secondary schools in South Africa, may not have addressed technology integration in their initial teacher training.

Furthermore, some teachers may not have participated in professional development courses focusing on specific technologies that could enhance their teaching methodologies. The absence of formal training and experiential exposure may impact how science teachers integrate technology into their classrooms, potentially hindering the judicious implementation of technology to meet learners' learning needs. Consequently, this study investigated how teachers lacking formal training in technology integration develop TPACK to integrate technology into teaching effectively. The research also identified the factors, practices, and experiences influencing teachers' TPACK development. A comprehensive understanding of teachers' TPACK development is anticipated to inform the design or restructuring of professional teacher development programmes. These efforts seek to establish improved platforms and opportunities for TPACK development, uniquely tailored to the distinctive context of rural schools.

The discussion of the significance of the findings from this study is addressed in separate sections, each corresponding to the specific research objectives of the study, that is,

a) To understand how rural secondary school Life Sciences teachers integrate technology into their teaching;
b) To understand how rural secondary school Life Sciences teachers describe their pedagogical technological content knowledge; and
c) To gain insights into the sources of pedagogical technological content knowledge rural Life Sciences teachers draw upon in their teaching.

8.3.1 Rural Life Sciences teachers' ways of integrating technologies

The first research question addressed the issues of teachers' technology access and usage, the rationale for technology use, and teachers' self-reported technical skills. The questionnaire, semi-structured interviews, lesson observations, and the sharing circle discussions generated data to describe the commonly used technology tools for teaching Life Sciences and how they were utilised.

The present study's findings revealed that teachers in rural schools own and have access to a diverse array of technological tools, such as smartphones, tablets, visualisers, data projectors, SMART Boards, the Internet, and computers. This observation suggests that the once-barrier of technological access is diminishing in rural educational settings, challenging conventional findings from earlier studies that often depicted a deficiency in technological resources in rural schools (Assey & Babyegeya, 2022; Bantwini, 2017; Hlalele, 2014). Specifically, the present study found the prevalence of smartphones and other mobile technologies, such as tablet usage among teachers compared to computers, in contrast to Khashan's (2019) study, where mobile phones were less preferred among science teachers. This discrepancy between the current study and Khashan's (2019) research can be attributed to several factors, including the different educational settings, regional disparities in technological infrastructure, and the five-year gap between the studies. Due to technology's rapid evolution during the five-year gap, mobile technologies may have evolved to offer better features, influencing teachers' preferences, as found in the present research.

Regarding teachers' technology usage patterns and time allocation, the study revealed that technology is part of daily life for all teachers. Notably, most teachers spend over four hours daily on computers, laptops, tablets, or mobile phones for personal use, emphasising the pervasive role of these devices beyond the classroom. This observation aligns with prior research, which established that to improve one's performance in a field, there need to be aspects between that field and what an individual experiences in their daily social life (Valente & Blikstein, 2019; Vygotsky, 1978). Therefore, the present study reinforces the idea that technologies (tools) are embedded in society, serving personal needs alongside the teachers' work functions (Clark, 2018; Dabbagh & Castaneda, 2020). However, despite using technology extensively for personal use, teachers reported allocating less time (only 2 to 3 hours daily) for teaching. This finding reveals a lower degree of technology integration for teaching than personal use. These outcomes stand in contrast to previous research by Berger and Wolling (2019), Hanshaw et al. (2022), and Jadhav and Takale (2020) that advocate for extensive technology integration in classrooms to enrich teaching and learning processes.

Furthermore, the current research established that all teachers who participated in this study have access to and use the Internet daily for both study and personal reasons, highlighting the substantial dependence on the Internet for these functions, albeit to varying degrees. While this finding supports prior studies that underscore the pervasive and increasing access to and use of the Internet by teachers (Ashok et al., 2022; Jaradat, 2020; Ramnarain & Penn, 2021), it offers fresh and exciting insights that Internet use in rural schools is increasing. The study further reveals that teachers primarily use technology to present content via projectors, PowerPoint presentations, or videos. However, this utilisation often results in limited engagement from learners in interacting with these technologies. This discrepancy runs counter to the guidance outlined in the CAPS science document, which urges teachers to facilitate learners in acquiring and applying knowledge and skills in manners pertinent to their daily lives. In many instances, learners assume a passive role as observers, merely watching as teachers incorporate technology into the instructional process.

Regarding teachers' technical skills to utilise various technologies, the current research has identified that Life Sciences teachers in rural schools rely on 'simple skill-based' technologies. This observation aligns with comparable conclusions from previous research, highlighting the infrequent utilisation of contemporary and advanced skill-based technologies among science teachers. Notably, none of the participants in the current study mentioned employing cutting-edge technologies such as augmented reality (AR) (Jaradat, 2020; Ramnarain & Penn, 2021), virtual reality (VR) (Oser & Fraser, 2015; Ramnarain & Penn, 2021; Rojas-Sánchez et al., 2023), robotics (Brady, 1984; Darmawansah et al., 2023; Vrontis et al., 2022), game-based science curriculum (Djelil & Sanchez, 2023; Hall et al., 2022; Squire, 2003), coding (Armoni et al., 2016; Greenberg et al., 2012; Jiang et al., 2023), artificial intelligence (AI) (Ashok et al., 2022; Holmes et al., 2023; Winston, 1992). This finding is disconcerting, especially considering the widespread availability of technological tools and Internet connectivity in rural educational settings. It prompts the question of when teachers in rural schools will embrace state-of-the-art technologies for enhancing science teaching.

Through their self-reported experiences, most teachers showcased robust technical skills in effectively using laptops/computers, cellphones, the Internet, and Microsoft tools (such as MS Word, PowerPoint, and Excel). Nonetheless, the current study revealed that many teachers reported limited technical skills when using interactive SMART Boards or Interactive Whiteboards. This finding corresponds with Larijani and Abedi's conclusions (2021), which attributed the underutilisation of SMART Boards to inadequate technical skills. One plausible reason for this trend could stem from the scarce availability or accessibility of SMART Boards in rural schools in the present study, resulting in a lack of familiarity and exposure among most teachers. Notably, this study's infrequent SMART Board usage contrasts with Vermette and Hechter's (2014) research, which reported widespread adoption of SMART Boards among science teachers. Encouragingly, a positive aspect emerges from most teachers reporting heightened levels of technical proficiency in using laptops/computers and cell phones. This outcome holds promise, given that laptops/computers and cell phones offer versatile tools for delivering teaching and accessing educational materials.

8.3.2 Life Sciences Teachers' TPACK Description

This section focuses on the Life Sciences teachers' self-reported TPACK assessed through the TPACK questionnaire, semi-structured interviews, and sharing circle discussions. The teachers' TPACK to respond to Research Question 2. Notably, this study is exclusively qualitative and did not adopt a mixed-methods approach despite utilising descriptive statistical methods to analyse questionnaire results on the TPACK knowledge domains (CK, PK, PCK, TK, TPK, and TPACK).

The present study findings disclosed that Life Sciences teachers in rural schools reported higher proficiency levels within non-technology-related domains (CK, PK, and PCK). These findings concur with the investigation by Doukakis et al. (2021) in Italy, which found higher ratings for

CK and PK than TPK. Similar results have also been reported by many other researchers, such as Koehler and Mishra (2007), Cox and Graham (2009), Jita (2016), and Gentles and Haynes-Brown (2021), which also found that practising teachers tend to report higher levels of PK, CK, and PCK compared to TK, TPK, and TPACK. This finding is not new and aligns with existing literature regarding teachers demonstrating higher CK, PK, and PCK. However, the importance of this finding lies in its contribution to the trends of TPACK development in under-researched rural contexts, as no such insights were found in the literature reviewed in the present study. Obtaining insights from these rural settings holds significant importance, as it can facilitate a more comprehensive grasp of how TPACK concepts are embraced and customised within various educational settings. By encompassing insights from rural contexts, this study elevates the overall applicability and significance of TPACK frameworks, ensuring their adaptability to a wider array of teaching scenarios. Nevertheless, the persistent low levels exhibited by teachers in technology-related domains raise the question of when they will attain higher proficiency in these areas.

Moreover, it is essential to underscore that the higher ratings of the non-technology than the technology-related domains suggests that Life Sciences teachers in the present study possess a more comprehensive grasp of subject content (CK) and teaching methodologies (PK) than technological knowledge areas (TK, TPK, TPACK). This finding flows from South Africa's national teacher training system, which mandates a minimum of a Bachelor's subject-specific degree qualification for teachers. This finding aligns with Neiss's (2011) TPACK development model, which asserts that teachers must first possess subject-specific knowledge (CK) and pedagogical expertise (PK), forming the basis of PCK (Shulman, 1986). Beyond this foundation, they must acquire TK and, ultimately, the skill of effectively integrating technology into science teaching (TPACK).

Notably, while Neiss's (2011) model outlines a linear progression towards TPACK, the transition from one domain to another is not uniformly cumulative. This suggests that teachers may draw from various TPACK domains simultaneously during their development of TPACK. For example, teachers may exhibit more strength in CK, PK, or TK compared to TPK in their teaching at different points, as observed in this study. However, although the teacher participants' elevated CK and PK self-assessments are encouraging, it is crucial to consider Bandura et al.'s (1999) cautionary perspective on the potential pitfalls of this confidence. Gess-Newsome (1999b, p.63) further underscores the notion that even teachers equipped with a

Bachelors' degree in a scientific discipline can possess a content and pedagogical knowledge that is "fragmented, compartmentalised, and poorly organised, making it difficult to access these knowledge areas efficiently when teaching."

Furthermore, akin to the findings of Violanti (2023), this study identifies TK as the predominant domain among the technology-related components. While Life Sciences teachers exhibited strong TK understanding, challenges arose when integrating it with CK and PK, as indicated by lower mean scores of TPK and TPACK (see Section 4.4.3.1). This pattern aligns with prior studies by Jang and Tsai (2013), Choi and Paik (2021), and Ong and Annamalai (2023). It confirms Koehler and Mishra's (2006) observation that teachers often encounter difficulties comprehending the dynamic interplay and interconnectedness of CK, PK, and TK.

Specifically, the present study found that the teachers expressed notable challenges in integrating and amalgamating these individual knowledge components into dual constructs such as TPK, ultimately forming a coherent TPACK. The challenge in synthesising these knowledge components indicates that the evolution of TPACK is not automatic through the enhancement of its individual elements. In other words, achieving high CK, PK, and TK levels does not guarantee a robust understanding of effectively incorporating technology into science teaching. This was evident from a teacher's response:

> *While I am familiar with the concept of TPACK, I find it quite challenging to grasp and explain fully. I understand that TPACK involves blending technology into teaching while having a command over the subject content. My difficulty lies in understanding and articulating these components' interaction and mutual influence to enhance technology-infused teaching.* (MaTshezi)

As a result, it becomes evident that most teachers struggle to conceive TPACK holistically and often exhibit fragmented domains. Similar outcomes were reported by Tanak (2020), who noted that science teachers in their study demonstrated a mixture of pedagogical, content, and technological knowledge rather than seamlessly integrating all three. This challenge underscores that meaningful technology integration remains elusive until teachers comprehend the interdependent relationships among individual TPACK domains. Therefore, the present study, like many others in the literature such as Choi and Paik (2021), argues that teachers must not only develop fluency and cognitive flexibility in each core domain, CK, PK, and TK, but also grasp how these domains interact to facilitate practical, differentiated, and contextually relevant learning opportunities. While mirroring prior research, the present study's findings offer a distinctive rural school perspective on TPACK development. This focus adds depth to existing knowledge by highlighting how teachers in resource-limited settings navigate challenges.

8.3.3 Sources of Life Science Teachers' TPACK in Rural Schools

Through their individual and collective voices and self-reported practices, the Life Sciences teachers in rural secondary schools, who lack formal training in technology integration and without guidelines, facilitated a better understanding of the sources of TPACK from which they draw in their teaching. Specifically, this chapter is premised on the research question: 'What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?' Findings related to this question are the results of the analysis of semi-structured interview data, lesson observations and sharing circle discussions. This inquiry to understand the sources of the teachers' TPACK is paramount as the researcher sought to delve into the underlying factors, practices, contexts, and experiences that shape the teachers' TPACK development in rural schools. This exploration is pivotal in illuminating the dynamics and intricacies that underlie TPACK development, thereby providing insights into the nuanced interplay between technology integration, pedagogy, and subject content knowledge. By unravelling these intricacies, the present study not only contributes to the broader scholarly discourse on effective pedagogical practices. It also holds the potential to inform educational policies and interventions tailored to enhance the quality of technology-enhanced teaching and learning experiences in rural schools.

The present investigation has revealed compelling insights into the sources of TPACK that Life Sciences teachers in rural secondary schools draw upon in their teaching. These diverse TPACK sources encompass a multitude of factors and experiences, such as initial teacher training, practical experiences during teacher training programmes, teaching experiences, self-directed learning, peer collaboration, and insights gained from learners. It is imperative to underscore that this research delved into the sources specific to each individual TPACK component, CK, PK, PCK, TK, TPK, and TPACK. This nuanced understanding of the sources contributing to each TPACK component empowers teachers to approach their professional development comprehensively. Through self-assessment, teachers can discern their strengths and weaknesses within each TPACK component, thereby facilitating the establishment of personalised goals for their ongoing professional growth. It is noteworthy that, in the context of this discourse, the focus is directed towards the overarching TPACK sources as reported by the participating teachers.

8.3.3.1 Teaching experience

The present study found that teaching experience emerged as the most significant source of the teachers' TPACK. The study posits that while Life Sciences teachers in rural secondary schools initially possess a strong CK and PK foundation from their teacher preparation, they lacked formal training in integrating technology. Despite this, their teaching contexts involve substantial technology usage. Consequently, through their interactions with various technological tools, these teachers gradually learned to effectively align technology with subject content and employ efficient pedagogical strategies. This process resonates with Vygotsky's notion that "tool mediation contributes to changing, broadening, or developing human knowledge" (1978, p.55). Thus, the study reveals that teaching experience empowered teachers to navigate and enhance their TPACK development adeptly.

It is noteworthy that through teaching experience, the teachers engage in reflective practices where they adjust and sharpen their technology integration in teaching. This iterative process of learning and growth contributes significantly to the overall development of teachers' TPACK. Remarkably, this study aligns with previous research by Firdaus and Robandi (2022), Niess and Gillow-Wiles (2017), and Malikova (2019), all highlighting teaching experience's crucial role in TPACK development. A quantitative study by Bingimlas (2018), which focused on 243 teachers in Saudi Arabia, similarly noted the positive correlation between teaching experience and TPACK. To comprehend the development of TPACK through teaching experience, as found in the present research, Vygotsky's (1978) concept of knowledge mediation offers valuable insights. This concept underscores that knowledge is shaped and facilitated through the use of "tools," particularly technological ones in this context. The specific utilisation of these tools holds pivotal importance in knowledge (TPACK) development and continuous learning.

8.3.3.2 Self-directed learning

Related to teaching experience is the self-directed learning that most teachers revealed as another TPACK source. This was evident in the following statements:

> *My university training as a teacher did not teach me how to integrate technology into my teaching. The little knowledge I have so far on teaching with technology was learned alone from my desire to be a better teacher.* (Xaba)

The study's findings underscored the teachers' commitment to continuous learning and proactive stance toward technology integration. They conscientiously allocate time for exploring new educational technologies and engaging in classroom experimentation to gain familiarity. Through this process of trial and error, the teachers reported uncovering inventive methods for incorporating technology, all the while aligning it with the curriculum and the unique needs of their learners. This process resonates with the principles of constructivism, elucidated in Chapter 3, which describes a 'theory of knowing' and 'coming to know' (O'Connor, 2022). This constructivist perspective highlights how individuals construct knowledge through exploratory and discovery-oriented processes. This notion of 'coming to know' emerged as a pivotal theme in this research, as it provided a lens to understand how Life Sciences teachers in rural secondary schools gradually grasp the art of integrating technology into their teaching routines and cultivating TPACK. In essence, the constructivist stance revealed how the teachers, despite lacking formal training in technology-infused teaching, organically develop TPACK as they familiarise themselves with various technologies through self-directed learning.

Moreover, the present study accentuates the role of reflective practice in the teachers' TPACK development. That is, upon incorporating technology into their lessons, the teachers thoughtfully reflect on its impact. This introspective process would aid in refining pedagogical strategies, informed decision-making regarding technology integration, and adaptive teaching approaches tailored to individual learner needs. The dedication to self-evaluation and the application of reflection as a tool for growth is palpable within their teaching philosophy. The trajectory of TPACK development through reflective practice among the present study's teacher participants echoes McCrory's insights (2008). In her perspective, McCroy (2008) explains that effective learning to teach with technology is a dynamic, iterative journey necessitating reflection and specific knowledge domains. This knowledge is finely tuned to the subject content, the learning environment, and the available technological resources. These contemplative analyses of TPACK enable teachers to deepen their comprehension of how TPACK can synergistically enhance effective instruction.

8.3.3.3 Peer-learning through social interaction

The study's findings showed that peer learning through social interaction provides opportunities for teachers to develop TPACK. The teachers indicated that these interactions could occur one-on-one or in group discussions. A noteworthy observation emerged when considering the input of a specific teacher, MaTshezi, who singled out the sharing circles in this study as instrumental in moulding his TPACK growth. MaTshezi articulated the significance of these sharing circles in the following manner:

> *Participating in the sharing circles here and hearing the experiences of other teachers have played instrumental roles in developing my TPACK. My goal has always been to find the best ways to integrate technologies into my classroom. I have heard how my fellow teachers attempt to use different tools and strategies in their teaching, and I believe I have learned various ways that could suit my context.* (MaTshezi)

Teachers have shared their experiences of peer learning and social interactions, exchanging effective strategies, gaining insights from each other's teaching methods, and exploring ways to seamlessly incorporate technology into their classrooms. While the role of peer-learning and social interactions in knowledge advancement has been extensively discussed in scholarly literature (Fullan & Hargreaves, 1991; Leonard & Leonard, 2003; Ni et al., 2023), the current study not only reaffirms these principles but also contributes by highlighting that peer-learning nurtures the development of TPACK within rural secondary schools. This finding aligns harmoniously with the underlying constructivist approach of this research, which asserts that learning is an active process wherein an individual's interactions with their surroundings, including peers, facilitate the construction of (TPACK) knowledge. Drawing inspiration from foundational thinkers such as Vygotsky (1978), Piaget (1981), Ajzen (1991), as well as Valente and Blikstein (2019), the study underscores how the engagement of teachers with diverse educational technologies and colleagues during workshops provided fertile ground for the cultivation of TPACK. The results align with a constructivist learning perspective, emphasising that meaningful engagement with peers and the environment contributes to knowledge construction. This supports the study's theoretical foundation and adds empirical evidence to the notion that learning is an active and social process.

8.3.3.4 Learning from Learners

During the sharing circle discussions, several intriguing and unexpected findings emerged concerning the role of learners as a source of TPACK for teachers. This unexpected interplay, where learners actively contribute to teachers' TPACK development, challenges the established and traditional approaches through which teachers typically acquire TPACK, as no such information was found in the literature reviewed in this study. The present study revealed that teachers identified learners as contributors to their TPACK development. This recognition stemmed from specific learners having advanced TK. The teachers then benefited from learner feedback, which enabled them to engage in reflective processes and enhance their use of technology for teaching purposes. This finding is interesting as it emphasizes the significance of recognising that 21st-century learners possess a wealth of valuable knowledge that can benefit their learning and teachers.

Specifically, the role of learners in shaping their teachers' TPACK development his concept aligns with Prensky's (2001, p.54) identification of modern learners as "digital natives," born into the digital era, becoming natural and proficient users of digital technology. Oriji and Torunarigha (2020) have even asserted that today's learners differ significantly from previous generations due to their advanced technological acumen. These attributes of modern learners consequently transform the process of teaching and learning into an enterprise of mutual exchange, wherein teachers also glean insights from their learners. Equally significant was the finding that 21st-century teachers also acknowledge the learner-teacher partnership in teaching, recognising that teachers can indeed learn from their learners. Hence, the results of this current study serve as a reminder to teachers regarding the untapped potential of learning from their learners, particularly in the context of developing TPACK within rural secondary schools. The subsequent section proposes a revised TPACK model for rural Life Sciences teachers.

8.4 PROPOSING A REVISED TPACK FRAMEWORK PERSPECTIVE FOR RURAL LIFE SCIENCES TEACHERS

The present study has unveiled a new perspective on the development of TPACK among rural Life Sciences teachers. This perspective is founded on two fundamental premises: TPACK development in rural contexts and TPACK development among in-service teachers. From these premises, the current study asserts that the development of TPACK for in-service teachers in this specific context should not be conflated with that of pre-service teachers. For pre-service teachers, the three primary components comprising TPACK (technology, pedagogy, content) are typically considered distinct entities. This division in the prevailing operational TPACK framework proposed by Mishra and Koehler (2006) aligns with research focused on pre-service teachers, where such distinctions are conceptually sound (see Figure 8). However, this research in rural Life Sciences teaching uncovers a unique landscape where it is found that pedagogy and content intertwine and overlap significantly, with technology serving as the pivotal element or 'add-on' to the already established PCK to develop TPACK. Consequently, the present study proposes a distinct perspective on TPACK development, tailor-made for Life Sciences teachers in rural school environments (see Figure 38). This perspective recognises that the traditional TPACK framework, rooted in pre-service teacher training, does not fully address the complexities and dynamics of teaching Life Sciences in rural South African schools. The implications of this perspective extend beyond the South African context and can be relevant to other regions facing similar challenges.

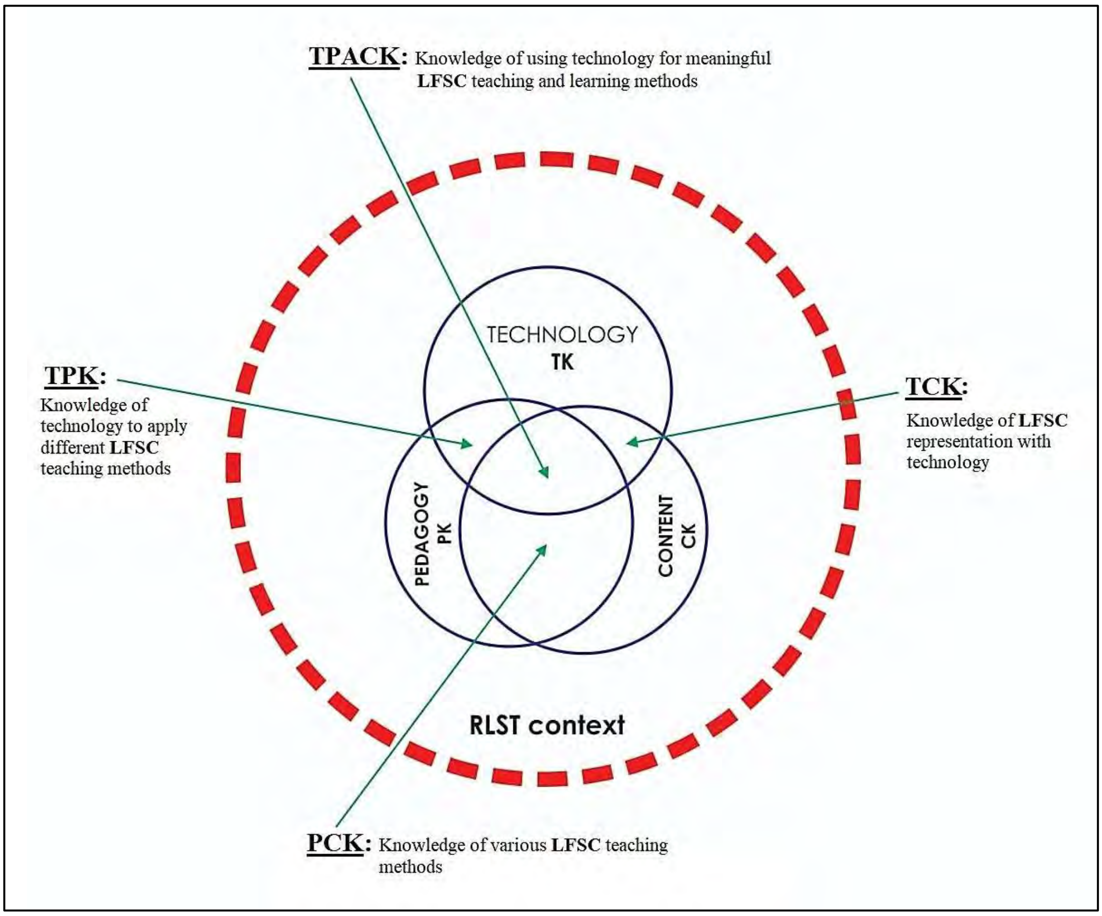


Figure 38: Proposed TPACK model for Rural Life Sciences teachers (Drawn by the researcher)

Mainly, a noteworthy finding of the present study underscores the rural context's substantial role in TPACK development in rural schools. This finding supports the existing literature that highlights the centrality of context in developing TPACK, prompting the need to revise the prevailing operational TPACK model initially presented in the study (see Figure 8). The adjustment was made to accentuate the significance of context (see Figure 38), a facet that had not been explicitly illuminated in the earlier prevailing operational TPACK detailed in Chapter 3, albeit implied across the study. This adjustment is not merely cosmetic; it symbolises a paradigm shift as it explicitly includes "contextual knowledge" - here referred to as "Rural Life Sciences teaching" - denoted by RLST context (as depicted in Figure 38). This reshaped framework underscores the notion that comprehending the specific rural schooling context within which technology is applied is indispensable for Life Sciences teachers to effectively integrate technology in rural school settings. The following subsections delve deeper into the two fundamental premises of the TPACK model for rural Life Sciences teachers: TPACK development in rural contexts and TPACK development among in-service teachers.

8.4.1 TPACK development in rural context

The emphasis on the rural context within the proposed framework signifies a crucial departure from the conventional TPACK model, highlighting the profound influence of the rural landscape on TPACK development. This recognition stems from understanding the specific challenges and opportunities that define the rural teaching context. In rural schools, limited access to resources, including technological infrastructure and up-to-date educational materials, presents a unique set of hurdles for teachers. These challenges necessitate innovative approaches to bridge the resource gap and deliver high-quality education. Additionally, cultural diversity is also a notable factor, as teachers must be sensitive to the cultural backgrounds of their learners, ensuring that the content and teaching methods resonate with the local context.

Therefore, by recognising the importance of the rural context, the framework proposed in this study acknowledges that effective TPACK development for Life Sciences teachers in these environments demands a nuanced understanding of these contextual dynamics. It underscores the idea that TPACK cannot be a one-size-fits-all approach; rather, it must be shaped by the distinctive challenges and opportunities presented by the rural South African schooling context. This recognition aligns with the broader educational philosophy that contextual factors significantly influence teaching and learning outcomes (Mishra & Koehler, 2006). Moreover, the present study demonstrates how the rural context shapes the TPACK development process, reaffirming the centrality of the rural environment in teaching. By explicitly incorporating 'Rural Life Sciences teaching context' as a core element, the proposed framework acknowledges that teachers must develop a deep awareness of the rural context within which they operate. This contextual knowledge becomes a foundational component in their ability to integrate technology effectively, design relevant pedagogical strategies, and tailor content to meet the unique needs of the learners in rural schools. Therefore, the importance of context in this proposed framework becomes a crucial testament to the intricate interplay between teaching and the environment in which it unfolds, highlighting the need for a context-specific approach to TPACK development in rural South African schools.

8.4.2 TPACK development among in-service teachers

To delve deeper into the distinctions between this proposed framework and the traditional TPACK model, the present study's findings demonstrate a more significant overlap between the teachers' PK and CK (see Figure 38), suggesting that the way teachers in rural schools develop TPACK differs significantly from pre-service teachers. This dissimilarity can be primarily attributed to the practical classroom experience and exposure that the teachers in rural schools have acquired throughout their teaching careers. This teaching experience would have enabled the teachers to refine their pedagogical techniques, aligning them more closely with the nuances of the content they are teaching, leading to a deeper integration and overlap of PK with CK to form PCK. Specifically, the present study contends that the Life Sciences teachers in rural schools have had the opportunity to adapt their pedagogical methods based on the needs and backgrounds of their learners, as they would have interacted with diverse learners over time. This adaptability would have led to a more natural blending of pedagogy and content knowledge, as they have honed their abilities to convey content in ways that resonate with their learners.

Consequently, the teachers in rural schools only require TK to develop TPACK as they already possess a solid PCK. Therefore, the teachers' TPACK in this study can be understood better through the lens of the proposed TPACK model for rural Life Sciences teachers. On the other hand, pre-service teachers are typically in the early stages of their teacher education and have not yet had the extensive classroom experience that in-service teachers possess. As a result, they may see pedagogy, content, and technology knowledge as more distinct entities, focusing on the separate acquisition of these components during their training. As a result, the pre-service teachers' TPACK can be viewed as compartmentalised entities of PK, CK and CK, as portrayed by Mishra and Koehler's (2005) TPACK model (see Figure 8).

8.4.3 Implications of the proposed TPACK model in rural schools

The implications of the proposed framework could be far-reaching and offer valuable insights for teachers and researchers in rural South African rural schools and other similar regions. Firstly, by recognising the centrality of the local context and the importance of tailoring teaching approaches to accommodate it, the framework equips teachers with a more effective and context-sensitive toolkit. This can empower teachers to deliver high-quality Life Sciences teaching that resonates with their learners' unique needs, backgrounds, and experiences. The proposed framework for teachers' TPACK development in rural schools may be instrumental in improving learning outcomes in rural settings, where learners may come from diverse cultural backgrounds and have varying levels of prior knowledge. In a broader global context, the proposed framework can offer researchers the lenses to view TPACK development in other rural and underserved communities. The framework proposed, derived from the rural Life Sciences teachers' voices, is crucial to understanding TPACK development in rural contexts. These voices have been notably absent in most TPACK research, making this study's insights particularly significant. The following section provides a summary of the chapter.

8.5 CHAPTER SUMMARY

The discussion of findings chapter provided a nuanced understanding of the data generated. This chapter served as a platform to interpret and contextualise the findings in relation to the research objectives. Specifically, the discussions in this chapter drew connections between the study's outcomes and the broader scholarly landscape. Given the absence of formal training in technology integration, this chapter addressed the research question of what sources these teachers drew upon in their teaching. The findings from the analysis of the semi-structured interviews, the classroom observations and the discussions in the sharing circle revealed the most important sources of TPACK. These sources include teaching experience, self-directed learning, peer learning through social interaction, and learning from learners.

Teaching experience emerged as the most significant source, allowing teachers to gradually align technology with subject content and develop efficient pedagogical strategies. In addition, the chapter showed that self-directed learning revealed the teachers' commitment to continuous improvement, involving the exploration of new educational technologies and classroom experimentation. Moreover, the chapter revealed that peer learning through social interaction also played a crucial role in shaping the teachers' TPACK. Unexpectedly, the chapter revealed that learners actively contributed to teachers' TPACK development, challenging traditional approaches that view MKOs as teachers and not learners. The chapter concluded by proposing a new TPACK framework for Life Sciences teachers in rural schools. The aim of the framework was to improve contextualised teaching and provide valuable insights for teachers' TPACK development in rural secondary schools. The next chapter, the final chapter, provides a summary of key findings, new knowledge generated, recommendations and conclusions.

CHAPTER NINE: SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSIONS

> Teaching is a profession where knowledge and expertise are built up incrementally over time through what has been called the 'apprenticeship of observation'. This apprenticeship begins when individuals start school and continue throughout their lives. (Lortie, 1975, p.61)

9.1 INTRODUCTION

This final chapter presents a snapshot of the research findings, followed by the new knowledge that this study generated, the recommendations and conclusions derived from the insights garnered. The study explored various facets of Life Sciences teachers' TPACK development in rural schools and sought to shed light on the factors, practices, and experiences that shape TPACK development. By analysing the teachers' self-reported perspectives, the research aimed to uncover valuable insights that contribute to understanding TPACK development and its implications for teachers in rural schools. Through a meticulous examination of data, the study unveiled noteworthy findings that provide new perspectives on TPACK development, which subsequently form the basis for the recommendations. Moreover, these findings collectively culminate in findings that address the research questions and implications for the broader field of technology integration in teaching. Together, the summary of findings, new knowledge, recommendations, and conclusions provide a comprehensive synthesis of the research journey and its implications for practice and further research. The following section summarises the key findings.

9.2 SUMMARY OF FINDINGS

The study delved into various aspects of rural Life Sciences teachers' integration of technologies and their TPACK development. The findings are grouped into three main sections: teachers' ways of integrating technologies, Life Sciences teachers' TPACK description, and sources of teachers' TPACK in rural schools.

8.3.1 Rural Life Sciences Teachers' Ways of Integrating Technologies

The research findings have unveiled an exciting perspective on the technological landscape in rural schools. Contrary to previous assumptions of technological scarcity, the study has shown that rural teachers have access to various technological tools, including smartphones, tablets, projectors, and computers. This finding challenges the preconceived notion that rural schools inherently lack technological resources. Of particular note is the prevalence of smartphone usage among rural teachers, surpassing computer usage. This shift in technology preference marks a departure from earlier research trends. The teachers in the study have seamlessly integrated these devices into their daily lives, using them for personal purposes for more than four hours a day. This substantial personal usage highlights the familiarity and comfort they have developed with these tools. However, a contrasting picture emerges when examining technology integration into their teaching practices. Despite their extensive personal usage, the teachers allocate only 2 to 3 hours daily for incorporating technology into their teaching. This result suggests a disconnect between technology's significant role in their personal lives and its relatively limited integration into their professional teaching methods.

8.3.2 Life Sciences Teachers' TPACK description

The study showed that Life Sciences in rural schools exhibit lower TPACK proficiency. When examining the specific components of TPACK, it becomes evident that the teachers reported higher levels in non-technology domains (CK, PK, PCK) compared to the technology-related domains (TK, TPK, TPACK). Interestingly, TK emerged as the dominant area of expertise among the technology-related domains. This observation reinforces the theory that while possessing TK is pivotal, technology integration's true efficacy This finding implies that for technology integration to move beyond surface-level applications and pave the way for more learner-centred pedagogical practices, teachers need to be equipped with technological skills and a profound grasp of knowledge and skills across all TPACK domains. This finding emphasises that effective technology adoption is a complex interplay of various knowledge domains, with technological expertise being just one piece of the puzzle. By doing so, teachers will be better poised to harness technology to foster constructive, learner-centred learning experiences. However, this learner-centred approach depends on teachers' TPACK and the broader contextual factors within the school environment.

8.3.3 Sources of Teachers' TPACK in Rural Schools

The study investigated the sources of TPACK development within the context of rural Life Sciences teachers. Notably, teaching experience emerged as a pivotal and influential source, equipping teachers with the necessary skills to effectively integrate technology into their teaching. This observation underscores the notion that accumulated years of teaching experience provide teachers with the insights and adaptability required to seamlessly incorporate technology within their pedagogical approaches. An equally significant source of TPACK development was identified as self-directed learning. The teachers' proactive engagement in exploring and experimenting with technology independently allowed them to align these technological tools with the curriculum's objectives. This self-directed learning process exemplifies the resourcefulness and autonomy demonstrated by the teachers, who actively seek ways to enhance their teaching practices through technology.

In addition to individual efforts, the study underscored the role of collaborative peer interactions in enriching TPACK. Through meaningful exchanges with colleagues, teachers had the opportunity to share innovative strategies and valuable insights related to technology integration. This collaborative approach not only fosters a culture of continuous improvement but also accelerates the growth of TPACK by tapping into collective wisdom. Moreover, an intriguing and unexpected discovery emerged regarding the influence of learners on teachers' TPACK development. The study revealed that teachers benefited from learners who possessed advanced TK. This dynamic reflects a two-way learning process in the digital age, where teachers and learners engage in mutual learning experiences. These findings challenge traditional teaching dynamics paradigms and underscore the learner-teacher relationship's evolving nature in today's technologically enriched educational landscape. These findings collectively illuminate a multidimensional TPACK development landscape among rural Life Sciences teachers. The study sheds light on the amalgamation of factors, from teaching experience and self-directed learning to peer interactions and learner engagement, that collectively contribute to teachers' holistic technological and pedagogical competence. This nuanced perspective calls for a comprehensive approach to teacher development. The approach should embrace the interplay between individual growth, collaboration, and the evolving nature of learner-teacher partnership in an increasingly digital educational landscape. Table 10 below shows the research questions and the major findings.

Table 10. Research Questions and Major Findings

Research Question	Major Findings
How do rural secondary school Life Sciences teachers describe their ways of integrating technology?	The study challenges assumptions of rural schools lacking technology resources, revealing diverse tools like smartphones. Teachers heavily use devices more for personal purposes than for teaching purposes. This disconnect underscores a gap between personal and professional tech use. However, the integration often remains basic, focusing on transmitting information rather than enhancing learner-centred teaching.
How do rural secondary school Life Sciences teachers describe their technological pedagogical content knowledge?	The study revealed lower TPACK proficiency in rural Life Sciences schools. Teachers reported higher proficiency in non-tech areas (CK, PK, PCK) than tech-related ones (TK, TPK, TPACK). Of these, TK stood out. This finding highlights the importance of a comprehensive grasp of all knowledge domains, aligning with Mishra and Koehler's proposal (2006) to enhance technology integration's effectiveness. Teachers must possess tech skills and a profound understanding of TPACK domains for deeper, learner-centred pedagogies.
What sources of technological pedagogical content knowledge do rural secondary school Life Sciences teachers draw upon in their teaching?	Teaching experience emerged as a vital TPACK source due to insights and adaptability gained over the years. Self-directed learning also played a significant role, with teachers proactively aligning tech with curriculum goals. Collaboration with peers enriched TPACK, fostering innovation and collective growth. Unexpectedly, learners with advanced TK impacted teachers' TPACK development, highlighting reciprocal learning in the digital age.

9.3 NEW KNOWLEDGE

Expanding upon the discussion of findings, this section unveils the novel insights unearthed by this study. The distinctive contribution of this research lies in its departure from the conventional approach observed in earlier studies, which primarily focused on the evaluation or assessment of teachers' TPACK (Aldemir Engin et al., 2023; Bingimlas, 2018; Choi & Paik, 2021; Schmidt et al., 2009). Instead, the present study delved more profoundly into the intricate process of TPACK development through the filters of teachers' self-reported practices, contextual influences, and experiential nuances that shape the development of TPACK. The present study contributes to the theory and methodology of TPACK development, as demonstrated below.

9.3.1 Theoretical contributions

Firstly, this investigation into the development of TPACK in rural schools in South Africa introduces a range of contributions that both broaden existing boundaries of knowledge and address gaps highlighted in Section 2.14. The primary contribution of this current study is its provision of fresh insights into TPACK development, not solely within South Africa but also in the context of the Global South. As demonstrated in Chapter 2, the majority of TPACK research has been conducted within the Global North (Chai et al., 2010 [Singapore]; Durdu et al., 2017 [Turkey]; Galindo, 2023 [Philippines]; Koehler & Mishra, 2005 [USA]; Luo et al., 2023 [China]), resulting in a less explored TPACK landscape in the Global South.

To the researcher's knowledge, this study marks an uncharted territory within South African secondary schools. While existing TPACK research in the South African context has focused primarily on the higher education level, the secondary schooling level has been neglected. This present study places particular emphasis on the secondary schooling level, establishing a novel research niche within science education in South Africa. This shift of focus from higher education to secondary schooling levels, specifically concerning the advancement of TPACK in teachers within secondary schools, has not been previously explored in the South African context. By so doing, this research addresses a notable population gap by studying TPACK development in Life Sciences teachers within secondary schools. This cohort has been inadequately examined in preceding studies.

Secondly, the present study's review of TPACK studies spanning the period from 2005 to 2023, as presented in Section 2.13, uncovered a notable dearth of research explicitly delving into the context of rural schools. Notably, only a single recent investigation conducted in the USA (Hill & Uribe-Florez, 2020) was conducted in a rural setting. This evident gap underscores the insufficient global exploration of the rural school context throughout the evolutionary trajectory of research on teachers' TPACK. As a result, the current study contributes significantly to the TPACK literature by focusing explicitly on its development within rural environments. This endeavour enhances the understanding of TPACK development across diverse educational settings and provides insights to guide effective pedagogical methods and policies tailored to rural schools.

Furthermore, a prevailing limitation in much of the prior research has been the lack of contextual information, posing challenges in relating the implications of these studies to various settings. To bridge this gap, the present research takes a substantial step forward by providing a detailed and comprehensive depiction of the context of secondary schooling in rural areas (see Sections 2.2 and 2.3). Moreover, the study extends this effort by offering in-depth insights into the participating teachers' educational backgrounds and teaching experiences. This thorough contextualisation ensures that the findings are pertinent and adaptable to various educational scenarios.

Thirdly, as elucidated in Section 2.14, the realm of TPACK knowledge has predominantly been shaped by research centred on pre-service teachers (Angeli & Valanides, 2009; Durdu et al., 2017; Hill & Uribe-Florez, 2020; Kohen & Kramarski, 2012; Luo et al., 2023). Consequently, the current understanding of TPACK largely stems from viewpoints expressed by pre-service teachers, with comparatively limited insights regarding in-service teachers (Adedayo et al., 2022; Jang & Tsai, 2013; Mensah et al., 2022; Tunjera & Chigona, 2020). Thus, the present study contributes theoretically by pushing the boundaries of TPACK understanding, casting light on its intricate and context-sensitive evolution within a relatively unexplored domain - that of practising teachers. To offer more precision, this research delved deeply into the practices, factors, and experiences that shape the development of TPACK among teachers in rural regions. What sets this study apart is its exclusive focus on Life Sciences teachers working in rural settings. It is worth noting that these teachers' perspectives have been conspicuously absent in the broader body of TPACK research. Therefore, the unique insights generated by this study carry substantial significance.

Fourthly, this study's proposed TPACK model offers a series of theoretical contributions within the context of TPACK development for rural Life Sciences teachers in South African schools. The model underscores the pivotal role of the rural context in shaping TPACK development, shedding light on how specific challenges, including limited access to resources and cultural diversity, influence technology integration in rural schools. Moreover, the study's proposed TPACK model explicitly encompasses 'contextual knowledge,' denoted as 'Rural Life Sciences teaching context.' This represents a new contribution to the conventional model, firmly emphasising the critical importance of the rural context in TPACK development. Therefore, the proposed TPACK framework for rural teachers advocates for a highly tailored approach to TPACK, recognising that a one-size-fits-all strategy does not suffice.

Additionally, the proposed model underlines a crucial distinction between in-service and pre-service teachers, illustrating how practical classroom experience enables teachers to find resonance naturally and seamlessly among the TPACK components. Beyond theory, the practical implications of the proposed framework are significant. It captures the nature of TPACK and its development in rural schools and amplifies the voices of rural teachers, a segment traditionally underrepresented in TPACK research. This amplification contributes to a holistic understanding of TPACK development, especially in rural and underserved communities, and holds the promise of benefiting similar contexts globally.

9.3.2 Methodological contributions

Fourth, as mentioned earlier, the majority of TPACK studies have adhered to a quantitative and mixed methodology (Dong et al., 2015; Kapici & Akcay, 2023; Koehler & Mishra, 2005; Luo et al., 2023). In particular, a recent study by Karchmer-Klein and Konishi (2023) in the USA employed a mixed-methods explanatory sequential study design to investigate the development and transfer of TPACK by novice K-12 teachers in their transition to full-time teaching after graduation. In a departure from this conventional trajectory, the current study adopted a qualitative approach to glean self-reported TPACK proficiency levels directly from the teachers, recognising that the core repository of this knowledge is intrinsically embedded within the teachers themselves.

Consequently, this study's unique methodological choice of learning from the teachers' lived experiences yields a distinctive contribution to the field of TPACK research. Particularly, the deliberate choice to adopt a qualitative approach was underpinned by the recognition that delving into the intricate nuances of TPACK development, particularly within the context of underrepresented rural schools, demanded a more holistic and in-depth exploration. Through the qualitative approach, the present study captured the rich tapestry of factors, experiences, and contextual intricacies that shape teachers' TPACK development. The researcher firmly believed that such an approach not only provided a deeper understanding of TPACK development but also allowed the voices of teachers themselves to play a central role in shaping the research narrative.

Fifth, related to the methodological contribution highlighted above, this research does not claim that its combination of the SCT and TPACK principles is new in TPACK research. This amalgamation has been undertaken by several researchers in other locations, mainly within the Global North, for example, Bostancıoğlu and Handley's (2018) quantitative investigation in the UK, Purwati's (2022) study utilising mixed methods in Indonesia, and Olofson's et al., (2016) qualitative research in the USA are notable examples of such endeavours. Nonetheless, the amalgamation of the SCT and TPACK frameworks within this study signifies a fresh and innovative approach, thereby extending the theoretical underpinnings of TPACK research within the Global South context, particularly in the South African context. The existing body of literature concerning TPACK development in South Africa is notably devoid of theory triangulation, particularly the amalgamation of SCT and TPACK frameworks.

Moreover, present studies often concentrate exclusively on the TPACK framework, consequently limiting the depth of insights garnered. This practice runs parallel to Koehler and Mishra's (2006) contention that within the intricate and dynamic domain of technology integration in teaching, a solitary framework inevitably falls short in explaining the multifaceted questions that arise. The present research provided a more comprehensive and nuanced exploration of TPACK development within rural schools. This understanding was achieved by synergistically merging the two influential frameworks, SCT and TPACK. The amalgamation of the two frameworks offered a more holistic understanding of the intricate interplay between teacher cognition, contextual influences, and technological integration in the unique setting of South African rural schools. As the first of its kind in South Africa, this study's analysis combining SCT and TPACK brings a theoretical contribution that is distinct from prior research that used other frameworks. Moreover, the present research provides a basis for future researchers in similar contexts who wish to explore TPACK development through the amalgamated theoretical lenses established in this study.

Sixth, the analysis of existing literature has revealed inherent contradictions and disputes surrounding the assessment of TPACK (Cox & Graham, 2009; Niess, 2011; Chan & Hume, 2019). These contradictions have consequently led to the proposition of various approaches for evaluating teachers' TPACK, which Koehler et al. (2012) categorised into four distinct types: evaluation of lesson plans (Aldemir Engin et al., 2023; Bingimlas, 2018; Kapici & Akcay, 2023), classroom observations (Aldemir Engin et al., 2023; Karakuş & Niess, 2023; Bingimlas, 2018; Choi & Paik, 2021), self-assessment surveys (Angeli & Valanides, 2009; Galindo, 2023; Kafyulilo et al., 2014; Kartal & Çınar, 2022), and an array of tools incorporating pre- and post-interviews, along with video recordings of teaching (Cox & Graham, 2009; Durdu et al., 2017; Kartal & Çınar, 2022). Amidst this diversity in approaches for measuring TPACK, the synthesis of the literature in the present study (refer to Table 2) indicates a prevailing and exclusive reliance on TPACK questionnaires. Nonetheless, the TPACK questionnaire often falls short of encompassing teachers' authentic classroom practices and contextual intricacies, potentially limiting the comprehensive depth of exploration. Setting itself apart from this prevalent pattern, the current research employed an array of instruments such as the TPACK questionnaire, semi-structured interviews, sharing circle discussions, and lesson observations. This study demonstrates that adopting similar data generation instruments can provide future researchers with a tried-and-true foundation for robust data collection.

The sharing circle discussions emerge as a groundbreaking innovation among the many research instruments used in the present study. Rooted in indigenous data generation methods, these discussions stand as a trailblazing advancement in TPACK research. This approach offers a fresh and inventive angle to studying TPACK, which deftly bridges the divide between traditional research practices and the compelling ambition of investigating TPACK from rural and indigenous perspectives. The strategic adoption of sharing circle discussions stands as a testament to the ever-evolving nature of research methodologies. These discussions, informed by indigenous knowledge-sharing traditions, introduce an alternative lens through which TPACK can be comprehended. This novel approach is uniquely poised to capture the nuanced intricacies of TPACK development within rural communities' specific cultural and educational contexts. Doing so encapsulates a holistic picture that conventional methods might inadvertently miss.

Moreover, this methodological innovation has broader implications for the research community. It underscores the significance of expanding the toolkit of research practices to embrace diversity and inclusivity. In a world where educational landscapes are both global and intensely local, methodologies like sharing circle discussions facilitate the exploration of TPACK that is rigorous, culturally sensitive, and contextually resonant. The next section provides implications and recommendations for practice and further research.

9.4 IMPLICATIONS AND RECOMMENDATIONS FOR PRACTICE AND FURTHER RESEARCH

This section provides implications and recommendations for practical applications and future research. The recommendations offer practical and actionable guidance based on the study's findings while also suggesting potential avenues for advancing future research.

9.4.1 Implications and Recommendations for Practice

This study has indicated that even though there is extensive access to various technologies in rural schools, the utilisation of these technologies by teachers primarily improved their methods of transmitting knowledge. This finding leads to reduced engagement at the lower levels of cognitive domains. Additionally, the study unveiled that most teachers possess a limited level of TPACK, which hinders their ability to implement transformative practices enhanced by technology. Furthermore, the teachers encountered challenges in employing technology due to various influencing factors. These findings carry several practical implications for teachers, school leaders, policymakers, researchers, and institutions responsible for teacher training.

9.4.1.1 For teachers

The TPACK framework can aid in identifying teachers' knowledge gaps to teach using technologies effectively. Moreover, the TPACK framework guides teachers on how technology can be adopted based on their lesson objectives and their purpose for integrating the technology (enhance versus transform, transmit knowledge versus promote constructivist learning) within the lesson. Additionally, including SCT within the TPACK framework allows teachers to comprehend how their social interactions with peers and continued use of technologies can enhance their TPACK development. Armed with this information, teachers can benefit by recognising their weaknesses and subsequently seeking professional and emotional support tailored to address these knowledge gaps to:

a) Embed the framework in teaching and learning activities, thereby transforming pedagogy.

b) Create chances for learners to utilise technologies to reshape their thinking and learning.

c) Foster pedagogical designs oriented towards constructivist principles, facilitating the use of technologies for knowledge production rather than mere knowledge transmission.

d) Engage in self-reflection regarding pedagogical practices and actively share and discuss these practices with colleagues.

9.4.1.2 For school principals and policymakers

The educational system in South Africa operates hierarchically, flowing directly from the national level (DBE) down to the school level. Consequently, the government is responsible for furnishing schools with all the requisite infrastructure and support services. Such infrastructures encompass elements like school buildings, classrooms, technological resources and facilities, and comprehensive training for professional teacher development. As a result, school leaders' assistance to their teachers is intrinsically tied to the support they receive from the DBE. This study has highlighted various challenges at the school level, including issues related to support from the SMTs and concerns regarding professional development training. These factors have significantly impacted how teachers incorporate technology into their pedagogical practices.

9.4.1.3 For teacher training institutions

This study's findings have indicated a limited enhancement in terms of TPACK through initial teacher training programmes offered by universities. These findings suggest that teacher training programmes should shift away from delivering technology as a distinct module, as previously proposed by Koehler and Mishra (2009). Instead, deliberate efforts should be made to assist pre-service teachers in seamlessly incorporating technology into their teaching practices in a cohesive manner. This adjustment involves more than simply offering a single technology-focused course to enhance technological skills. It encompasses:

a) **Incorporate TPACK into Core Curriculum:** Integrate TPACK principles into the core curriculum of teacher training programs. Rather than treating technology as an isolated subject, infuse it across subjects and modules, reflecting its integral role in modern education.

b) **Collaborative Projects:** Design collaborative projects requiring pre-service teachers to create lesson plans or instructional materials seamlessly integrating technology, content, and pedagogy. This encourages a holistic understanding of how technology enhances teaching and learning.

c) **Authentic Teaching Practice:** Provide opportunities for pre-service teachers to engage in real classroom settings during their training. This practical experience allows them to experiment with integrating technology into various teaching contexts, fostering confidence and competence.

d) **Subject-Specific Integration:** Tailor technology integration to the subject content such that each discipline has its unique needs and opportunities for technology incorporation.

e) **Case Studies and Scenarios:** Present pre-service teachers with real-world case studies or scenarios that require them to analyse situations and propose technology-infused solutions. This promotes critical thinking about effective TPACK integration.

f) **Ongoing Professional Development:** Extend training beyond the initial teacher education period by offering continuous professional development sessions that explore emerging technologies and innovative teaching strategies.

g) **Technology in Pedagogy Courses:** Develop pedagogy courses specifically dedicated to demonstrating how different technologies can be utilised to facilitate effective teaching.

h) **Reflective Practice:** Encourage regular self-reflection on integrating technology, content, and pedagogy. This could be journals, discussions, or presentations that prompt pre-service teachers to articulate their evolving TPACK understanding.

i) **Mentoring and Collaboration:** Establish mentorship programmes where experienced teachers guide pre-service teachers in planning and executing technology-rich lessons.

9.4.1.4 For similar rural contexts

While the primary focus of this study's contribution lies within the context of South African rural schools, the suggested recommendations possess applicability to other regions that share similar characteristics, given the global reach of TPACK. Fundamentally, these recommendations underscore two crucial elements critical to successful technology integration. These factors are the expertise of teachers and the contextual factors that impact their ability to integrate technology effectively. Consequently, the practical suggestions outlined earlier can serve as valuable guidance for teachers and educational policymakers in various contexts. Therefore, the recommendations delineated in this study not only enrich the existing body of literature concerning teachers' TPACK and technology integration but also contribute to the ongoing discourse on technology's role in education.

9.4.1.5 Enhancing Professional Teacher Development

The findings from the current research highlight a notable gap in teachers' proficiency (TPACK) for effectively incorporating technology into their teaching. As a result, it is imperative for professional development to transition from the current focus solely on how to use technological tools to guide them in seamlessly integrating technology into their teaching approaches.

Furthermore, this research strongly suggests that providing professional development within the familiar confines of teachers' schools and classrooms is highly beneficial. This approach facilitates the immediate application of newly acquired skills and knowledge to their teaching practices. Additionally, the study reveals that teachers often feel unsupported by their peers or colleagues when integrating technology in their classrooms. To mitigate this, it is recommended that professional development sessions group teachers based on their departments or subject areas. This collaborative setting would enable teachers to collectively explore and implement technologies within their actual teaching environments. This approach can foster a sense of peer support and enhance teachers' confidence and competence in effectively utilising technology.

Moreover, a proficient ICT teacher within the school, acting as a catalyst for change, is crucial. This designated ICT expert would play a pivotal role in assisting teachers who may be hesitant to adopt new technologies due to limited technological proficiency. The chosen ICT "champion" role involves personalised sessions with teachers to understand their concerns and reservations about integrating technology into teaching and learning. To ensure meaningful integration, the ICT "champion" would illuminate the potential benefits of these tools through the following steps:

a) Offer continuous support as teachers implement the training content.

b) Address factors such as infrastructure, technology support, and ICT policy-related issues at the school level that might impede progress.

c) Facilitate relevant professional development for teachers, school management, IT support staff, and school leaders.

d) Allocate training time during working hours to minimise disruptions and establish mechanisms for evaluating and following up on training.

e) Provide opportunities for teachers to observe exemplary technology usage to enhance their learning experiences.

f) Foster collaborative learning through professional communities, promoting peer-led initiatives.

g) Ensure that training is both comprehensive and sustained over time.

h) Tailor technology training to specific subjects, enhancing teachers' content and pedagogy alignment proficiency.

i) Encourage teachers to gain experience in various instructional design models and materials creation.

9.4.1.6 Infrastructure and resource allocation

At the outset of this study, the researcher emphasised that the rural school context is rife with numerous challenges due to the absence of adequate science infrastructure. This study has unveiled two pivotal contextual factors that profoundly influence the successful integration of technology. These are persistent power outages and restricted Internet connectivity. While tackling power interruptions might pose a difficulty for rural schools, especially concerning the affordability of generators, however, administrators could ensure that the school infrastructure facilitates dependable wireless and wired connectivity across the entire school premises.

Moreover, each teacher requires access to Internet-enabled devices. Providing teachers with the requisite tools will empower them to comprehend the potential advantages of educational technologies. Additionally, provisions should be instituted to address concerns about infrastructure maintenance, encompassing enhancements to wired and wireless accessibility and replacing antiquated digital devices. These measures are crucial to meet the evolving needs of teachers and ensure the necessary speed for harnessing technologies in rural schools. Furthermore, advocacy endeavours should be undertaken to secure augmented funding and resource allocation to integrate technology in rural schools.

9.4.2 Implications and Recommendations for Future Research

The findings of the current study have ignited considerations for further research. As TPACK development in rural school teachers constitutes a novel research domain, particularly in the Global South, a range of prospective directions for future research have come to the forefront. These lines of inquiry highlight uncharted research pathways that have surfaced because of this study. Therefore, this study would welcome more research focused on the following areas:

First, while the present study honed in on Life Sciences teachers' TPACK development in rural secondary schools, a compelling argument exists for expanding research boundaries into subjects beyond the sciences, such as the Languages or Arts within rural educational settings. This cross-disciplinary approach could enrich the scholarly discourse by unveiling patterns, similarities, and disparities, ultimately contributing to a more comprehensive understanding of teachers' TPACK development. Moreover, engaging in TPACK research that spans diverse disciplines can catalyse innovative pedagogical approaches. Teachers and policymakers could draw inspiration from successful practices in one domain and apply them creatively in others, fostering cross-pollination of ideas and methodologies.

Second, the scope of the conclusions drawn from a study can be constrained by the nature of the collected data. The present study generated qualitative data to discern how teachers incorporated technology and the factors that shape their TPACK development. The reported findings were rooted in the teachers' self-awareness and capacity to recollect their teaching methodologies, practices, and experiences. Consequently, the description of their technology use and TPACK development might have been moulded by each teacher's individual views, inherent inclinations, and subjective prejudices. While the present study has made valuable contributions by employing a qualitative approach, a mixed-methods approach could provide a more comprehensive understanding of the complex dynamics of teachers' TPACK development within rural schools. This comprehensive approach would combine the strengths of qualitative insights and quantitative data, painting a more detailed and accurate picture of the phenomenon. Qualitative research, as utilised in this study, involves delving into the participants' underlying motivations, experiences, and perspectives. By conducting interviews, surveys, or observations, researchers can gather rich data that goes beyond mere numerical figures, offering a more nuanced understanding of the phenomenon under investigation. Specifically, quantitative data, such as surveys and statistical analyses, can provide a broader overview of TPACK development trends and patterns across a larger sample size.

Third, the current research findings reveal a significant lack of support from colleagues concerning technology integration, prompting the need for a comprehensive investigation into support structures within schools. This inquiry should scrutinise the mechanisms and frameworks essential for facilitating the successful incorporation of technology in rural educational settings. This would entail examining the roles of school leaders, district-level support, and community partnerships in providing the necessary resources and assistance. Additionally, the study should seek to shed light on the impact of professional learning networks and collaboration opportunities in enhancing technology integration. By shedding light on these dimensions, the study would unpack the intricate interplay of leadership, administrative support, and peer collaborations in creating an environment conducive to successful technology adoption within rural educational settings.

Fourth, the use of teachers' personal narratives to understand the factors influencing their technology integration and TPACK development within their school context presents a limitation, as these factors were specific to the seven participants in the study. A quantitative, broader-scale survey could be conducted to gain a more comprehensive understanding. This approach would enable a thorough assessment of the factors influencing teachers nationwide. In future research, quantitative instruments could be refined or developed to measure teacher-related aspects (beliefs, attitudes, TPACK competencies) and contextual factors (resource access, technical support, time constraints, leadership and training support, parental and national-level support), particularly in the context of developing countries. Such data would facilitate meaningful comparisons between variables, shedding light on the most critical factors for successful technology integration and TPACK development. This approach would offer readers and researchers a broader perspective on the influences on teachers' TPACK development efforts nationwide.

Fifth, as illustrated in Section 2.14, research on TPACK in teaching represents a new frontier in education, particularly in the Global South. Consequently, the present study undertook pioneering efforts by establishing a foundation and initiating the first steps towards investigating TPACK development in South Africa's rural schools. Nevertheless, it is crucial to acknowledge that the findings presented in this study were derived from data collected at a single point in time. As a result, their capacity to elucidate the trajectory of TPACK development over time is limited. To address this limitation, the current research proposes conducting longitudinal studies that offer insights into the enduring effects of technology integration on pedagogical practices and TPACK development. Furthermore, this study recommends delving deeper into interventionist studies, offering a promising avenue to explore practical applications and real-world impact. Building upon this research's foundations, such studies can design targeted interventions to address specific challenges and foster TPACK development among teachers in rural school contexts, contributing both to academic discourse and making tangible field advancements. Recognising that technology adoption and teaching methodologies are subject to evolution, longitudinal studies conducted over an extended duration hold the promise of furnishing invaluable perspectives regarding the persistent impacts and challenges arising from technology integration within rural classrooms. By delving into the longitudinal dynamics, scalability, and sustainability of technology-infused education, such studies would contribute significantly to the broader understanding of TPACK development and its implications in the educational landscape.

9.5 LIMITATIONS OF THE STUDY

Like any human endeavour, the current study and its reported findings are not exempt from limitations. These limitations encompass various aspects, including methodological considerations, the collected data, and the specific contexts of the participating individuals.

An example of these limitations lies in the present research's constrained timeframe for data collection. The data collection phase coincided with a demanding period for the participating teachers, as evidenced by the timeline. The questionnaire data were gathered from the third week of November 2022 until the fourth week of December 2022, aligning with their administration and assessment of end-of-year examinations. Subsequently, the collection of semi-structured interviews, sharing circle sessions, and lesson observational data transpired between the last week of January 2023 and the last week of April 2023. This period was marked by teachers grappling with the need to complete the curriculum for the first term and adequately prepare learners for formal examinations. It is plausible, therefore, to speculate that the time constraints during these periods could have influenced the extent to which teachers provided comprehensive responses to the questions posed. Nevertheless, it is worth noting that the researcher took measures to enhance the study's validity by employing a mix of data collection methods. While each approach carries its inherent limitations and potential sources of error, the amalgamation of these methods through triangulation worked synergistically to strengthen the confidence in the study's findings.

Furthermore, the study could have been susceptible to biases and subjectivity due to its reliance on the participating teachers' self-reported perspectives and personal experiences. Their individual viewpoints, convictions, or prior experiences might have influenced their responses, thereby introducing potential biases into the collected data. This propensity for bias was further pronounced by the study investigating the TPACK development of teachers who report to the researcher in their line of work, potentially influencing how they responded. To counterbalance this, the study adeptly employed a range of data sources to mitigate these potential biases and cross-referenced the ensuing findings. However, it is essential to note that the participants were purposively selected based on their voluntary participation and school location. Consequently, the researcher urges readers to exercise caution while interpreting the findings of this study.

Additionally, it is imperative to acknowledge that the study's sample size might be small. Specifically, the findings were drawn from the responses of merely seven participants. This potentially limits the extent to which the findings can be generalised to a wider population of Life Sciences teachers in rural regions. Furthermore, the study's sample was confined to teachers hailing from a singular district, a characteristic that shared contextual factors among participants. Expanding the scope to encompass a more diverse and expansive sample would undoubtedly enhance the representative nature of the findings. This would facilitate a more holistic comprehension of teachers' TPACK development factors and experiences spanning across varying rural contexts. This proposition emerges from the recognition that the study's current emphasis on a particular rural district restricts the extent to which its findings can be applied to other rural locations. This flows from the understanding that different rural areas may be imbued with unique attributes, resources, and challenges that invariably mould the trajectory of TPACK development. Consequently, the current study findings should be approached cautiously within the defined geographical research context. The following section wraps up the research.

9.6 CONCLUSIONS AND FINAL REFLECTIONS

This section weaves together all the components presented in this thesis. This study investigated Life Sciences teachers' TPACK development in the context of rural secondary schools in the Global South.

The research was grounded in two theories: the SCT and TPACK framework. These theoretical foundations also influenced the design of the research questions. A vantage point emerged by adopting a blended theoretical approach through which the various factors influencing teachers' TPACK development in rural schools were better understood. The SCT offered a lens to understand how collaborative learning experiences and interactions with peers, learners, and technology tools contributed to developing teachers' TPACK. On the other hand, the TPACK framework horned on teachers' knowledge and pedagogical practices concerning integrating technology into teaching. The merging of these perspectives enriched the analysis and interpretation of the study's findings. As a result, this investigation contends that the combination of SCT and TPACK frameworks, when applied to data collection and analysis, can significantly aid in comprehensively understanding the intricacies of teachers' TPACK development.

This research adopted a qualitative approach within the interpretive paradigm. The study involved seven Life Sciences teachers who were purposefully selected from rural schools in the Eastern Cape province of South Africa, specifically within the Joe Gqabi district. Multiple data generation instruments were employed to ensure a comprehensive dataset, including questionnaires, semi-structured interviews, sharing circle discussions, and lesson observations. The collected data underwent thematic analysis to facilitate meaningful interpretation and discourse on TPACK development in rural schools.

This research has demonstrated that teachers in the study predominantly employed ‘low-skill’ technologies, such as presentation software, to enhance their teaching approaches. These technologies were primarily used for traditional, teacher-centred methods that focused on transmitting knowledge to learners. Furthermore, the study identified several key factors that influenced teachers’ technology adoption. These factors encompassed challenges associated with school infrastructure, resources, facilities, Internet connectivity, Wi-Fi availability, school leadership, and teacher professional development training.

Moreover, the findings of this study indicated that the Life Sciences teachers who participated in the research have low TPACK proficiency. However, a closer examination of the individual components of TPACK has revealed an interesting pattern. The teachers exhibited higher levels of expertise in non-technology-related domains than technology-related ones. Notably, a significant and intriguing discovery from this research is that teachers’ TPACK development in rural schools is closely linked to their years of teaching experience, with little contribution from the initial teacher training.

As a Subject Advisor (Senior Education Specialist) responsible for guiding and assisting rural Life Sciences teachers, this study has provided valuable insights that prompted me to rethink my approach. It has reinforced my commitment to advocating for technology integration in their teaching practices. I am now more attuned to the challenges and specific factors that might hinder teachers from seamlessly adopting technology. This heightened awareness equips me to offer more focused guidance, tailoring my advice to address challenges like limited training opportunities or teachers’ hesitancy towards technologies. Additionally, the study has deepened my understanding of the importance of teachers’ TPACK and the factors, practices and experiences that shape the development of this craft knowledge. With these insights at my disposal, I am now better equipped to organise workshops that emphasise the fusion of technology with teaching methods as part of my duties. Unlike past workshops that solely covered technology tools, I now recognise the need to emphasise aligning technology with effective teaching approaches. This change will help me better support and empower Life Sciences teachers in seamlessly incorporating technology into their teaching, ultimately enhancing the learning experiences for their learners.

In summary, this research has contributed to the global discourse on TPACK. Notably, its significance stems from its unique focus on South Africa, as no previous studies of a similar nature were identified in the synthesised literature. By investigating the development of teachers' TPACK within rural secondary schools, particularly in the Global South and specifically in South Africa, this study has introduced a distinctive dimension to the broader understanding of teachers' TPACK development. Furthermore, this research opens up many avenues for further exploration that can deepen the understanding of TPACK. Looking forward, the prospect of integrating technologies into rural science education holds promise. Despite potential obstacles like limited electricity access and Internet connectivity in rural schools, this study highlights the enthusiasm of rural teachers who lack formal technology integration training to incorporate technology into their teaching methods. This positive outlook augurs well for their ongoing TPACK development. As Harari (2018) points out in the epigraph of the present study's abstract, teachers need to prepare themselves for a world where technology is constantly changing and evolving. Thus, it would be interesting to follow up on these teachers as they progress in their TPACK development journey.

REFERENCES

Abbitt, J. T. (2011). Measuring technological pedagogical content knowledge in preservice teacher education: A review of current methods and instruments. *Journal of Research on Technology in Education*, *43*(4), 281-300. https://0-doi.org.wam.seals.ac.za/10.1080/15391523.2011.10782573.

Abdurrahman, A. (2023). Integrated Science Curriculum in the Unpredictable World. In *Integrated Education and Learning*, 181-199. Cham: Springer International Publishing. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-031-15963-3_11.

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea?. *International journal of science education*, *30*(10), 1405-1416. https://0-doi.org.wam.seals.ac.za/10.1080/09500690802187041.

Absari, N., Priyanto, P., & Muslikhin, M. (2020). The effectiveness of Technology, Pedagogy and Content Knowledge (TPACK) in learning. *Jurnal Pendidikan Teknologi dan Kejuruan*, *26*(1), 43-51. https://doi.org/10.21831/jptk.v26i1.24012.

Acock, A. C. (2005). Working with missing values. *Journal of Marriage and family*, *67*(4), 1012-1028. https://0-doi.org.wam.seals.ac.za/10.1111/j.1741-3737.2005.00191.x.

Afgan, E., Sloggett, C., Goonasekera, N., Makunin, I., Benson, D., Crowe, M., Gladman, S., Kowsar, Y., Pheasant, M., Horst, R. and Lonie, A., (2015). Genomics virtual laboratory: a practical bioinformatics workbench for the cloud. *PloS one*, *10*(10), p.e0140829. https://doi.org/10.1371/journal.pone.0140829.

Afonso-Nhelevilo, R. (2013). Entrepreneurial orientation and business performance: An empirical study of small and medium-sized enterprises in Mozambique. (Doctoral dissertation, Universidade do Algarve). https://www.ualg.pt/sites/ualg.pt/files/fe/guidelines_masters-final-work_feualg_jun2019.pdf.

Agunbiade, E., Ngcoza, K., Jawahar, K. and Sewry, J., (2017). An exploratory study of the relationship between learners' attitudes towards learning science and characteristics of an afterschool science club. *African Journal of Research in Mathematics, Science and Technology Education*, *21*(3), 271-281. http://doi.org/10.1080/18117295.2017.1350678.

Ahmadi, D., & Reza, M., (2018). The use of technology in English language learning: A literature review. *International Journal of Research in English Education*, *3*(2), 115-125. http://dx.doi.org/10.29252/ijree.3.2.115.

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179-211. https://0-doi.org.wam.seals.ac.za/10.1016/0749-5978(91)90020-T.

Akayoğlu, S. (2019). Theoretical frameworks used in CALL studies: A systematic review. *Teaching English with Technology*, *19*(4), 104-118. http://doi.org/10.4018/978-1-5225-7286-2.ch003.

Aldemir Engin, R., Karakuş, D., & Niess, M. L. (2023). TPACK development model for pre-service mathematics teachers. *Education and Information Technologies*, *28*(4), 4769-4794. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-022-11381-1.

Alhawsawi, S., & Jawhar, S. S. (2021). Negotiating pedagogical positions in higher education during COVID-19 pandemic: teacher's narratives. *Heliyon*, e07158. https://doi.org/10.1016/j.heliyon.2021.e07158.

Altheide, D., Coyle, M., DeVriese, K., & Schneider, C. (2008). Emergent qualitative document analysis. *Handbook of emergent methods*, *2008*, 127-151.

Amineh, R. J., & Asl, H. D. (2015). Review of constructivism and social constructivism. *Journal of Social Sciences, Literature and Languages*, *1*(1), 9-16. https://doi.org/10.12691/education-8-5-14.

Angeli, C., & Valanides, N. (2005). Preservice elementary teachers as information and communication technology designers: An teaching systems design model based on an expanded view of pedagogical content knowledge. *Journal of computer assisted learning*, *21*(4), 292-302. https://0-doi.org.wam.seals.ac.za/10.1111/j.1365-2729.2005.00135.x.

Angeli, C., & Valanides, N. (Eds.). (2014). *Technological pedagogical content knowledge: Exploring, developing, and assessing TPCK*. Springer. http://dx.doi.org/10.1007/978-1-4899-8080-9.

Angeli, C., & Valanides, N., (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & education*, *52*(1), 154-168. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2008.07.006.

Armoni, M. (2016). COMPUTING IN SCHOOLS Computer science, computational thinking, programming, coding: the anomalies of transitivity in K-12 computer science education. *ACM Inroads*, *7*(4), 24-27. http://0-dx.doi.org.wam.seals.ac.za/10.1145/3011071.

Ashok, M., Madan, R., Joha, A., & Sivarajah, U. (2022). Ethical framework for Artificial Intelligence and Digital technologies. *International Journal of Information Management*, *62*, 102433. https://0-doi.org.wam.seals.ac.za/10.1016/j.ijinfomgt.2021.102433.

Aspers, P., & Corte, U. (2021). What is qualitative in research. *Qualitative Sociology*, 44(1), 1-10. https://0-doi.org.wam.seals.ac.za/10.1007/s11133-021-09497-w.

Assey, E.S., & Babyegeya, E. (2022). The Challenges Facing Effective Teaching, Learning and Assessment in Community-Based Secondary Schools in Tabora Region. *American Journal of Education and Practice*, *6*(2), 1-17. https://doi.org/10.47672/ajep.1084.

Bagozzi, R. P. (2007). The legacy of the technology acceptance model and a proposal for a paradigm shift. *Journal of the Association for Information Systems*, 8(4), 244-254. http://doi.org/10.17705/1jais.00122.

Bandura, A., Freeman, W. H., & Lightsey, R. (1999). *Self-efficacy: The exercise of control.* New York, NY: W. H. Freeman. https://doi.org/10.1891/0889-8391.13.2.158.

Bantwini, B. (2017). Analysis of teaching and learning of natural sciences and technology in selected Eastern Cape province primary schools, South Africa. *Journal of Education*, (67), 39-64. https://doi.org/10.17159/2520-9868/i67a02.

Baraldi, A. N., & Enders, C. K. (2010). An introduction to modern missing data analyses. *Journal of school psychology*, *48*(1), 5-37. https://0-doi.org.wam.seals.ac.za/10.1016/j.jsp.2009.10.001.

Bazeley, P. (2013). *Qualitative data analysis: Practical strategies*. sage. http://hdl.handle.net/1959.7/uws:48650.

Bell, M. L., Whitehead, A. L. & Julious, S. A. (2018). Guidance for using pilot studies to inform the design of intervention trials with continuous outcomes. *Clinical epidemiology*, *10*:153. https://0-doi.org.wam.seals.ac.za/10.2147/CLEP.S146397.

Bennett, K. J., Borders, T. F., Holmes, G. M., Kozhimannil, K. B., & Ziller, E. (2019). What is rural? Challenges and implications of definitions that inadequately encompass rural people and places. *Health Affairs*, *38*(12), 1985-1992. https://doi.org/10.1377/hlthaff.2019.00910.

Berger, P., & Wolling, J. (2019). They need more than technology-equipped schools: teachers' practice of fostering learners' digital protective skills. *Media and Communication*, *7*(2), 137-147. https://doi.org/10.17645/mac.v7i2.1902.

Bernardes, T. S., & de Andrade Neto, A. S. (2020). Technological pedagogical Content Knowledge (TPACK) in pre-service and in-service chemistry teacher training: a systematic literature review. *RENOTE*, *18*(2), 611-620. https://doi.org/10.22456/1679-1916.110304.

Bingham, A. J. (2023). From Data Management to Actionable Findings: A Five-Phase Process of Qualitative Data Analysis. *International Journal of Qualitative Methods*, *22*, 16094069231183620. https://0-doi.org.wam.seals.ac.za/10.1177/16094069231183620.

Bingimlas, K. (2018). Investigating the level of teachers' Knowledge in Technology, Pedagogy, and Content (TPACK) in Saudi Arabia. *South African Journal of Education*, *38*(3). https://0-doi.org.wam.seals.ac.za/10.15700/saje.v38n3a1496.

Bohn, R. E. (2009). Measuring and managing technological knowledge. In *The Economic impact of knowledge*, 295-314. Routledge. https://doi.org/10.4324/9780203878099.012.

Bostancıoğlu, A., & Handley, Z. (2018). Developing and validating a questionnaire for evaluating the EFL 'Total PACKage': Technological Pedagogical Content Knowledge (TPACK) for English as a Foreign Language (EFL). *Computer assisted language learning*, *31*(5-6), 572-598. https://0-doi.org.wam.seals.ac.za/10.1080/09588221.2017.1422524.

Bouchard, L.M., & Wike, T.L. (2022). Good as gone: narratives of rural youth who intend to leave their communities. *Rural Society*, *32*(2) 1-18. https://0-doi.org.wam.seals.ac.za/10.1080/10371656.2022.2084584.

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative research journal*, *9*(2), 27-40. https://doi.org/10.3316/QRJ0902027.

Brady, M. (1984). Artificial intelligence and robotics. In *Robotics and Artificial Intelligence*, 47-63. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-82153-0_4.

Brantley-Dias, L., & Ertmer, P. A. (2013). Goldilocks and TPACK: Is the construct 'just right?'. *Journal of Research on Technology in Education*, *46*(2), 103-128. https://0-doi.org.wam.seals.ac.za/10.1080/15391523.2013.10782615.

Braun, V., & Clarke, V. (2012). Thematic analysis. In *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological,* American Psychological Association, 57-71. https://psycnet.apa.org/doi/10.1037/13620-004.

Bwalya, A., & Rutegwa, M. (2023). Technological pedagogical content knowledge self-efficacy of pre-service science and mathematics teachers: A comparative study between two Zambian universities. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(2), em2222. https://doi.org/10.29333/ejmste/12845.

Candela, A. G. (2019). Exploring the function of member checking. *The qualitative report*, *24*(3), 619-628. https://doi.org/10.46743/2160-3715/2019.3726.

Chai, C.S., Koh, J.H.L., & Tsai, C.C. (2010). Facilitating preservice teachers' development of technological, pedagogical, and content knowledge (TPACK). *Journal of Educational Technology & Society*, *13*(4), 63-73. https://doi.org/10.2307/23968623.

Chaipidech, P., Srisawasdi, N., Kajornmanee, T., & Chaipah, K. (2022). A personalized learning system-supported professional training model for teachers' TPACK development. *Computers and Education: Artificial Intelligence*, *3*, 100064. https://0-doi.org.wam.seals.ac.za/10.1016/j.caeai.2022.100064.

Chan, K.K.H., & Hume, A. (2019). Towards a consensus model: Literature review of how science teachers' pedagogical content knowledge is investigated in empirical

studies. *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science*, 3-76. https://0-doi.org.wam.seals.ac.za/10.1007/978-981-13-5898-2_1.
Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T., & Fischer, F., (2020). Simulation-based learning in higher education: A meta-analysis. *Review of Educational Research*, *90*(4), 499-541. https://0-doi.org.wam.seals.ac.za/10.3102/0034654320933544.
Chilisa, B. (2012). Postcolonial indigenous research paradigms. *Indigenous research methodologies*, 98-127. https://doi.org/10.4129/9781412958820.ch004.
Choi, K., & Paik, S.H., (2021). Development of Pre-Service Teachers' TPACK Evaluation Framework and Analysis of Hindrance Factors of TPACK Development. *Journal of The Korean Association For Science Education*, *41*(4), 325-338. https://doi.org/10.14697/jkase.2021.41.4.325.
Clark, K. R. (2018). Learning theories: constructivism. *Radiologic Technology*, *90*(2), 180-182. https://doi.org/10.2962/00338397.90.2.180.
Clarke, V., Braun, V., & Hayfield, N. (2015). Thematic analysis. *Qualitative psychology: A practical guide to research methods*, *222*(2015), 248. https://0-doi.org.wam.seals.ac.za/10.1080/17439760.2016.1262613.
Cloke, P., (2006). Conceptualizing rurality. *Handbook of rural studies*, *18*, pp.18-28. https://orca.cardiff.ac.uk/id/eprint/2366.
Cohen, L., Manion, L., & Morrison, K. (2018). Research methods in education (eight edition). *Abingdon, Oxon*, 532-533. https://doi.org/10.4324/9781315456539.
Conger, S., Krauss, K., & Simuja, C. (2015). Human factors issues in developing country remote K-12 education. *Procedia Manufacturing*, *3*, 1566-1573.
Conger, S., Krauss, K., & Simuja, C. (2016). Issues in using Internet in remote South African high schools. In *2016 11th Iberian Conference on Information Systems and Technologies (CISTI)* (pp. 1-6). IEEE.
Conole, G. (2009). The role of mediating artefacts in learning design. In *Handbook of research on learning design and learning objects: issues, applications, and technologies,* 188-208. IGI global. https://doi.org/10.4018/978-1-59904-861-1.ch009.
Constantinou, C.P., Tsivitanidou, O.E., & Rybska, E., (2018). What is inquiry-based science teaching and learning?. In *Professional development for inquiry-based science teaching and learning*, 1-23. Springer, Cham. https://doi.org/10.1007/978-3-319-91406-0_1.
Contant, T.L., Tweed, A.L., Bass, J.E., & Carin, A.A., (2018). *Teaching science through inquiry-based instruction*. New York, NY: Pearson. https://doi.org/10.1002/9781119568153.
Cox, S., & Graham, C.R. (2009). Using an elaborated model of the TPACK framework to analyze and depict teacher knowledge. *TechTrends*, *53*(5), 60-69. https://0-doi.org.wam.seals.ac.za/10.1007/s11528-009-0327-1.
Creighton, T.B., (2018). Digital Natives, Digital Immigrants, Digital Learners: An International Empirical Integrative Review of the Literature. *Education Leadership Review*, *19*(1), 132-140. https://doi.org/10.2304/elr.2018.19.1.132.
Dabbagh, N., & Castaneda, L., (2020). The PLE as a framework for developing agency in lifelong learning. *Educational Technology Research and Development*, *68*(6), 3041-3055. https://0-doi.org.wam.seals.ac.za/10.1007/s11423-020-09831-z.
Dalati, S., & Marx Gómez, J. (2018). Surveys and questionnaires. In *Modernizing the Academic Teaching and Research Environment* 175-186. Springer, Cham. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-319-74173-4_10.

Dar, W.A. (2021). Pedagogy for its own sake: teacher's beliefs about activity-based learning in rural government schools of Kashmir. *Quality Assurance in Education*. *29*(2), 311-327. https://0-doi.org.wam.seals.ac.za/10.1108/QAE-01-2021-0013.

Darmawansah, D., Hwang, G. J., Chen, M. R. A., & Liang, J. C. (2023). Trends and research foci of robotics-based STEM education: a systematic review from diverse angles based on the technology-based learning model. *International Journal of STEM Education*, *10*(1), 1-24. https://doi.org/10.1186/s40594-023-00400-3.

Davie, G., & Wyatt, D. (2021). Document analysis. In *The Routledge handbook of research methods in the study of religion* 245-255. Routledge. https://doi.org/10.4324/9780203154281.ch2_4.

Denzin, N.K., & Lincoln, Y. (2021). The SAGE Handbook for Research in Education: Pursuing Ideas as the Keystone of Exemplary Inquiry, 2nd edn. Thousand Oaks, CA: Sage. *Research Methods and Methodologies in Education*, 20. https://us.sagepub.com/en-us/nam/the-sage-handbook-for-research-in-education/book234443.

Dewey, J. and Bentley, A., (1949). Knowing and the Known. The later works 1949-1952, 16. https://books.google.com/books/about/Knowing_and_the_Known.html?id=u6hs208TpWwC.

Djelil, F., & Sanchez, E. (2023). Game design and didactic transposition of knowledge. The case of progo, a game dedicated to learning object-oriented programming. *Education and Information Technologies*, *28*(1), 283-302. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-022-11158-6.

Dnyaneshvar, S. Shrinivas M., & Nandkishor, M.K., (2020). Role of ICT in Quality Enhancement of Teaching at Higher Educational Institutions. ISSN: 2394-3114Vol-40, Special Issue-05. NAAC sponsored two days National Conference on New Accreditation Process and Quality Enhancement for rural colleges.

Dong, Y., Chai, C.S., Sang, G.Y., Koh, J.H.L., & Tsai, C.C., (2015). Exploring the profiles and interplays of pre-service and in-service teachers' technological pedagogical content knowledge (TPACK) in China. *Journal of Educational Technology & Society*, *18*(1), 158-169. https://doi.org/10.1080/03055698.2020.1814698.

Doukakis, S., Psaltidou, A., Stavraki, A., Adamopoulos, N., Tsiotakis, P., & Stergou, S., (2021). Measuring the technological pedagogical content knowledge (TPACK) of in-service teachers of computer science who teach algorithms and programming in upper secondary education. *arXiv preprint arXiv:2105.09252*. https://doi.org/10.48550/arXiv.2105.09252.

Du Plessis, P., & Mestry, R., (2019). Teachers for rural schools–a challenge for South Africa. *South African Journal of Education*, *39*. https://0-doi.org.wam.seals.ac.za/10.15700/saje.v39ns1a1774.

Durdu, L., & Dag, F., (2017). Pre-service teachers' TPACK development and conceptions through a TPACK-based course. *Australian Journal of Teacher Education (Online)*, *42*(11), 150-171. https://search.informit.org/doi/10.3316/informit.245910712701186.

Dursun, O.O., (2019). Pre-service information technology teachers' self-efficacy, self-esteem and attitudes towards teaching: A four-year longitudinal study. *Contemporary Educational Technology*, *10*(2), 137-155. https://doi.org/10.30935/cet.554478.

Ertmer, P.A., (1999). Addressing first-and second-order barriers to change: Strategies for technology integration. *Educational technology research and development*, *47*(4), .47-61. https://0-doi.org.wam.seals.ac.za/10.1007/BF02299597.

Evens, M., Tielemans, K., Elen, J. & Depaepe, F., (2019). Pedagogical content knowledge of French as a foreign language: differences between pre-service and in-service teachers. *Educational Studies*, *45*(4), 422-439. https://0-doi.org.wam.seals.ac.za/10.1080/03055698.2018.1446339.

Falloon, G., (2020). From digital literacy to digital competence: the teacher digital competency (TDC) framework. *Educational Technology Research and Development*, *68*(5), 2449-2472. https://0-doi.org.wam.seals.ac.za/10.1007/s11423-020-09767-4.

Farjon, D., Smits, A. & Voogt, J., (2019). Technology integration of pre-service teachers explained by attitudes and beliefs, competency, access, and experience. *Computers & Education*, *130*, 81-93. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2018.11.010.

Finucane, N. (2021). *Factors influencing the provision of science learning experiences in early childhood education in Ireland: a case study of teachers' perceptions and practices* (Doctoral dissertation, University of Sheffield).

Firdaus, N. M., & Robandi, B. (2022). EFFECTIVENESS OF USING INTERNET TECHNOLOGY IN FINDING KNOWLEDGE AND SKILLS FOR PKBM LEARNING CITIZENS. *Journal Of Educational Experts (JEE)*, *4*(2), 46-50. https://doi.org/10.30740/jee.v4i2p46-50.

Flick, U. (2022). *An introduction to qualitative research*. 1-100. Sage. http://digital.casalini.it/9781529783544.

Fullan, M. G., & Hargreaves, A. (1991). *What's worth fighting for? Working together for your school*. The Regional Laboratory for Educational Improvement of the Northeast & Islands, 300 Brickstone Square, Suite 900, Andover, MA 01810

Galindo, J. N. (2023). Technological Pedagogical and Content Knowledge (TPACK) Assessment of Basic Education Teachers in St. Paul University Surigao. *3*(6), 368-378. https://doi.org/10.47760/cognizance.2023.v03i06.023.

Gao, J., Pham, Q. H. P., & Polio, C. (2022). The role of theory in quantitative and qualitative second language learning research: A corpus-based analysis. *Research Methods in Applied Linguistics*, *1*(2), 100006. https://0-doi.org.wam.seals.ac.za/10.1016/j.rmal.2022.100006.

GARDIN, J. C. (1973). Document analysis and linguistic theory. *Journal of documentation*, *29*(2), 137-168.

Gentles, C.H. & Haynes-Brown, T., (2021). Latin American and Caribbean teachers' transition to online teaching during the pandemic: Challenges, Changes and Lessons Learned. *Píxel-Bit. Revista de Medios y Educación*, *61*, 131-163. https://doi.org/10.12795/pixelbit.88054.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In *Examining pedagogical content knowledge: The construct and its implications for science education*, *6* 3-17. Dordrecht: Springer Netherlands. https://0-doi.org.wam.seals.ac.za/10.1007/0-306-47217-1_1.

Gibbs, G. R. (2014). Using software in qualitative analysis. *The SAGE handbook of qualitative data analysis*, 277-294. SAGE.

Glăveanu, V.P., Ness, I.J., Wasson, B., & Lubart, T. (2019). Sociocultural perspectives on creativity, learning, and technology. In *Creativity under duress in education?* 63-82. Springer, Cham. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-319-90272-2_4.

Goldberg, A. E., & Allen, K. R. (2015). Communicating qualitative research: Some practical guideposts for scholars. *Journal of Marriage and Family*, *77*(1), 3-22. https://0-doi.org.wam.seals.ac.za/10.1111/jomf.12153.

Grant, C., & Osanloo, A. (2014). Understanding, selecting, and integrating a theoretical framework in dissertation research: Creating the blueprint for your "house". *Administrative issues journal*, *4*(2), 4. https://doi.org/10.5929/2014.4.2.9.

Gray, M.L., Johnson, C.R. & Gilley, B.J. eds., 2016. *Queering the countryside: New frontiers in rural queer studies* (Vol. 11). NYU Press. https://0-muse.jhu.edu.wam.seals.ac.za/pub/193/monograph/book/76201 ER.

Greenberg, I., Kumar, D. & Xu, D., 2012, February. Creative coding and visual portfolios for CS1. In *Proceedings of the 43rd ACM technical symposium on Computer Science Education,* 247-252. https://0-doi.org.wam.seals.ac.za/10.1145/2157136.2157214.

Guillemin, M., Barnard, E., Allen, A., Stewart, P., Walker, H., Rosenthal, D., & Gillam, L. (2018). Do research participants trust researchers or their institution?. *Journal of Empirical Research on Human Research Ethics*, *13*(3), 285-294. https://0-doi.org.wam.seals.ac.za/10.1177/1556264618763253.

Haddaway, N.R., Woodcock, P., Macura, B. & Collins, A., 2015. Making literature reviews more reliable through application of lessons from systematic reviews. *Conservation Biology*, *29*(6), 1596-1605. http://onlinelibrary.wiley.com/wol1/doi/10.1111/cobi.12541/fullpdf.

Hamilton, A. B. & Finley, E. P. (2020). Qualitative methods in implementation research: an introduction. *Psychiatry research*, *280*: 112-516. https://0-doi.org.wam.seals.ac.za/10.1016/j.psychres.2019.112516.

Hanshaw, J., Talbert, S., & Smith, J., 2022. Technology Integration in the Post-Pandemic Secondary Classroom. In *Preparing Faculty for Technology Dependency in the Post-COVID-19 Era*, 195-211. IGI Global. https://doi.org/10.4018/978-1-7998-9235-9.ch011.

Hanson, A., & Danyluk, P. (2022). Talking circles as indigenous pedagogy in online learning. *Teaching and Teacher Education*, *115*, 103715. https://0-doi.org.wam.seals.ac.za/10.1016/j.tate.2022.103715.

Harris, J., & Wildman, A. (Eds.). (2020, April 7). TPACK newsletter issue #43: April 2020. TPACK Newsletters Archive. https://activitytypes.wm.edu/TPACKNewsletters/TPACKNewsletterIssue43.pdf.

Harris, J.B., (2016). In-service teachers' TPACK development: Trends, models, and trajectories. In *Handbook of technological pedagogical content knowledge (TPACK) for teachers*, 201-216. Routledge. https://doi.org/10.4324/9781315771328.ch12.

Harrison, H., Birks, M., Franklin, R., & Mills, J. (2017), January. Case study research: Foundations and methodological orientations. In *Forum qualitative Sozialforschung/Forum: qualitative social research*, *18*(1), 1-17. https://doi.org/10.17169/fqs-18.1.2655.

Headley, M. G., Plano Clark, V. L., Stitzlein, S. M., Brown, R. D., & Swoboda, C. M. (2023). Symbolic Mathematics Language Literacy: A Framework and Evidence from a Mixed Methods Analysis. In *Mathematical Teaching and Learning: Perspectives on Mathematical Minds in the Elementary and Middle School Years*, 185-206. Cham: Springer International Publishing. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-031-31848-1_11.

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-based nursing*, *18*(3), 66-67. https://doi.org/10.1136/eb-2015-102129.

Hendren, K., Newcomer, K., Pandey, S. K., Smith, M., & Sumner, N. (2023). How qualitative research methods can be leveraged to strengthen mixed methods research in public policy and public administration?. *Public Administration Review*, *83*(3), 468-485. https://0-doi.org.wam.seals.ac.za/10.1111/puar.13528.

Herron, M. D. (1971). The nature of scientific enquiry. *The school review*, *79*(2):171-212. https://doi.org/10.1086/442968.

Hill, J.E. & Uribe-Florez, L., (2020). Understanding Secondary School Teachers' TPACK and Technology Implementation in Mathematics Classrooms. *International Journal of Technology in Education*, *3*(1), 1-13. https://dx.doi.org/10.46328/ijte.v3i1.8.
Hirose, M., & Creswell, J. W. (2023). Applying core quality criteria of mixed methods research to an empirical study. *Journal of Mixed Methods Research*, *17*(1), 12-28. https://0-doi.org.wam.seals.ac.za/10.1177/15586898221086346.
Hlalele, D. & Mosia, M., (2020). Teachers' sense of community in rural learning ecologies. *Alternation*, *27*(2), 101-124. https://doi.org/10.29086/2519-5476/2020/v27n2a6.
Hlalele, D., (2014). Rural education in South Africa: Concepts and practices. *Mediterranean journal of social sciences*, *5*(4), 462-462. https://doi.org/10.5901/mjss.2014.v5n4p462.
Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, 36(15): 2534-2553. https://0-doi.org.wam.seals.ac.za/10.1080/09500693.2014.899722.
Hofstein, A. & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science education*, 88(1): 28-54. https://0-doi.org.wam.seals.ac.za/10.1002/sce.10106.
Holbrook, J. & Rannikmae, M., (2007). The nature of science education for enhancing scientific literacy. *International Journal of science education*, *29*(11), 1347-1362. https://0-doi.org.wam.seals.ac.za/10.1080/09500690601007549.
Holbrook, J., Chowdhury, T.B.M. & Rannikmäe, M., (2022). A Future Trend for Science Education: A Constructivism-Humanism Approach to Trans-Contextualisation. *Education Sciences*, *12*(6), 413. https://doi.org/10.3390/educsci12060413.
Holmes, A. G. D. (2020). Researcher Positionality--A Consideration of Its Influence and Place in Qualitative Research--A New Researcher Guide. *Shanlax International Journal of Education*, *8*(4), 1-10. https://doi.org/10.34293/education.v8i4.3232.
Holmes, W., Bialik, M., & Fadel, C. (2023). Artificial intelligence in education. Globethics Publications. 621-653. https://doi.org/10.58863/20.500.12424/4276068. https://0-doi.org.wam.seals.ac.za/10.3758/s13428-023-02114-4.
Hunt, S. C., & Young, N. L. (2021). Blending Indigenous Sharing Circle and Western Focus Group Methodologies for the Study of Indigenous Children's Health: A Systematic Review. *International Journal of Qualitative Methods*, *20*, 16094069211015112. https://0-doi.org.wam.seals.ac.za/10.1177/16094069211015112.
Ibrohim, I., Purwaningsih, E., Munzil, M., Hidayanto, E., Sudrajat, A. K., Saefi, M., & bin Hassan, Z. (2022). Possible links between Indonesian science teacher's TPACK perception and demographic factors: Self-reported survey. *EURASIA Journal of Mathematics, Science and Technology Education*, *18*(9), em2146. https://doi.org/10.29333/ejmste/12282.
Impedovo, M. A., Andreucci, C., & Ginestié, J. (2017). Mediation of Artefacts, Tools and Technical Objects: an international and French perspective. *International Journal of Technology and Design Education*, *27*(1), 19-30. https://0-doi.org.wam.seals.ac.za/10.1007/s10798-015-9335-y.
Iphofen, R. & Tolich, M. (eds.). (2018). *The SAGE handbook of qualitative research ethics*. Sage.
Irwanto, I., (2021). Research Trends in Technological Pedagogical Content Knowledge (TPACK): A Systematic Literature Review from 2010 to 2021. *European Journal of Educational Research*, *10*(4), 2045-2054. https://doi.org/10.12973/eu-jer.10.4.2045.

Jadhav, J.M & Takale S, N., (2020). Multidimensional use of ICT in Higher Education. ISSN: 2394-3114Vol-40, Special Issue-05. NAAC sponsored two days National Conference on New Accreditation Process and Quality Enhancement for rural colleges.

Jakachira, G., (2020). *The prospects and complexities of quality education in satellite primary schools of Makonde District, Zimbabwe* (Doctoral dissertation).

James, W. (1890). The principles of psychology (Vol. 1). New York, NY: Holt.

Jang, S.J. & Tsai, M.F., (2013). Exploring the TPACK of Taiwanese secondary school science teachers using a new contextualized TPACK model. *Australasian Journal of Educational Technology*, *29*(4). https://doi.org/10.14742/ajet.282.

Jang, S.J., (2010). Integrating the interactive whiteboard and peer coaching to develop the TPACK of secondary science teachers. *Computers & Education*, *55*(4), 1744-1751. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2010.07.020.

Jaradat, S.M., (2020). Assessing the Effects of Virtual Lab Simulations on Learners' Achievements in Secondary School Physics in Jordan. (Doctoral thesis, Middle East Technical University).

Jen, T.H., Yeh, Y.F., Hsu, Y.S., Wu, H.K. & Chen, K.M., (2016). Science teachers' TPACK-Practical: Standard-setting using an evidence-based approach. *Computers & Education*, *95*, 45-62. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2015.12.009.

Jiang, H., Chugh, R., Turnbull, D., Wang, X., & Chen, S. (2023). Modeling the impact of intrinsic coding interest on STEM career interest: evidence from senior high school learners in two large Chinese cities. *Education and Information Technologies*, *28*(3), 2639-2659. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-022-11277-0.

Jita, T. (2016). Pre-service teachers' competence to teach science through information and communication technologies in South Africa. *Perspectives in Education*, *34*(3), 15-28. http://dx.doi.org/10.18820/2519593X/pie.v34i3.2.

Johnson, J. L., Adkins, D., & Chauvin, S. (2020). A review of the quality indicators of rigor in qualitative research. *American journal of pharmaceutical education*, *84*(1). https://doi.org/10.5688/ajpe7120.

Kafyulilo, A., Fisser, P. & Voogt, J., (2016). Factors affecting teachers' continuation of technology use in teaching. *Education and Information Technologies*, *21*(6), 1535-1554. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-015-9398-0.

Kapici, H. O., & Akcay, H. (2023). Improving learner teachers' TPACK self-efficacy through lesson planning practice in the virtual platform. *Educational Studies*, *49*(1), 76-98. https://0-doi.org.wam.seals.ac.za/10.1080/03055698.2020.1835610.

Karchmer-Klein, R., & Konishi, H. (2023). A mixed-methods study of novice teachers' technology integration: Do they leverage their TPACK knowledge once entering the profession?. *Journal of Research on Technology in Education*, *55*(3), 490-506. https://0-doi.org.wam.seals.ac.za/10.1080/15391523.2021.1976328.

Karppinen, K., & Moe, H. (2012). What we talk about when we talk about document analysis. *Trends in communication policy research: New theories, methods and subjects*, 177-193.

Kartal, B. & Çınar, C., (2022). Preservice mathematics teachers' TPACK development when they are teaching polygons with geogebra. *International Journal of Mathematical Education in Science and Technology*, 1-33. https://0-doi.org.wam.seals.ac.za/10.1080/0020739X.2022.2052197.

Kartal, T. & Dilek, I., (2021). Preservice Science teachers' TPACK development in a technology-enhanced Science teaching method course. *Journal of Education in Science Environment and Health*, *7*(4), 339-353. https://doi.org/10.21891/jeseh.994458.

KAZMI, Z., & MOHAMMAD, A. (2023). Use of Information and Communication Technologies in Teaching of Science: A Perception and Practices of Science Teachers. *TOJET: The Turkish Online Journal of Educational Technology*, *22*(1). https://doi.org/10.29329/tojet.2023.221.226.

Khashan, D.S.R., (2019). *How Teachers Integrate and Implement Educational Technology in Mississippi Delta High Schools: Qualitative Case Study* (Doctoral dissertation, University of Phoenix).

Khoza, S.B. & Biyela, A.T., (2020). Decolonising technological pedagogical content knowledge of first year mathematics learners. *Education and Information Technologies*, *25*(4), 2665-2679. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-019-10084-4.

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in science education*, *45*(2), 169-204. https://0-doi.org.wam.seals.ac.za/10.1080/03057260903142285.

Koehler, M & Mishra, P., (2009). What is technological pedagogical content knowledge TPACK? *Contemporary Issues in Technology and Teacher Education*, 91: 60-70. https://doi.org/10.1177/0963297X0900900106.

Koehler, M. J., & Mishra, P. (2014). Introducing tpck. In *Handbook of technological pedagogical content knowledge (TPCK) for teachers*, 13-40. Routledge. https://doi.org/10.4324/9781315759630.

Koehler, M. J., & Mishra, P., (2006) What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research, 322*, 131–152. https://0-doi.org.wam.seals.ac.za/10.2190/0EW7-01WB-BKHL-QDYV.

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)?. *Journal of education*, *193*(3), 13-19. https://0-doi.org.wam.seals.ac.za/10.1177/002205741319300303.

Koehler, M. J., Shin, T. S., & Mishra, P. (2012). How do we measure TPACK? Let me count the ways. In *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches*, 16-31. IGI Global. https://doi.org/10.4018/978-1-60960-750-0.ch002.

Koehler, M.J., & Mishra, P., (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of educational computing research*, *32*(2), 131-152. https://0-doi.org.wam.seals.ac.za/10.2190/0EW7-01WB-BKHL-QDYV.

Koehler, M.J., Mishra, P. & Yahya, K., (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology. *Computers & Education*, *49*(3), 740-762. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2005.11.012.

Koehler, MJ, Mishra, P, Akcaoglu, M & Rosenberg, JM., (2008). Technological pedagogical content knowledge for teachers and teacher teachers, in ICT integrated teacher education: a resource book, edited by N Bharati & S Mishra. New Delhi: Commonwealth Educational Media Center for Asia: 1-8.

Koh, J. H. L., & Sing, C. C. (2011). Modeling pre-service teachers' technological pedagogical content knowledge (TPACK) perceptions: The influence of demographic factors and TPACK constructs. In *ASCILITE-Australian Society for Computers in Learning in Tertiary Education Annual Conference*, 735-746. Australasian Society for Computers in Learning in Tertiary Education.

Kohen, Z. & Kramarski, B., (2012). Developing a TPCK-SRL assessment scheme for conceptually advancing technology in education. *Studies in Educational*

Evaluation, *38*(1), 1-8. https://0-doi.org.wam.seals.ac.za/10.1016/j.stueduc.2012.03.001.
Kohler, M. J., & Mishra, P. (2006). What happens when teachers design educational technology? The development of Technological Pedagogical Content Knowledge. *J. Educational Computing Review*, 32 (2), 131-152. https://0-doi.org.wam.seals.ac.za/10.1016/j.stueduc.2012.03.001.
Kokela, S. J., & Malatji, K. S. (2023). *An Evaluation of the Capacity of South African Schools to offer Multi-grade Teaching: A Case Study of Schools in the Sekhukhune South District*. https://doi.org/10.4102/emr.v22i1.2533
Kolb, A. & Kolb, D., (2018). Eight important things to know about the experiential learning cycle. *Australian educational leader*, *40*(3), 8-14. https://search.informit.org/doi/10.3316/informit.192540196827567.
Kriek, J. & Stols, G., (2010). Teachers' beliefs and their intention to use interactive simulations in their classrooms. *South African Journal of Education*, *30*(3). https://0-doi.org.wam.seals.ac.za/10.15700/saje.v30n3a284.
Krosnick, J. A. (1999). Survey research. *Annual review of psychology*, *50*(1), 537-567. https://doi.org/10.1146/annurev.psych.50.1.537.
Kwak, S. K., & Kim, J. H. (2017). Statistical data preparation: management of missing values and outliers. *Korean journal of anesthesiology*, *70*(4), 407-411. https://doi.org/10.4097/kjae.2017.70.4.407.
Kyngäs, H., Kääriäinen, M. & Elo, S. (2020). The trustworthiness of content analysis. In *The application of content analysis in nursing science research* , 41-48. Cham: Springer, https://0-doi.org.wam.seals.ac.za/10.1007/978-3-030-30199-6_5.
Kyriazos, T., & Poga, M. (2023). Dealing with Multicollinearity in Factor Analysis: The Problem, Detections, and Solutions. *Open Journal of Statistics*, *13*(3), 404-424. https://doi.org/10.4236/ojs.2023.133020.
Larijani, M. & Abedi, M. (2021). A Sociological study of Science teachers' Views on the Applications of ICT and Prerequisites for Realizing it in Classrooms in Tehran. *Research Square*. https://doi.org/10.21203/rs.3.rs-217215/v1.
Lauer, T. (2022). A Qualitative Study on Teachers' Perceptions of Virtual Instruction During the COVID-19 Pandemic in a Midwest Public School District. https://doi.org/10.18783/Lindenwood.edu-001.0001.731.
Lavallée, L. F. (2009). Practical application of an Indigenous research framework and two qualitative Indigenous research methods: Sharing circles and Anishnaabe symbol-based reflection. *International journal of qualitative methods*, *8*(1), 21-40. https://0-doi.org.wam.seals.ac.za/10.1177/160940690900800103.
Leahy, S., & Mishra, P. (2023, March). TPACK and the Cambrian explosion of AI. In *Society for Information Technology & Teacher Education International Conference*, 2465-2469. *Association for the Advancement of Computing in Education (AACE).* https://www.learntechlib.org/primary/p/222145/.
Lemon, L. L., & Hayes, J. (2020). Enhancing trustworthiness of qualitative findings: Using Leximancer for qualitative data analysis triangulation. *The Qualitative Report*, *25*(3), 604-614. https://doi.org/10.46743/2160-3715/2020.4222.
Leonard, L., & Leonard, P. (2003). The continuing trouble with collaboration: Teachers talk. *Current issues in education*, *6*. https://doi.org/10.1177/109892440300600015.
Liao, Y., Deschamps, F., Loures, E.D.F.R. & Ramos, L.F.P., (2017). Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. *International journal of production research*, *55*(12), 3609-3629. https://0-doi.org.wam.seals.ac.za/10.1080/00207543.2017.1308576.

Little, S. & Derr, V., (2020). The influence of nature on a child's development: Connecting the outcomes of human attachment and place attachment. *Research handbook on childhoodnature: Assemblages of childhood and nature research*, 151-178. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-319-67286-1_10.

Long, T., Zhao, G., Li, X., Zhao, R., Xie, K., & Duan, Y. (2022). Exploring Chinese in-service primary teachers' Technological Pedagogical Content Knowledge (TPACK) for the use of thinking tools. *Asia Pacific Journal of Education*, *42*(2), 350-370. https://0-doi.org.wam.seals.ac.za/10.1080/02188791.2020.1812514.

Lortie, D. C. (1975). Schoolteacher: A sociological study. Chicago, IL: University of Chicago Press. https://doi.org/10.7208/chicago/9780226492972.001.0001.

Løvlie, A. S., Waagstein, A., & Hyldgård, P. (2023). "How Trustworthy Is This Research?" Designing a Tool to Help Readers Understand Evidence and Uncertainty in Science Journalism. *Digital Journalism*, *11*(3), 431-464. https://0-doi.org.wam.seals.ac.za/10.1080/21670811.2023.2193344.

Luo, W., Berson, I. R., Berson, M. J., & Park, S. (2023). An exploration of early childhood teachers' Technology, Pedagogy, and Content Knowledge (TPACK) in Mainland China. *Early Education and Development*, *34*(4), 963-978. https://0-doi.org.wam.seals.ac.za/10.1080/10409289.2022.2079887.

Lyublinskaya, I., & Kaplon-Schilis, A. (2022). Analysis of differences in the levels of TPACK: Unpacking performance indicators in the TPACK proficiency rubric. *Education Sciences*, *12*(2), 79. https://doi.org/10.3390/educsci12020079.

Magaldi, D., & Berler, M. (2020). Semi-structured interviews. *Encyclopedia of personality and individual differences*, 4825-4830. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-319-24612-3_857.

Major, C., & McDonald, E. (2021). Developing instructor TPACK: A research review and narrative synthesis. *Journal of Higher Education Policy and Leadership Studies*, *2*(2), 51-67. http://dx.doi.org/10.52547/johepal.2.2.51.

Maknun, J. (2023). Development of Critical Thinking Skills Through Science Learning. In *Integrated Education and Learning,* 129-141. Cham: Springer International Publishing. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-031-15963-3_8.

Malikova, S., (2019). Modern innovative methods in teaching complicated dimention works in the subject of" art of conducting". *Culture and arts of Central Asia*, *10*(1), 67-71. https://doi.org/10.32205/2218-4028.2019.10.1.67-71.

Malterud, K., Siersma, V.D., & Guassora, A.D. (2016). Sample size in qualitative interview studies: guided by information power. *Qualitative health research*, *26*(13), 1753-1760. https://0-doi.org.wam.seals.ac.za/10.1177/1049732315617444.

Margerum-Leys, J., & Marx, R. W. (2002). Teacher knowledge of educational technology: A case study of learner/mentor teacher pairs. *Journal of Educational Computing Research*, *26*(4), 427-462. https://0-doi.org.wam.seals.ac.za/10.2190/JXBR-2G0G-1E4T-7MaZikhaliM.

Mariam, C., & Levan, M. (2023, April). CHALLENGES AND BENEFITS OF INTEGRATING EDUCATIONAL TECHNOLOGIES INTO THE CLASSROOM. In *The 15th International scientific and practical conference "The main directions of the development of scientific research"(April 18–21, 2023) Helsinki, Finland. International Science Group. 2023. 405,* 240. https://doi.org/10.35545/15th-ISPS-2023-240.

Marietto, M.L. (2018). Participant and non-participant observation: Theoretical contextualization and guide suggestion for methods application. *Revista Ibero-Americana de Estratégia*, *17*(4), 5-18. https://doi.org/10.5585/riae.v17i4.2717.

Mason-Bish, H. (2019). The elite delusion: reflexivity, identity and positionality in qualitative research. *Qualitative Research*, *19*(3), 263-276. https://0-doi.org.wam.seals.ac.za/10.1177/1468794118770078.
Mbonambi, F. T., Ajani, O. A., & Gamede, B. T. (2023). Why Do Teaching and Learning Business Studies in South African Rural High Schools Face Challenges?. *International Journal of Social Science Research and Review*, *6*(6), 865-877. https://doi.org/10.47814/ijssrr.v6i6.1623.
McBeath, A., & Bager-Charleson, S. (2020). Introduction: Considering qualitative, quantitative and mixed methods research. *Enjoying Research in Counselling and Psychotherapy: Qualitative, Quantitative and Mixed Methods Research*, 1-12. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-030-55127-8_1.
McCrory, A., & Reiss, M. J. (2023). *The Place of Ethics in Science Education: Implications for Practice*. Bloomsbury Publishing. https://doi.org/10.5040/9781350255135.
MCCRORY, R., (2014). Science, technology, and teaching: The topic-specific challenges of TPCK in science. In *Handbook of Technological Pedagogical Content Knowledge (TPCK) for Teachers*, 203-216. Routledge. https://doi.org/10.4324/9781315759630-17.
McNaught, C., & Lam, P. (2010). Using Wordle as a supplementary research tool. *Qualitative Report*, *15*(3), 630-643. https://doi.org/10.46743/2160-3715/2010.1167.
Mensah, B., Poku, A. A., & Quashigah, A. Y. (2022). Technology integration into the teaching and learning of geography in senior high schools in Ghana: A TPACK assessment. *Social Education Research*, 80-90. https://doi.org/10.37256/ser.3120221218.
Merriam, S. B. & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation*. John Wiley & Sons. https://doi.org/10.4018/978-1-4666-7409-7.ch007.
Miles, M. B., Huberman, A. M., & Saldaña, J. (2018). *Qualitative data analysis: A methods sourcebook*. Sage publications. https://doi.org/10.4135/9781506353074.
Mohebi, L., (2022). Theoretical Models of Integration of Interactive Learning Technologies into Teaching: A Systematic Literature Review. *International Journal of Learning, Teaching and Educational Research*, *20*(12). https://doi.org/10.26803/ijlter.20.12.14.
Moloi, T., Matabane, M. E., Simuja, C., Seo, B. I., & Tarman, B. (2023). Constructing a Social Justice Curriculum Policy in the 21st Century. *Research in Educational Policy and Management*, *5*(3), i-iv.
Moosa, S., & Bhana, D. (2023). Men who teach Early Childhood Education: Mediating Masculinity, Authority and Sexuality. *Teaching and Teacher Education*, *122*, 103959. https://0-doi.org.wam.seals.ac.za/10.1016/j.tate.2022.103959.
Moseley, M. J. (2023). *Accessibility: the rural challenge*. Taylor & Francis. http://worldcat.org/issn/0416712304.
Mtsi, N. & Maphosa, C. (2016). Challenges encountered in the teaching and learning of the natural sciences in rural schools in South Africa. *Journal of Social Sciences*, 47(1): 58-67. https://0-doi.org.wam.seals.ac.za/10.1080/09718923.2016.11893544.
Muktiar, P. & Sharma, C.K., (2019). In search of a better future: Nepali rural out-migration from Assam. *Sociological Bulletin*, *68*(3), 307-324. https://0-doi.org.wam.seals.ac.za/10.1177/0038022919876407.
Munyanyo, J., & Simuja, C. (2024). Experiences of Rural Secondary School Teachers in the Integration of Technology during Emergency Remote Teaching during the COVID-19 Pandemic in Namibia: An Exploratory Study. *Africa Education Review*, 1-16.
Mutanga, P., Nezandonyi, J., & Bhukuvhani, C. (2018). Enhancing Engineering Education through Technological Pedagogical and Content Knowledge (TPACK): A Case

Study. *International Journal of Education and Development using Information and Communication Technology*, *14*(3), 38-49. https://www.proquest.com/scholarly-journals/enhancing-engineering-education-through/docview/2167266740/se-2.

Mutanho, C. (2021). Exploring indiginising the university's science curriculum through bottom-up decolonisation: Affordances and hindrances. (Doctoral dissertation, Rhodes University).

Nachtigal, P.M. & Director, P.N., (2019). *Rural education: In search of a better way*. Routledge. https://doi.org/10.4324/9780429305047.

Natow, R. S. (2020). The use of triangulation in qualitative studies employing elite interviews. *Qualitative research*, *20*(2), 160-173. https://0-doi.org.wam.seals.ac.za/10.1177/1468794119830077.

Ndlovu, M., & Meyer, D. (2023). Teachers' TPACK readiness to teach mathematics with technology: A case study of a private high school in South Africa. In *Information and Communications Technology in STEM Education*, 145-159. Routledge. https://doi.org/10.4324/9780367819111-11.

Nelson, M.J., Voithofer, R. & Cheng, S.L., (2019). Mediating factors that influence the technology integration practices of teacher teachers. *Computers & Education*, *128*, 330-344. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2018.09.023.

Nemes, G. & Tomay, K., (2022). Split realities–dilemmas for rural/gastro tourism in territorial development. *Regional Studies*, 1-10. https://0-doi.org.wam.seals.ac.za/10.1080/00343404.2022.2084059.

Nepembe, V., & Simuja, C. (2023). Instructors' perspectives of TPACK in a vocational training classroom in Namibia. *Journal of Vocational, Adult and Continuing Education and Training*, *6*(1), 90-107.

Ngcoza, K., & Southwood, S. (2015). Professional development networks: From transmission to co-construction. *Perspectives in education*, *33*(1), 1-11. https://0-hdl.handle.net.wam.seals.ac.za/10520/EJC168545.

NHASE, Z. (2019). *A thesis submitted in fulfillment of the requirements for the degree* (Doctoral dissertation, RHODES UNIVERSITY).

Ni, L., Bausch, G., & Benjamin, R. (2023). Computer science teacher professional development and professional learning communities: A review of the research literature. *Computer Science Education*, *33*(1), 29-60. https://0-doi.org.wam.seals.ac.za/10.1080/08993408.2021.1993666.

Nicolopoulou, A. (1993). Play, cognitive development, and the social world: Piaget, Vygotsky, and beyond. *Human development*, *36*(1), 1-23. https://doi.org/10.1159/000277285.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and teacher education*, *21*(5), 509-523. https://0-doi.org.wam.seals.ac.za/10.1016/j.tate.2005.03.006.

Niess, M. L. (2011). Investigating TPACK: Knowledge growth in teaching with technology. *Journal of educational computing research*, *44*(3), 299-317. https://0-doi.org.wam.seals.ac.za/10.2190/EC.44.3.c.

Niess, M.L., & Gillow-Wiles, H. (2017). Expanding teachers' technological pedagogical reasoning with a systems pedagogical approach. *Australasian Journal of Educational Technology*, *33*(3). https://doi.org/10.14742/ajet.3473.

Nomlomo, V. S. (2007). *Science teaching and learning through the medium of English and isiXhosa: A comparative study in two primary schools in the Western Cape* (Doctoral dissertation, University of the Western Cape).

Nouah, K., Nnaji, O., & Linusi, O. (2023). The problems of secondary and higher secondary education in the rural areas of Africa; Challenges & Learnings from

experience. *Journal of Positive School Psychology*, *7*(2), 23-36. https://doi.org/10.21037/jps.2023.07.02.03.
Nyirenda, I., & Simuja, C. (2023). The use of M-learning to foster the development of self-regulated learning in university students: A systematic review. *The Independent Journal of Teaching and Learning*, *18*(2), 78-92.
O'Connor, K. (2022). Constructivism, curriculum and the knowledge question: tensions and challenges for higher education. *Studies in Higher Education*, *47*(2), 412-422. https://0-doi.org.wam.seals.ac.za/10.1080/03075079.2020.1750585.
Obilor, E. I. (2023). Convenience and purposive sampling techniques: Are they the same. *International Journal of Innovative Social & Science Education Research*, *11*(1), 1-7. https://doi.org/10.33390/ijisser.11.1.1-7.
Ocak, C. & Baran, E., (2019). Observing the indicators of technological pedagogical content knowledge in science classrooms: Video-based research. *Journal of Research on Technology in Education*, *51*(1), 43-62. https://0-doi.org.wam.seals.ac.za/10.1080/15391523.2018.1550627.
Okojie, M.C., Olinzock, A.A. & Okojie-Boulder, T.C., (2006). The pedagogy of technology integration. *Journal of technology studies*, *32*(2), 66-71. https://doi.org/10.52337/pjer.v5i2.527.
Olayinka, T. A., Ngcoza, K., Simuja, C., & Shambare, B. (2023). Promoting pre-service teachers' TPACK development in an education science course. In *Information and Communications Technology in STEM Education*, 182-197. Routledge. https://doi.org/10.4324/9781003279310-11.
Oliver, P. (2010). *The learner's guide to research ethics*. McGraw-Hill Education (UK). https://doi.org/10.1007/978-0-333-70563-8.
Olivier, J. & Kruger, D. (2022). Science Education in South Africa. In: *Science Education in Countries Along the Belt & Road*, 185-203. Singapore: Springer. https://0-doi.org.wam.seals.ac.za/10.1007/978-981-16-6955-2_12.
Olofson, M. W., Swallow, M. J., & Neumann, M. D. (2016). TPACKing: A constructivist framing of TPACK to analyze teachers' construction of knowledge. *Computers & Education*, *95*, 188-201. https://0-doi.org.wam.seals.ac.za/10.1016/j.compedu.2015.12.010.
Olympiou, G. & Zacharia, Z.C., (2014). Blending physical and virtual manipulatives in physics laboratory experimentation. In *Topics and trends in current science education,* 419-433. Springer, Dordrecht. https://0-doi.org.wam.seals.ac.za/10.1007/978-94-007-7281-6_26.
Ong, Q. K. L., & Annamalai, N. (2023). Technological pedagogical content knowledge for twenty-first century learning skills: the game changer for teachers of industrial revolution 5.0. *Education and Information Technologies*, 1-42. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-023-11852-z.
Onyema, O. G., & Daniil, P. (2017). Educating the 21st century learners: are teachers using appropriate learning models for honing skills in the mobile age?. *Journal of Entrepreneurship Education*, *20*(2), 1-15. https://doi.org/10.1528/2651-20-2-109.
Opoku, M.P., Jiya, A.N., Kanyinji, R.C. & Nketsia, W., (2022). Retention and job satisfaction among rural primary school teachers in Malawi. *Rural Society*, 1-14. https://doi.org/10.1080/10371656.2022.2087293.
Oriji, A. & Torunarigha, Y.D., (2020). Digitized education: Examining the challenges of digital immigrant teachers in the face of net generation learners. *KIU Journal of Social Sciences*, *5*(4), 337-347. https://doi.org/10.36887/kiujss.2020.4.337.
Oser, R. & Fraser, B.J., (2015). Effectiveness of virtual laboratories in terms of learning environment, attitudes and achievement among high-school genetics

learners. *Curriculum and Teaching*, *30*(2), 65-80. https://0-doi.org.wam.seals.ac.za/10.7459/ct/30.2.05.
Pallant, J. (2020). *SPSS survival manual: A step by step guide to data analysis using IBM SPSS*. McGraw-hill education (UK). https://doi.org/10.4324/9781003117452.
Pandey, P., & Pandey, M.M. (2021). *Research methodology tools and techniques*. Bridge Center. https://doi.org/10.13140/RG.2.2.16333.90089.
Paradise, T., Schilling, M.R., Grohs, J. & Laney, J.L., (2022). Teacher Experiences in a Community-Based Rural Partnership: Recognizing Community Assets. *Journal of Pre-College Engineering Education Research (J-PEER)*, *12*(1), 3. https://doi.org/10.7771/2157-9288.1316.
Park, S. & Oliver, J.S., (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in science Education*, *38*(3), 261-284. https://0-doi.org.wam.seals.ac.za/10.1007/s11165-007-9049-6.
Park, S., Jang, J.Y., Chen, Y.C. & Jung, J., (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. *Research in Science Education*, *41*(2), pp.245-260.
Passarelli, A. M., & Kolb, D. A. (2023). Experiential Learning Theory. *Learner Learning Abroad: What Our Learners Are Learning, What They're Not, and What We Can Do About It*, 137-161. Stylus Publishing. http://doi.org/10.4324/9781003447184-8.
Pathak, V., Jena, B., & Kalra, S. (2013). Qualitative research. *Perspectives in clinical research*, *4*(3). https://doi.org/10.4103/2229-3485.115389.
Patton, C. M., & Broward, J. (2023). The Giants and Forerunners of Phenomenology: Husserl, Heidegger, and their Predecessors. *American Journal of Qualitative Research*, *7*(4), 79-94. https://doi.org/10.29333/ajqr/13600.
Patton, M.Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications. https://doi.org/10.4135/9781506351929.
Pedersen, H.D., (2018). Is out of sight out of mind? Place attachment among rural youth out-migrants. *Sociologia Ruralis*, *58*(3), 684-704. https://0-doi.org.wam.seals.ac.za/10.1111/soru.12214.
Pedró, F., (2009), September. New millennium learners in higher education: Evidence and policy implications. In *International Conference on 21st Century Competencies, Brussels: OECD/CERI*. https://doi.org/10.1787/218524892373.
Pesigan, I. J. A., & Cheung, S. F. (2023). Monte Carlo confidence intervals for the indirect effect with missing data. *Behavior Research Methods*, 1-19.
Phillips, M., Koehler, M., Rosenberg, J. & Zunica, B., (2017). Unpacking TPACK: reconsidering knowledge and context in teacher practice. In *Society for information technology & teacher education international conference,* 2422-2429. Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/d/177538.
Piaget, J. (1981). *Intelligence and affectivity: Their relationship during child development.(Trans & Ed TA Brown & CE Kaegi)*. Annual Reviews.
Piaget, J. (2003). Part I: Cognitive Development in Children--Piaget Development and Learning. *Journal of research in science teaching*, *40*. https://doi.org/10.1002/tea.3660020306.
Pierson, M. E. (2001). Technology integration practice as a function of pedagogical expertise. *Journal of research on computing in education*, *33*(4), 413-430.
Prensky, M., (2001). Fun, play and games: What makes games engaging. *Digital game-based learning*, *5*(1), 5-31. https://0-doi.org.wam.seals.ac.za/10.1080/08886504.2001.10782325.

Prosek, E.A., & Gibson, D.M. (2021). Promoting rigorous research by examining lived experiences: A review of four qualitative traditions. *Journal of Counseling & Development*, *99*(2), 167-177. https://0-doi.org.wam.seals.ac.za/10.1002/jcad.12364.

Purwati, O. (2022). In-service EFL Teachers' Sociocultural-based TPACK Beliefs and Practices: Voice of Teachers and Learners. *Computer Assisted Language Learning*, *23*(1), 278-293. https://doi.org/10.1080/09588023.2021.1992191.

Putri, S.A., Sulaeman, N.F. & Putra, P.D.A., (2022). Trend of Technological Pedagogical Content Knowledge (TPACK) for Pre-service Science Teacher: A Historical Review. *Jurnal Pendidikan Fisika*, *10*(2), 165-175. https://doi.org/10.26618/jpf.v8i2.3293.

Quintão, C., Andrade, P., & Almeida, F. (2020). How to Improve the Validity and Reliability of a Case Study Approach?. *Journal of Interdisciplinary Studies in Education*, *9*(2), 264-275. https://doi.org/10.32674/jise.v9i2.2026.

Quoc, N. L., & Van, L. H. (2023). Enhancement of EFL learners' lexical retention: The role of social constructivism. *Cogent Education*, *10*(1), 2223811. https://0-doi.org.wam.seals.ac.za/10.1080/2331186X.2023.2223811.

Rahman, M., (2019). 21st century skill' problem solving': Defining the concept. *Asian Journal of Interdisciplinary Research*, *2*(1), 64-74. https://doi.org/10.34256/ajir1917.

Ramnarain, U. & Hlatswayo, M. (2018). Teacher beliefs and attitudes about inquiry-based learning in a rural school district in South Africa. *South African Journal of Education*, 38(1). https://0-doi.org.wam.seals.ac.za/10.15700/saje.v38n1a1431.

Ramnarain, U. & Penn, M. (2021). An Investigation of South African Pre-service Teachers' Use of Simulations in Virtual Physical Sciences Learning: Process, Attitudes and Reflections. *Virtual and Augmented Reality, Simulation and Serious Games for Education*, 81-99. Singapore: Springer. https://0-doi.org.wam.seals.ac.za/10.1007/978-981-16-1361-6_7.

Ramnarain, U. (2020). Inquiry-based learning in South African schools. *School science practical work in Africa*,1-13. New York. Routledge. https://doi.org/10.4324/9780429299111-1.

Rapley, T. (2018). *Doing conversation, discourse and document analysis* (Vol. 7). 1-176. Sage. http://digital.casalini.it/9781526426178.

Raschka, S., Patterson, J., & Nolet, C. (2020). Machine learning in python: Main developments and technology trends in data science, machine learning, and artificial intelligence. *Information*, *11*(4), 193. https://doi.org/10.3390/info11040193.

Reyes, P.B., (2013). Implementation of a Proposed Model of a Constructivist Teaching-Learning Process–A Step Towards an Outcome Based Education in Chemistry Laboratory Instruction. *Asia Pacific Journal of Multidisciplinary Research| Vol*, *1*(1).

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences*, *4*(2), 155-169. https://0-doi.org.wam.seals.ac.za/10.1007/BF01405730.

Rob, M. & Rob, F., (2018). Dilemma between constructivism and constructionism: Leading to the development of a teaching-learning framework for learner engagement and learning. *Journal of International Education in Business*, *11*(2), 273-290. https://0-doi.org.wam.seals.ac.za/10.1108/JIEB-01-2018-0002.

Roberts, R. E. (2020). Qualitative Interview Questions: Guidance for Novice Researchers. *Qualitative Report*, *25*(9). https://doi.org/10.46743/2160-3715/2020.4640.

Rogers, E.M., (1995). Diffusion of Innovations: modifications of a model for telecommunications. In *Die diffusion von innovationen in der telekommunikation*, 25-38. Springer, Berlin, Heidelberg. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-642-79868-9_2.

Rojas-Sánchez, M. A., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2023). Systematic literature review and bibliometric analysis on virtual reality and education. *Education and Information Technologies*, *28*(1), 155-192. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-022-11167-5.
Rolfe, S. A. (2020). Direct observation. In *Doing early childhood research*, 224-239. Routledge. https://doi.org/10.4324/9780429431658-17.
Roopa, S., & Rani, M. S. (2012). Questionnaire designing for a survey. *Journal of Indian Orthodontic Society*, *46*(4_suppl1), 273-277. https://doi.org/10.5005/jp-journals-10021-1104.
Roulston, K., & Choi, M. (2018). Qualitative interviews. *The SAGE handbook of qualitative data collection*, 233-249. http://digital.casalini.it/9781526416063.
Rupavath, R., (2022). Impact of Poverty on Education and Adivasis in India. In *Politics of Education in India*, 89-109. Routledge India. https://doi.org/10.4324/9780429285523-10.
Ryan, G., (2018). Introduction to positivism, interpretivism and critical theory. *Nurse researcher*, *25*(4), 41-49. https://doi.org/10.7748/nr.2018.e1466.
Säljö, R. (2002). Learning as the use of tools: A sociocultural perspective on the human–technology link. In *Learning with computers*,158-175. Routledge. https://doi.org/10.7748/nr.2018.e1466.
Sandelowski, M. (2001). Real qualitative researchers do not count: The use of numbers in qualitative research. *Research in nursing & health*, *24*(3), 230-240. https://0-doi.org.wam.seals.ac.za/10.1002/nur.1025.
Sarıyalçınkaya, A. D., Karal, H., Altinay, F., & Altinay, Z., (2021). Reflections on Adaptive Learning Analytics: Adaptive Learning Analytics. In *Advancing the Power of Learning Analytics and Big Data in Education*, 61-84. IGI Global. https://doi.org/10.4018/978-1-7998-7103-3.ch003.
Sastria, E. (2023). Indonesian Pre-service and In-service Science Teachers' TPACK proficiency. *International Journal of Biology Education Towards Sustainable Development*, *3*(1), 1-15. https://doi.org/10.53889/ijbetsd.v3i1.143.
Scharp, K. M., & Sanders, M. L. (2019). What is a theme? Teaching thematic analysis in qualitative communication research methods. *Communication Teacher*, *33*(2), 117-121. https://0-doi.org.wam.seals.ac.za/10.1080/17404622.2018.1536794.
Schauble, L., Glaser, R., Duschl, R.A., Schulze, S. & John, J., (1995). Learners' understanding of the objectives and procedures of experimentation in the science classroom. *The journal of the Learning Sciences*, *4*(2), 131-166. https://0-doi.org.wam.seals.ac.za/10.1207/s15327809jls0402_1.
Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK) the development and validation of an assessment instrument for preservice teachers. *Journal of research on Technology in Education*, *42*(2), 123-149. https://0-doi.org.wam.seals.ac.za/10.1080/15391523.2009.10782544.
Schmidt-Crawford, D. A., Tai, S. J. D., Wang, W., & Jin, Y. (2016). Understanding teachers' TPACK through observation. *Handbook of technological pedagogical content knowledge (TPACK) for teachers*, *107*. https://doi.org/10.4324/9781315771328-9.
Schunk, D. H., & Zimmerman, B. J. (2023). Self-regulation in education: Retrospect and prospect. In *Self-regulation of learning and performance*, 305-314. Routledge. https://doi.org/10.4324/9780203876428-15.
Sepula, C., & Simuja, C. (2024). Pre-service Teachers' Pedagogical Awareness of Technology Integration in the Classroom. In *Global Perspectives on Teaching with Technology* (pp. 93-109). Routledge.

Setiawan, H., Phillipson, S. & Isnaeni, W., (2019). Current trends in TPACK research in science education: a systematic review of literature from 2011 to 2017. In *Journal of Physics: Conference Series (1317)*1, 012213. IOP Publishing. https://doi.org/10.1088/1742-6596/1317/1/012213.

Shah, S., (2022). Over-The-Top Streaming Services: Predicting Users' Behavior through Unified Theory of Acceptance and Use of Technology Model. *Available at SSRN 4027153*. https://doi.org/10.2139/ssrn.4027153.

Shambare, B. & Simuja, C., (2022). A Critical Review of Teaching With Virtual Lab: A Panacea to Challenges of Conducting Practical Experiments in Science Subjects Beyond the COVID-19 Pandemic in Rural Schools in South Africa. *Journal of Educational Technology Systems*, .00472395211058051. https://0-doi.org.wam.seals.ac.za/10.1177/00472395211058051.

Shambare, B., Simuja, C., & Olayinka, T. A. (2022). Educational technologies as pedagogical tools: Perspectives from teachers in rural marginalised secondary schools in South Africa. *International Journal of Information and Communication Technology Education (IJICTE)*, *18*(1), 1-15. https://doi.org/10.4018/IJICTE.307109

Shambare, B., Simuja, C., & Olayinka, T. A. (2022). The Pedagogical and Technological Experiences of Science Teachers in Using the Virtual Lab to Teach Science in Rural Secondary Schools in South Africa. *International Journal of Technology-Enhanced Education (IJTEE)*, *1*(1), 1-15. https://doi.org/10.4018/IJTEE.302641

Shambare, B., Simuja, C., & Olayinka, T. A. (2022). Understanding the enabling and constraining factors in using the virtual lab: Teaching Science in rural schools in South Africa. *International Journal of Information and Communication Technology Education (IJICTE)*, *18*(1), 1-15. https://doi.org/10.4018/IJICTE.307110

Shambare, B., Simuja, C., & Theodorio, A. O. (2022). Understanding rural secondary school teachers' perceptions and attitudes on the use of ICT for teaching and learning. *Journal of African Education*, *3*(1). https://hdl.handle.net/10520/ejc-aa_jae_v3_n1_a3

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for information*, *22*(2), 63-75. https://doi.org/10.3233/EFI-2004-22201.

Shreffler, J. & Huecker, M. R. 2022. *Exploratory data analysis: Frequencies, descriptive statistics, histograms, and boxplots*. StatPearls Publishing. https://doi.org/10.32491/NBK557570.

Shulman, L., (1987). Knowledge and teaching: Foundations of the new reform. *Harvard educational review*, *57*(1), 1-23. https://0-doi.org.wam.seals.ac.za/10.17763/haer.57.1.j463w79r56455411.

Shulman, L.S., (2013). Those who understand: Knowledge growth in teaching. *Educational researcher*, *15*(2), 4-14. https://0-doi.org.wam.seals.ac.za/10.3102/0013189X015002004.

Shulman, L.S., (2015). PCK: Its genesis and exodus. In *Re-examining pedagogical content knowledge in science education*, 13-23. Routledge. https://doi.org/10.4324/9781315735665.1.

Silberman, M.L. ed., (2007). *The handbook of experiential learning*. John Wiley & Sons. https://lccn.loc.gov/2006100391.

Silverman, D. (Ed.). (2020). *Qualitative research*. sage. https://doi.org/10.4135/9781526402264.

Simms, L. J., Zelazny, K., Williams, T. F., & Bernstein, L. (2019). Does the number of response options matter? Psychometric perspectives using personality questionnaire data. *Psychological assessment*, *31*(4), 557. https://psycnet.apa.org/doi/10.1037/pas0000648.

Simuja, C. (2017). New Pedagogical Approaches with Technologies. *International Journal of Technology and Human Interaction*, *13*(4).

Simuja, C. Exploration of Foundation Phase: Pre-service Teachers' Perspectives on Their Abilities to Integrate Technology in the Classroom. In *Global Perspectives on Teaching with Technology* (pp. 110-126). Routledge.

Simuja, C., & Shikesho, H. (2024). Investigating the Experiences of Mathematics Teacher Technology Integration in the Selected Rural Primary Schools in Namibia. *International Journal of Technology-Enhanced Education (IJTEE)*, *3*(1), 1-15.

Simuja, C., & Silvanus, S. (2023). Understanding Sources of TPACK Primary Science Teachers Draw on to Integrate Technology in Selected Rural Schools in Namibia. *Journal of African Education*, *4*(3), 123-138.

Slough, S., & Connell, M. (2006, March). Defining technogogy and its natural corollary, Technological Content Knowledge (TCK). In *Society for Information Technology & Teacher Education International Conference*, 1053-1059. Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/p/22191/.

Snyder, H., (2019). Literature review as a research methodology: An overview and guidelines. *Journal of business research*, *104*, 333-339. https://0-doi.org.wam.seals.ac.za/10.1016/j.jbusres.2019.07.039.

South, L., Saffo, D., Vitek, O., Dunne, C., & Borkin, M. A. (2022, June). Effective Use of Likert Scales in Visualization Evaluations: A Systematic Review. In *Computer Graphics Forum (41)*343-55. https://0-doi.org.wam.seals.ac.za/10.1111/cgf.14521.

Spangenberg, E.D., & De Freitas, G. (2019). Mathematics teachers' levels of technological pedagogical content knowledge and information and communication technology integration barriers. Pythagoras, 40(1), 1-13. https://0-hdl.handle.net.wam.seals.ac.za/10520/EJC-1c9688b738.

Speed, E. (2019). The Process of Psychological Assessment: A Critique of Non-Participatory Observations Within Educational Psychology Practice and the Process of Psychological Assessment. *Educational Psychology Research and Practice*, *5*(2), 1-8. https://doi.org/10.15123/uel.88739.

Squire, K., (2003). Video games in education. *Int. J. Intell. Games & Simulation*, *2*(1), 49-62. https://doi.org/10.1145/950566.950583.

Statistics South Africa. (2023). Census 2022 Population Count Results - 10 October 2023. Retrieved October 28, 2023, from https://www.statssa.gov.za/?p=16716.

Subero, D., Llopart, M., Siqués, C., & Esteban-Guitart, M. (2018). The mediation of teaching and learning processes through identity artefacts. A Vygotskian perspective. *Oxford Review of Education*, *44*(2), 156-170. https://0-doi.org.wam.seals.ac.za/10.1080/03054985.2017.1352501.

Suri, H. (2011). Purposeful sampling in qualitative research synthesis. *Qualitative research journal*, *11*(2), 63-75. https://doi.org/10.3316/QRJ1102063.

Tachine, A. R., Bird, E. Y., & Cabrera, N. L. (2016). Sharing circles: An Indigenous methodological approach for researching with groups of Indigenous peoples. *International Review of Qualitative Research*, *9*(3), 277-295. https://0-doi.org.wam.seals.ac.za/10.1525/irqr.2016.9.3.277.

Taherdoost, H. (2016). Validity and reliability of the research instrument; how to test the validation of a questionnaire/survey in a research. *How to test the validation of a questionnaire/survey in a research (August 10, 2016)*. https://econpapers.repec.org/scripts/redir.pf?u=https%3A%2F%2Fhal.science%2Fhal-02546799%2Fdocument;h=repec:hal:journl:hal-02546799.

Taherdoost, H. (2019). What is the best response scale for survey and questionnaire design; review of different lengths of rating scale/attitude scale/Likert scale. *Hamed Taherdoost*, *(8)*1, 1-10. https://ssrn.com/abstract=3588604.

Tanak, A., (2020). Designing TPACK-based course for preparing learner teachers to teach science with technological pedagogical content knowledge. *Kasetsart Journal of Social Sciences*, *41*(1), 53-59. https://so04.tci-thaijo.org/index.php/kjss/article/view/229145.

Thompson, J. (2022). A Guide to Abductive Thematic Analysis. *The Qualitative Report*, *27*(5): 1410-1421. https://doi.org/10.46743/2160-3715/2022.5340.

Tsakeni, M., Vandeyar, S. & Potgieter, M. (2019). Inquiry opportunities presented by practical work in school physical sciences. A South African case study. *Gender and Behaviour*, 17(3): 13722-13733. https://0-hdl.handle.net.wam.seals.ac.za/10520/EJC-1975177d59.

Tseng, J.J., Chai, C.S., Tan, L., & Park, M. (2020). A critical review of research on technological pedagogical and content knowledge (TPACK) in language teaching. *Computer Assisted Language Learning*, 1-24. https://0-doi.org.wam.seals.ac.za/10.1080/09588221.2020.1868531.

Tunjera, N., & Chigona, A. (2020). Teacher Teachers' appropriation of TPACK-SAMR models for 21st century pre-service teacher preparation. *International Journal of Information and Communication Technology Education (IJICTE)*, *16*(3), 126-140. https://doi.org/10.4018/IJICTE.2020070110.

Turner III, D. W., & Hagstrom-Schmidt, N. (2022). Qualitative interview design. *Howdy or Hello? Technical and Professional Communication*. 151-164, https://doi.org/10.4324/9781315778700-11.

Valente, J. A., & Blikstein, P. (2019). Maker education: Where is the knowledge construction?. *Constructivist Foundations*, *14*(3), 252-262. https://constructivist.info/14/3/252.

Valtonen, T., Sointu, E., Kukkonen, J., Mäkitalo, K., Hoang, N., Häkkinen, P., Järvelä, S., Näykki, P., Virtanen, A., Pöntinen, S. & Kostiainen, E., (2019). Examining pre-service teachers' Technological Pedagogical Content Knowledge as evolving knowledge domains: A longitudinal approach. *Journal of Computer Assisted Learning*, *35*(4), 491-502. https://0-doi.org.wam.seals.ac.za/10.1111/jcal.12353.

Van Driel, J.H., Verloop, N. & De Vos, W., (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *35*(6), 673-695. https://0-doi.org.wam.seals.ac.za/10.1002/tea.20078.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. *The Electronic Journal for Research in Science & Mathematics Education*. https://doi.or/10.12973/ejse.7615.

Vermette, L.A., & Hechter, R. (2014). Tech-savvy science education? Understanding teacher pedagogical practices for integrating technology in K-12 classrooms. *Journal of Computers in Mathematics and Science Teaching*, *33*(1), 27-47. https://doi.org/10.2966/jcst.2014.33.1.27.

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of curriculum studies*, *44*(3), 299-321. https://0-doi.org.wam.seals.ac.za/10.1080/00220272.2012.668938.

Vrontis, D., Christofi, M., Pereira, V., Tarba, S., Makrides, A. & Trichina, E., (2022). Artificial intelligence, robotics, advanced technologies and human resource management: a systematic review. *The International Journal of Human Resource Management*, *33*(6), 1237-1266. https://0-doi.org.wam.seals.ac.za/10.1080/09585192.2020.1871398.

Vygotsky, L. (1978). Interaction between learning and development. *Readings on the development of children*, *23*(3), 34-41. https://doi.org/10.4236/jmmce.2011.108054.
Wa-Mbaleka, S. (2020). The researcher as an instrument. In *Computer Supported Qualitative Research: New Trends on Qualitative Research (WCQR2019),* 33-41. Springer International Publishing. https://0-doi.org.wam.seals.ac.za/10.1007/978-3-030-31787-4.
Warr, M., & Mishra, P. (2023, March). Exploring Technological Contextual Knowing. In *Society for Information Technology & Teacher Education International Conference*, 2506-2509. Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/p/222232/.
Watkins, M., Noble, G., & Driscoll, C. (2015). Pedagogy: The unsaid of socio-cultural theory. In *Cultural pedagogies and human conduct*, 1-16. Routledge. http://handle.uws.edu.au:8081/1959.7/uws:32162.
Watson, S. A. (2023). *The Presence and Prevalence of Underqualified High School Science Teachers in Mississippi* (Doctoral dissertation, The University of Mississippi).
Whelan, B. (2016). *The Landscape of Ideas: Navigating the Intellectual Pathways of Literature*. Routledge. https://doi.org/10.4324/9781315555649.
Whipp, J.L., Eckman, E.W., & van den Kieboom, L. (2015). Using sociocultural theory to guide teacher use and integration of teaching technology in two professional development schools. *Journal of Computing in Teacher Education*, *22*(1), 37-43. https://0-doi.org.wam.seals.ac.za/10.1080/10402454.2005.10784534.
White, S. & Downey, J. eds., (2021). *Rural education across the world: Models of innovative practice and impact*. Springer Nature. https://doi.org/10.1007/978-981-33-6116-4.
Wilkinson, D., & Dokter, D. (2023). *The researcher's toolkit: the complete guide to practitioner research*. Taylor & Francis. https://lccn.loc.gov/00031055.
Winston, P.H., (1992). *Artificial intelligence*. Addison-Wesley Longman Publishing Co., Inc. https://dl.acm.org/doi/10.5555/129914.
Wong, R., (2020). When no one can go to school: does online learning meet learners' basic learning needs?. *Interactive learning environments*, 1-17. https://0-doi.org.wam.seals.ac.za/10.1080/10494820.2020.1789672.
Wood, L. M., Sebar, B., & Vecchio, N. (2020). Application of rigour and credibility in qualitative document analysis: Lessons learnt from a case study. *The qualitative report*, *25*(2), 456-470. https://doi.org/10.46743/2160-3715/2020.4240.
Xiao, Y. & Watson, M., (2019). Guidance on conducting a systematic literature review. *Journal of planning education and research*, *39*(1), 93-112. https://0-doi.org.wam.seals.ac.za/10.1177/0739456X17723971.
Yulisman, H., Widodo, A., Riandi, R. & Nurina, C.I.E., (2019). THE CONTRIBUTION OF CONTENT, PEDAGOGY, AND TECHNOLOGY ON THE FORMATION OF SCIENCE TEACHERS'TPACK ABILITY. *Edusains*, *11*(2), 173-185. http://doi.org/10.15408/es.v11i2.10700.
Zimmerman, B. J. (2023). Dimensions of academic self-regulation: A conceptual framework for education. In *Self-regulation of learning and performance*, 3-21. Routledge. https://doi.org/10.4324/9780203763353-1.
Zou, D., Huang, X., Kohnke, L., Chen, X., Cheng, G. & Xie, H., (2023). A bibliometric analysis of the trends and research topics of empirical research on TPACK. *Education and Information Technologies*, 1-25. https://0-doi.org.wam.seals.ac.za/10.1007/s10639-022-10991-z.

APPENDICES

APPENDIX A: LETTER TO THE EASTERN CAPE DEPARTMENT OF EDUCATION

RHODES UNIVERSITY
Where leaders learn

ACCESS LETTER REQUESTING PERMISSION TO CONDUCT RESEARCH

Rhodes University
Drosty Road,
Grahamstown,
6139

The Chairperson
Departmental Research Committee
Eastern Cape Department of Education
Private Bag X 0032
Bhisho
5605

20 October 2022

Dear Mr S. Mutangabende

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

My name is Brian Shambare. I am an employee (Subject advisor – Life Sciences) in the Eastern Cape Department of Education in the Joe Gqabi district. Firstly, thank you for granting me the permission to conduct a study in your schools for my Masters' degree and in compliance with your conditions, I am glad that I was able to provide your office with a copy of my Masters' thesis.

I am now a registered PhD scholar in the Department of Education at the Rhodes University. My supervisors are Dr Clement Simuja and Prof. K.M Ngcoza. As part of my PhD programme, I am required to conduct research on an aspect of interest to contribute to the knowledge and understanding of the issues under study.

The proposed topic of my research is: *Technological Pedagogical Content Knowledge: An examination of rural secondary school science teachers' integration of technology in Eastern Cape Province*. The objectives of the study are:

(a) To understand how rural secondary school Life Sciences teachers integrate technology in their teaching.
(b) To understand how rural secondary school Life Sciences teachers describe their pedagogical technological content knowledge
(c) To gain insights into the sources of pedagogical technological content knowledge rural Life Sciences teachers draw upon in their teaching.

Rhodes University, Research Office, Ethics
Ethics Coordinator: ethics-commitee@ru.ac.za
t: +27 (0) 46 603 7727 f: +27 (0) 86 616 7707
Room 220, Main Admin Building, Drostdy Road, Grahamstown, 6139

RHODES UNIVERSITY
Where leaders learn

I am hereby, once more, seeking your consent to conduct a research in your schools and teachers in the Joe Gqabi district. The purpose of the study is to understand the development of technological pedagogical content knowledge from the perspectives of secondary school Life Sciences teachers in rural schools.

To assist you in reaching a decision, I have attached to this letter:

(a) A copy of an ethical clearance certificate issued by the University
(b) A copy of an approval certificate of the research proposal
(c) A copy the research instruments which I intend using in my research
(d) A full research proposal as approved by the Rhodes University
(e) Completed ECDoE departmental application form
(f) 2 slides presentation for the Research Committee
(g) My Curriculum Vitae

Should you require any further information, please do not hesitate to contact me or my supervisor. Our contact details are as follows:

brian.shambare@ecdoe.gov.za
c.simuja@ru.ac.za
k.ngcoza@ru.ac.za

Upon completion of the study, as I did with my Masters' study, I undertake to provide you with a feedback

Your permission to conduct this study will be greatly appreciated.

Yours sincerely,

BRIAN SHAMBARE

Rhodes University, Research Office, Ethics
Ethics Coordinator: ethics-commitee@ru.ac.za
t: +27 (0) 46 603 7727 f: +27 (0) 86 616 7707
Room 220, Main Admin Building, Drostdy Road, Grahamstown, 6139

APPENDIX B: LETTER TO LIFE SCIENCES TEACHER. INVITATION TO RESPOND TO THE QUESTIONNAIRE

DEAR RESPONDENT,

I am a doctoral candidate currently working under the guidance of Dr. Clement Simuja and Prof. M. Ngcoza at the Department of Education, Rhodes University. I extend an invitation for your involvement in a research initiative titled *'Technological Pedagogical Content Knowledge (TPACK): An Examination of rural secondary school Life Sciences Teachers' Integration of Technology in Eastern Cape Province.'* The primary objective of this study is to gain insights into the progression of technological pedagogical content knowledge among science teachers in rural secondary schools.

Your valuable participation in this research is sought due to your unique position to contribute meaningful perspectives to the subject under investigation. To participate, you will be required to complete the survey questionnaire provided below. Additionally, you may be invited to engage in an interview, a sharing circle discussion, and a lesson observation. Rest assured that all information, including your identity and responses, will be handled with strict confidentiality and will not be associated with you or your school. The collected data will be securely stored, and the outcomes of this research will be utilized solely for academic purposes. Your involvement is entirely voluntary, and there will be no repercussions for choosing not to participate. It is important to emphasize that participation is entirely at your discretion, and you can withdraw at any point without justifying. However, once the questionnaire is submitted, withdrawal will not be possible. Your willingness to contribute to this study is highly appreciated. Thank you for dedicating your time and cooperation.

This research has received approval from the Rhodes University Ethical Standards Committee, the Rhodes University Education Department Higher Degrees Committee, and The Eastern Cape Department of Education. If you have any concerns during the research, please feel free to address them with the Rhodes University ethics committee, ethics-committee@ru.ac.za and Dr C. Simuja (Supervisor), c.simuja@ru.ac.za.

Warmest regards,
……………………
Brian Shambare

CONSENT: I AM AWARE THAT

- I willingly agree to participate in the specified research topic.
- I am open to being interviewed and am committed to allocating time for it.
- I retain the freedom to withdraw from the study at any point without facing negative consequences.
- I understand that the information I provide will be utilized solely for the research project.
- My identity in this study will be safeguarded in accordance with the code of ethics outlined by Rhodes University.
- Having duly considered the provided information, I voluntarily choose to participate in the research process and affirm that I have not been coerced into doing so.

DECLARATION
I__________________________________(full name and surname of participant) hereby confirm that I understand the contents of this letter and the nature of the research project. I consent to participate in the research project.

Participant's Signature: ______________________Date: ___________________
Researcher's Signature: ______________________Date: ___________________

APPENDIX C: LETTER TO LIFE SCIENCES TEACHER. INVITATION TO PARTICIPATE IN A SEMI-STRUCTURED INTERVIEW

DEAR LIFE SCIENCES TEACHER

I am a doctoral candidate under the supervision of Dr. Clement Simuja and Prof. M. Ngcoza at Rhodes University's Department of Education. I extend an invitation for your voluntary participation in a research study titled *'Technological Pedagogical Content Knowledge (TPACK): An Examination of rural secondary school Life Sciences Teachers' Integration of Technology in Eastern Cape Province.'* This study aims to gain insights into the development of technological pedagogical content knowledge from the perspectives of secondary school science teachers in rural settings.

Your valuable insights as a secondary school science teacher in a rural setting make you an ideal participant for this study. The interview, which will last no longer than 60 minutes, can be scheduled at a location and time convenient for you. Additionally, you will have the opportunity to validate the interview transcript and contribute to the data analysis, which will also require approximately 60 minutes of your time upon completion of the study.

Your involvement is deeply appreciated, and as a token of gratitude, I will formally acknowledge your participation through a thank-you letter. Furthermore, you will have the option to receive a copy of the final thesis for your records. Thank you for considering participation in this research.

This research has received approval from the Rhodes University Ethical Standards Committee, the Rhodes University Education Department Higher Degrees Committee, and The Eastern Cape Department of Education. If you have any concerns during the course of the research, please feel free to address them with the Rhodes University ethics committee, ethics-committee@ru.ac.za and Dr C. Simuja (Supervisor), c.simuja@ru.ac.za.

Warmest regards,
……………………
Brian Shambare

CONSENT: I AM AWARE THAT

- I willingly agree to participate in the specified research topic.
- I am open to being interviewed and am committed to allocating time for it.
- I retain the freedom to withdraw from the study at any point without facing negative consequences.
- I understand that the information I provide will be utilized solely for the research project.
- My identity in this study will be safeguarded in accordance with the code of ethics outlined by Rhodes University.
- Having duly considered the provided information, I voluntarily choose to participate in the research process and affirm that I have not been coerced into doing so.

DECLARATION
I_________________________________(full name and surname of participant) hereby confirm that I understand the contents of this letter and the nature of the research project. I consent to participate in the research project.

Participant's Signature: ____________________Date: __________________
Researcher's Signature: ____________________Date: __________________

APPENDIX D: LETTER TO LIFE SCIENCES TEACHER. INVITATION TO PARTICIPATE IN LESSON OBSERVATIONS AND SHARING CIRCLE DISCUSSIONS

DEAR LIFE SCIENCES TEACHER

I am a doctoral candidate under the supervision of Dr. Clement Simuja and Prof. M. Ngcoza at Rhodes University's Department of Education. I extend an invitation for your voluntary participation in a research study titled '*Technological Pedagogical Content Knowledge (TPACK): An Examination of rural secondary school Life Sciences Teachers' Integration of Technology in Eastern Cape Province.'* This study aims to gain insights into the development of technological pedagogical content knowledge from the perspectives of secondary school science teachers in rural settings.

Your participation in this research would be valuable due to your unique position to provide insights into the investigated topic. Involvement in this study is voluntary and specifically open to secondary school science teachers in rural schools. The lesson observations will be pre-scheduled at mutually convenient dates, and the sharing circle discussions will be limited to one hour, arranged at a location and time convenient for you. While I will take measures to ensure your information remains disconnected from your identity during the sharing circle, I cannot guarantee the same for other participants. I will, however, strongly encourage all participants to treat the shared information with confidentiality. To safeguard your privacy, you are advised not to disclose sensitive personal information during the sharing circle discussions. Your cooperation in this regard is appreciated.

This research has received approval from the Rhodes University Ethical Standards Committee, the Rhodes University Education Department Higher Degrees Committee, and The Eastern Cape Department of Education. If you have any concerns during the course of the research, please feel free to address them with the Rhodes University ethics committee, ethics-committee@ru.ac.za and Dr C. Simuja (Supervisor), c.simuja@ru.ac.za.

Warmest regards,
…………………
Brian Shambare

CONSENT: I AM AWARE THAT

- I willingly agree to participate in the specified research topic.
- I am open to being interviewed and am committed to allocating time for it.
- I retain the freedom to withdraw from the study at any point without facing negative consequences.
- I understand that the information I provide will be utilized solely for the research project.
- My identity in this study will be safeguarded in accordance with the code of ethics outlined by Rhodes University.
- Having duly considered the provided information, I voluntarily choose to participate in the research process and affirm that I have not been coerced into doing so.

DECLARATION
I___________________________________(full name and surname of participant) hereby confirm that I understand the contents of this letter and the nature of the research project. I consent to participate in the research project.

Participant's Signature: _____________________Date: __________________
Researcher's Signature: ______________________Date: __________________

APPENDIX E: LETTER TO PRINCIPAL

DEAR PRINCIPAL

CONSENT LETTER TO CONDUCT LESSON OBSERVATIONS

My name is Brian Shambare, and I am studying for a PhD at Rhodes University. As part of my PhD programme, I am required to research an aspect of interest to contribute to the knowledge and understanding of the issues under study. I hereby humbly request your consent for me to conduct lesson observations with the Life Sciences teacher in your school. This research is titled *Technological Pedagogical Content Knowledge (TPACK): An Examination of Rural Secondary School Life Sciences Teachers' Integration of Technology in Eastern Cape Province.* The study aims to understand technological pedagogical content knowledge development from the perspectives of secondary school Life Sciences teachers in rural schools. The study will involve myself conducting three lesson observations in the teacher's class during teaching. The lesson observations will be scheduled in advance. The teacher has consented to be observed (see attached teacher consent form).

The following institutions have approved this research: the Rhodes University Ethical Standards Committee, the Rhodes University Education Department Higher Degrees Committee, and The Eastern Cape Department of Education. During the research, any concerns may be directed to the Rhodes University ethics committee, ethics-committee@ru.ac.za and Dr C. Simuja (Supervisor), c.simuja@ru.ac.za.

SCHOOL PRINCIPAL'S CONSENT

- I acknowledge and comprehend the objectives of Brian Shambare's research study.
- I am aware that the Life Sciences teacher's participation in this study is voluntary, and all queries will be addressed satisfactorily.
- The Life Sciences teacher understands the option to withdraw from the study at any time without facing penalties and comprehends the extent of involvement.
- I am aware that strict confidentiality measures will be applied to all information, and data will be securely stored in password-protected facilities.
- Given these constraints, the research findings may be submitted for potential publication in national or international journals or presented at educational conferences.
- I understand that interviews will be tape-recorded, and participants have the right to request temporary or permanent cessation of recording. Participants will also receive a copy of the interview transcript for accuracy verification.
- With full understanding of the above terms, I grant permission for the study to be conducted with the teacher in this school.

DECLARATION BY SCHOOL PRINCIPAL

I____________________________ (full name and surname of Principal) hereby confirm that I give permission to the researcher to conduct the study with a teacher in our school.

Signature of Principal___________________Date________________

SCHOOL STAMP

APPENDIX F: TPACK SURVEY

SECTION A: BIOGRAPHICAL AND BACKGROUND INFORMATION

(Please check √ only one option for each statement below)

1. How do you currently describe your gender identity?

Female	
Male	
Other	
Prefer not to answer	

2. What is your age?

21 and below		41-50	
22-30		51-60	
31-40		61 and over	

3. I identify my ethnicity as

Black		Coloured	
Indian		Other	
White		Prefer not to answer	

4. What grade(s) do you teach? Please select all that apply.

10	
11	
12	

5. What is your current teaching experience?

0-4		16-20	
5-10		21-25	
11-15		26 or more years	

6. What is the highest level of education you have completed?

Bachelor’s Degree		Doctoral Degree (PhD, EdD)	
Post-Graduate Certificate		Other	
Master’s Degree			

7. Which degree(s)/Certificates(s) do you have? Please select all that apply.

Bachelor of Education		Master of Education	
Bachelor of Science		Master of Science	
Post-Graduate Certificate		Other	

SECTION B: TECHNOLOGY ACCESS AND USE
(Please check √ only one answer)

	<1hr	1hr	2-3hrs	4-6hrs	7+hrs
8. How many hours a day do you spend on a computer /laptop/tablet/cell-mobile phone for teaching purposes?					
9. How many hours a day do you spend on a computer /laptop/tablet/cell-mobile phone for personal purposes?					
10. How many hours a day do you use the Internet for study purposes? (e.g., Blackboard, Google Scholar, Educational sites, etc.)					
11. How many hours a day do you use the Internet for personal purposes? (Such as Facebook, online shopping; YouTube; WhatsApp; etc.)					

SECTION C: LIFE SCIENCES TEACHERS' UNDERSTANDING OF TPACK
(Please check √ only one answer)

WHICH ONE OF THESE DEFINITIONS/EXPLANATIONS BEST DESCRIBES YOUR UNDERSTANDING OF TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK)?	
12. TPACK is a framework to understand and describe the kinds of knowledge needed by a teacher for effective pedagogical practice in a technology-enhanced learning environment	
13. TPACK considers what teachers need to know to be able to integrate technology; focuses on three main components of teacher knowledge: technology, pedagogy, and content knowledge	
14. TPACK is a model to describe the knowledge requirements for teachers to integrate technology into teaching	
15. TPACK is a framework to describe the kinds of knowledge needed by a teacher to implement effective pedagogy in a technology-enhanced learning environment	
I do not know what TPACK is	

SECTION D: TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE TO INTEGRATE TECHNOLOGIES IN TEACHING
Please rate the extent to which you agree with each statement below.
(Please check √ only one answer)

1=Strongly Disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly Agree					
D1. TECHNOLOGY KNOWLEDGE (TK)					
16. I can learn to use educational technologies easily.	1	2	3	4	5
17. I keep up with important emerging technologies.	1	2	3	4	5
18. I frequently play around with technologies.	1	2	3	4	5
19. I know about a lot of different technologies.	1	2	3	4	5
20. I can teach with the use of different technologies.	1	2	3	4	5
21. I know which technologies would work best for my teaching.	1	2	3	4	5
D1.2 I HAVE THE TECHNICAL SKILLS I NEED TO USE THE FOLLOWING FOR TEACHING					
22. Data projector	1	2	3	4	5
23. Document viewer/document camera	1	2	3	4	5
24. Interactive White Board	1	2	3	4	5

25. Laptop/computer	1	2	3	4	5
26. Mobile phone/Cell phone/Smartphone/Tablet	1	2	3	4	5
27. Google suite (google docs/ forms / books, etc.)	1	2	3	4	5
28. Internet	1	2	3	4	5
29. Microsoft: documents; spreadsheets; presentations	1	2	3	4	5
30. Other	1	2	3	4	5
D2. CONTENT KNOWLEDGE (CK)	1	2	3	4	5
31. I possess sufficient content knowledge to teach the subject.	1	2	3	4	5
32. I can use a scientific way of thinking.	1	2	3	4	5
33. I have various strategies for developing my scientific understanding.	1	2	3	4	5
34. I am familiar with the subject content that is prescribed by CAPS.	1	2	3	4	5
35. I have various ways and strategies of developing my understanding of my subject	1	2	3	4	5
36. I have sufficient knowledge to answer most learners' questions.	1	2	3	4	5
D3. PEDAGOGICAL KNOWLEDGE (PK)					
37. I know how to assess learners' performance in the classroom, including knowledge of different cognitive levels, degrees of question difficulty and the concept of a 'reasonable learner'.	1	2	3	4	5
38. I can adapt my teaching depending on what learners understand or do not understand.	1	2	3	4	5
39. I can adapt my teaching style to different learners.	1	2	3	4	5
40. I know how to assess learning in multiple ways.	1	2	3	4	5
41. I can use a variety of teaching strategies in my science class.	1	2	3	4	5
42. I am familiar with common learners' understandings and misconceptions of science.	1	2	3	4	5
43. I know how to organise and maintain class management and control.	1	2	3	4	5
44. I am familiar with the prescribed textbooks and other learning resources used in most South African classrooms.	1	2	3	4	5
D4. PEDAGOGICAL CONTENT KNOWLEDGE (PCK)					
45. I know how to teach specific science concepts/topics using specific technologies.	1	2	3	4	5
46. I can select effective teaching approaches to guide learner thinking and learning in my subject.	1	2	3	4	5
D5 TECHNOLOGICAL PEDAGOGICAL KNOWLEDGE (TPK)					
47. I can plan a lesson that incorporates the use of technologies.	1	2	3	4	5
48. I can choose technologies that enhance the teaching approaches for a lesson.	1	2	3	4	5
49. I can choose technologies that enhance learners' understanding for a lesson.	1	2	3	4	5
50. I always think critically about how to use technologies in my class.	1	2	3	4	5
51. I can select technologies to use in my classroom that enhance what I teach, how I teach and what learners learn.	1	2	3	4	5
52. I can provide leadership in helping others to coordinate the use of content, technologies, and teaching approaches.	1	2	3	4	5
53. I can choose technologies that enhance the content for a lesson.	1	2	3	4	5
D6. TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK)					
54. I can adapt and use specific technologies to meet my different learners' learning capabilities.	1	2	3	4	5
55. I can teach concepts/topics that appropriately combine the content with technology and teaching approaches.	1	2	3	4	5
56. I can choose technologies that enhance the content for a lesson.	1	2	3	4	5

APPENDIX G: SEMI-STRUCTURED INTERVIEW PROTOCOL

Greetings, my name is Brian Shambare. I am very pleased that you have agreed to join me today. We are here to talk about a range of issues concerning the development of your technological pedagogical content knowledge. The discussion we will have is called a semi-structured interview, wherein I will ask you some questions and be able to follow up on the responses you give. Please answer each of the following questions and, where possible, include relevant examples. Also, please note that there are no "right" or "wrong" answers to the following questions. I am only interested in your opinion on a number of issues about technological pedagogical content knowledge.

INFORMED CONSENT FORM: INTERVIEW WITH AUDIO RECORDINGS
I will conduct all the interviews with field note records and audio recordings. The interviews will be conducted without audio if you do not wish to be audio recorded. If you do not wish certain parts of the interview to be audio recorded, the audio can be switched off for these parts. The interview field notes will be written up for the research without identifying the speakers. Part of the interview audio recording will be transcribed into written form without identifying the speakers. The field notes and audio recordings will be erased when the research dissertation has been completed, not later than six months after completion.

Please tick the following boxes to indicate whether you have read the information and understand how you will be invited to participate in the research interviews:

- ☐ I understand that participation in the interviews is voluntary and that I am free to withdraw my consent at any time until the completion of the interviews.
- ☐ I understand that all the information gathered in the interviews will be kept strictly confidential and that my name and school name will not be included in any reports.
- ☐ I understand that the interviews can be audio recorded, and I am free to withdraw my consent to be audio recorded.
- ☐ I understand that I may ask that the recorder be turned off at any point during the interview if there is something that I do not want to be recorded.

PLEASE TICK ONE OF THE FOLLOWING BOXES TO INDICATE WHETHER OR NOT YOU AGREE TO TAKE PART IN THE RESEARCH INTERVIEWS:

- ☐ I AGREE to take part in the research interviews
- ☐ I DO NOT AGREE to take part in the research interviews

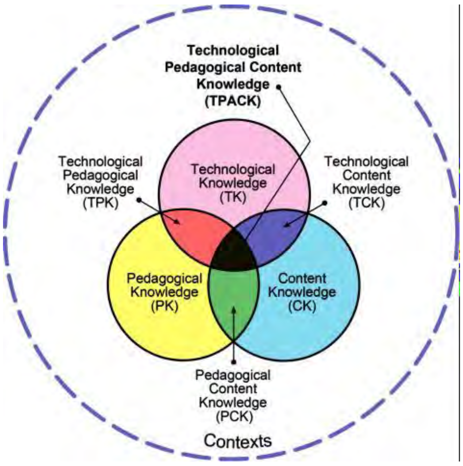
PLEASE TICK ONE OF THE FOLLOWING BOXES TO INDICATE WHETHER OR NOT YOU AGREE TO TAKE PART IN THE RESEARCH INTERVIEWS WITH AUDIO RECORDING:

- ☐ I AGREE to take part in the research interviews with audio recording
- ☐ I DO NOT AGREE to take part in the research interviews with audio recording

SIGNATURE: ______________________DATE:_____________________

SEMI-STRUCTURED INTERVIEW QUESTIONS

1. What were your first experiences teaching with technology?
    - Tell me about how you've used technology in your classes.
    - Tell me about assignments you've designed that require technology
2. How has your teaching with technology changed?
    - Tell me about things you've worked on during college workshops
3. Has teaching with technology gotten easier or more difficult?
    - What are some challenges you have experiences teaching with technology?
    - What are some challenges you anticipate experiencing in the future using technology for teaching?
4. How would you describe your technology integration in your teaching?
    - How would you describe your experiences learning to use technology for teaching?
5. Please answer the following questions based on the TPACK diagram below.



5.1 Please place an 'X' on the diagram to identify where you believe your current TPACK resides with respect to your understanding of technology, pedagogy, and content knowledge for your teaching.

5.2 How would you describe your own TPACK based on where you marked X above?

5.3 According to your knowledge which factors, practices, or experiences (sources) from where do you draw your TPACK in your teaching?

5.4 Have you had experiences teaching with technology that you would not repeat?

5.5 How has teaching with technology factored in your work outside of the classroom?

APPENDIX H: TPACK LESSON OBSERVATION SCHEDULE

PART 1: PRE-LESSON REVIEW (BACKGROUND INFORMATION)

1. Name of observer	
2. Name of teacher	
3. Name of school	
4. Name of Circuit	
5. Grade and class	
6. Subject being taught	
7. No. of learners in the class	
8. Observation Date	
9. Observation Time	

1. WHAT IS THE TEACHER'S LESSON OBJECTIVES IN THE LESSON?

(If possible, I will speak with the teacher before the observation begins and complete this section with the following information: What is the teacher planning to do? Are there particular outcomes the teacher is hoping for? Is there evidence of pedagogical intention to integrate technologies in the lesson plans? How does the teacher plan to integrate technology in the lesson?)

2. WHAT TECHNOLOGY RESOURCES ARE PRESENT IN THE CLASSROOM?

(Describe the technology resources present in the classroom and include the number of each)

PART 2: LESSON OBSERVATION GUIDE

In this section, I will take detailed notes in real time as he observes classroom activities. The following questions serve as guidelines for what I will document during the classroom observation. For each topic/question, I will note what he observes in the left-hand column; and in the right-hand column will be his ideas about what he thinks.

STRUCTURE AND CONTENT OF THE LESSON (CK)

I will describe the structure of the lesson that I will observe:

- What is happening in the classroom? What are the teacher and the learners doing?
- Does the teacher present some kind of introduction 'hook' (story or problem or information or brainstorm to engage the learners on the topic?
- Does the teacher provide appropriate information and clear instructions/guidelines for the class activities?
- Does the teacher have various ways and strategies of demonstrating his/her own science understanding of the content to be taught as prescribed by CAPS?
- Is the teacher able to answer most of the questions asked by the learners?

What you see	What you think works well/less well

USE OF TECHNOLOGY TO SUPPORT CONTENT PRESENTATION (TCK)

- What technologies were being used (links to websites use of the laptop by learners; use of the computer lab; use of mobile phones to conduct research, make presentations, spreadsheet, word or other).
- How is the technology being used?
- What did the teacher do with the technology?
- What did learners do with the technology?
- How does technology shape the way the lesson progresses?
- Is the teacher experiencing difficulties in their use of the technology/device? Are they able to troubleshoot?

What you see	What you think works well/less well

USE OF TECHNOLOGY & PEDAGOGICAL STRATEGIES (TPK)

- What levels of questioning does the teacher engage the learners with (remembering, understanding, analysing, applying, evaluating & creating type questions)? I will try to capture examples of the type of questions teachers ask learners and how learners respond, as well as the questions learners ask teachers and the teacher's responses.
- What specific technologies does the teacher combine with certain pedagogical strategies during lesson delivery?
- How does the technology support the teaching strategies?

What you see	What you think works well/less well

APPLICATION OF TECHNOLOGY, PEDAGOGY, AND CONTENT KNOWLEDGE (TPACK)

- How do the teachers' pedagogical strategies (project-based learning, questioning levels, group work organisation for collaborative learning) and choice of technology (presentation, web links, library books computer lab, textbooks, manila paper) fit together with the content topic?
- How are the teachers using the technology to interact with content in new ways?
- Does the technology give teachers the opportunity to improve on their technological pedagogical content knowledge?
- Do the technology activities allow learners to build or practice higher order thinking skills (i.e., problem solving, reasoning, synthesising information, creating content)?

What you see	What you think works well/less well

APPENDIX I: SHARING CIRCLE DISCUSSION SESSION GUIDE

SHARING CIRCLE QUESTION GUIDE

Greetings. My name is Brian Shambare. I am very pleased that you have agreed to join me today. We are here to discuss a range of issues concerning developing your technological pedagogical content knowledge. The discussion we are going to have is called a sharing circle discussion. Please allow me to take this opportunity to explain a little bit about sharing circle discussions. Sharing circle discussions are economic interviews used to gather information informally from a small group of individuals who have a common interest in a particular subject, in this instance, the development of technological pedagogical content knowledge in secondary school science teachers in rural schools. In sharing circles, there are no right or wrong answers. I encourage everyone in this room to participate in the discussion. I am pleased that you can be part of this group because I think you have important ideas regarding the development of technological pedagogical content knowledge. Do not hesitate to speak up when you have a point you would like to make. I will be moderating the session and moving us along so that we can evaluate all the key subjects on our agenda. My role today is to see that we have a productive discussion and to summarise the group's feelings. I will not refer to any participant by name in the reports that I will prepare. The information will be kept confidential and used only for research purposes. You are free to withdraw from the discussion or indicate whenever you feel uncomfortable. This session will be recorded; therefore, I kindly ask you to indicate by signing the consent forms if you agree.

INFORMED CONSENT FORM: SHARING CIRCLE WITH AUDIO RECORDINGS

I will conduct all the sharing circle discussions with field note records and audio recordings. If you do not wish to be audio recorded, the discussions will be conducted without audio. The discussion field notes will be written up for the research without identifying the speakers. Part of the discussion audio recording will be transcribed into written form without identifying the speakers. The field notes and audio recordings will be erased when the research dissertation has been completed, not later than six months after completion.

Please tick the following boxes to indicate whether you have read the information and understand how you will be invited to participate in the sharing circle:

- ☐ I understand that participation in the sharing circle is voluntary and that I am free to withdraw my consent at any time until the completion of the sharing circle.
- ☐ I understand that all the information gathered in the sharing circle will be kept strictly confidential and that my name and school name will not be included in any reports.
- ☐ I understand that the sharing circle can be audio recorded, and I am free to withdraw my consent to be audio recorded.
- ☐ I understand that I may ask that the recorder be turned off at any point during the sharing circle if there is something that I do not want recorded.

PLEASE TICK ONE OF THE FOLLOWING BOXES TO INDICATE WHETHER OR NOT YOU AGREE TO TAKING PART IN THE RESEARCH INTERVIEWS:

- ☐ I <u>AGREE</u> to taking part in the sharing circle.
- ☐ I <u>DO NOT AGREE</u> to taking part in the sharing circle.

PLEASE TICK ONE OF THE FOLLOWING BOXES TO INDICATE WHETHER OR NOT YOU AGREE TO TAKING PART IN THE SHARING CIRCLE WITH AUDIO RECORDING:

- ☐ I <u>AGREE</u> to taking part in the sharing circle with audio recording
- ☐ I <u>DO NOT AGREE</u> to taking part in the sharing circle with audio recording

SIGNATURE: ______________________ DATE: ____________________

SHARING CIRCLE QUESTIONS

1. Which educational technologies do you use in your teaching and for what purpose(s)? Please freely explain.
2. Explain how you socially interact with your colleagues as you integrate technology in your classroom. Do you think the interaction assisted in developing your technological, cognitive abilities? Please elaborate with an example.
3. In your view, in what ways do access to, and your interaction with various technology tools, created opportunities for you to develop technological pedagogical content?
4. Explain some of the technological challenges you encountered during your teaching. How did you overcome these?
5. In your view, does the use of technology open new opportunities in your teaching?
6. Based on your experiences of teaching with technology, what noticeable TPACK component (s) were you able to identify in your teaching? How? Why?
7. Based on your experience of integrating technology in your classroom, how would you describe your own TPACK and what contributed to its development?
8. Based on your overall experiences of technology integration, how important (or not) is it for secondary school science teachers in rural schools to develop TPACK?

APPENDIX J: RHODES UNIVERSITY ETHICS CLEARANCE

RHODES UNIVERSITY
Where leaders learn

Rhodes University, Education Faculty
Research Ethics Committee
PO Box 94, Makhanda, 6140, South Africa
Tel: +27 (0) 46 603 8393
Fax: +27 (0) 46 603 8028
email: e.rosenberg@ru.ac.za

https://www.ru.ac.za/researchgateway/ethics/

6 December 2022

Dr Clement Simuja

Education Department

C.Simuja@ru.ac.za

Dear Dr Clement Simuja and Mr Brian Shambare

Re: Technological Pedagogical Content Knowledge: An examination of rural secondary school Life Sciences teachers' integration of technology in Eastern Cape Province

APPLICATION NUMBER: 2022-5958-7224

This letter confirms that your research ethics application has been reviewed and **APPROVED** by the Education Faculty Research Ethics Committee (EF-REC). Your permission letter(s) where applicable have been received and you are free to proceed with your study.

Approval is granted for 1 year. An annual progress report is required in order to renew approval for an additional period. You will receive an email notifying you when the progress report is due.

Should any substantive change(s) be made during the research process, that may have ethical implications, you should notify the Education Faculty REC Chair via email. This includes changes in investigators. The REC Chair will advise as to whether a new application is necessary.

Do keep this clearance letter secure and accessible throughout your study and after its completion. It will be needed when a thesis is examined and when publications are submitted to journals.

Please also submit a brief report to the REC Chair on the completion of the research. This can be done via email. The purpose of this report is to indicate whether the research was conducted successfully and whether any ethics-related matters arose that the committee should be aware of, in order to guide future studies.

Sincerely,

ERosenberg

Prof Eureta Rosenberg

Chair: Education Faculty Research Ethics Committee

APPENDIX K: ECDoE PERMISSION TO CONDUCT RESEARCH

Province of the
EASTERN CAPE
EDUCATION

CORPORATE PLANNING, MONITORING, POLICY AND RESEARCH COORDINATION
Steve Vukile Tshwete Complex, Zone 6 Zwelitsha, 5608, Private Bag X0032, Bhisho, 5605 REPUBLIC OF SOUTH AFRICA:
Enquiries: **Ms. F. Pakade Tel: 040 608 7170/4001 . Fax :040 608 4372. Email:** fundiswa.pakade@ecdoe.gov.za
Website: www.ecdoe.gov.za **Date: 05 December 2022**

Mr. Brian Shambare

P O Box 92718

Mount Frere

4770

Dear Mr Shambare

PERMISSION TO UNDERTAKE A DOCTORATE RESEARCH: TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE: AN EXAMINATION OF RURAL SECONDARY SCHOOL LIFE SCIENCE TEACHERS' INTEGRATION OF TECHNOLOGY IN THE EASTERN CAPE PROVINCE.

1. Your application to conduct the above-mentioned research involving one hundred (100) participants from four selected secondary schools of the Joe Gqabi district under the jurisdiction of the Eastern Cape Department of Education (ECDoE) is hereby approved based on the following conditions:

   a. there will be no financial implications for the Department;

   b. institutions and respondents must not be identifiable in any way from the results of the investigation;

   c. you seek parent's consent for minors;

   d. it is not going to interrupt educators' time and task;

   e. the research may not be conducted during official contact time;

   f. the research may not be conducted during official contact time, provided that an arrangement to do research at the school including getting inside a classroom has been arranged and agreed upon in writing with the Principal and the affected teacher/s;

   g. you present a copy of the written approval letter of the Eastern Cape Department of Education (ECDoE) to the Cluster and District Directors before any research is undertaken at any institutions within that particular district;

   h. you will make all the arrangements concerning your research;

i. should you wish to extend the period of research after approval has been granted, an application to do this must be directed to Chief Director: Corporate Strategy Management;

j. you present the Department with a copy of your final paper/report/dissertation/thesis free of charge in hard copy and electronic format. This must be accompanied by a separate synopsis (maximum 2 – 3 typed pages) of the most important findings and recommendations if it does not already contain a synopsis;

k. you present the findings to the Research Committee and/or Senior Management of the Department when and/or where necessary;

l. you are requested to provide the above to the Chief Director: Corporate Strategy Management upon completion of your research;

m. you comply with all the requirements as completed in the Terms and Conditions to conduct Research in the ECDoE document duly completed by you;

n. you comply with your ethical undertaking (commitment form);

o. You submit on a six-monthly basis, from the date of permission of the research, concise reports to the Chief Director: Corporate Strategy Management.

2. The Department reserves a right to withdraw the permission should there be non-compliance to the approval letter and contract signed in the Terms and Conditions to conduct Research in the ECDoE and/or legal requirements to do so.

3. The Department will publish the completed Research on its website.

4. The Department wishes you well in your undertaking. You can contact the Mrs. Fundiswa Pakade on the numbers indicated in the letterhead or email fundiswa.pakade@ecdoe.gov.za should you need any assistance.

T. MASOEU
CHIEF DIRECTOR: CORPORATE STRATEGY MANAGEMENT

FOR SUPERINTENDENT-GENERAL: EDUCATION