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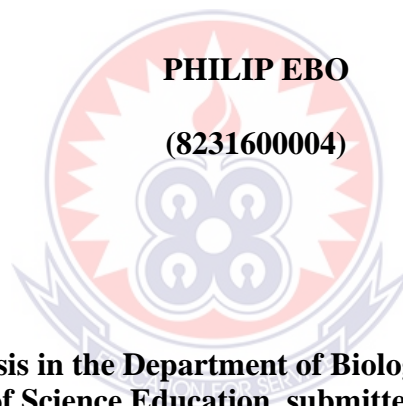
**Exploring biology teachers' technological pedagogical content knowledge in
Senior High Schools in selected Municipalities within the greater Accra Region**



MASTER OF PHILOSOPHY

UNIVERSITY OF EDUCATION, WINNEBA

**EXPLORING BIOLOGY TEACHERS' TECHNOLOGICAL PEDAGOGICAL
CONTENT KNOWLEDGE IN SENIOR HIGH SCHOOLS IN SELECTED
MUNICIPALITIES WITHIN THE GREATER ACCRA REGION**



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**A thesis in the Department of Biology Education,
Faculty of Science Education, submitted to the school of
Graduate Studies, in partial fulfilment
of the requirements for the award of the degree of
Master of Philosophy
(Biology Education)
in the University of Education, Winneba.**

JULY, 2025

DECLARATION

STUDENT'S DECLARATION

I, PHILIP EBO, declare that this dissertation, with the exception of quotations and references contained in published works, which have all been identified and duly acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:

DATE:

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work were supervised in accordance with the guidelines for supervision of the thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: DR. YEBOAH KWAKU OPOKU

SIGNATURE:

DATE:

DEDICATION

I dedicated this work to God Almighty, my parents, and the entire Ebo family.



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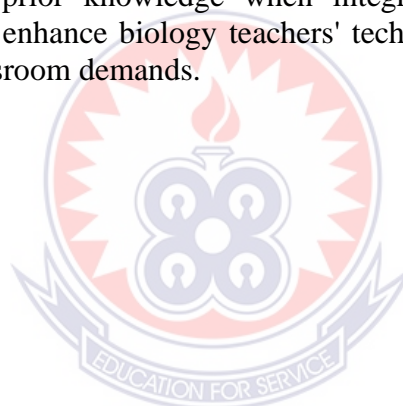
GLOSSARY

TPACK:	Technological Pedagogical Content Knowledge
CK:	Content Knowledge
PK:	Pedagogical Knowledge
TCK:	Technological Content Knowledge
PCK:	Pedagogical Content Knowledge
TK:	Technological Knowledge



ABSTRACT

This study explored the Technological Pedagogical Content Knowledge (TPACK) of senior high school biology teachers in selected municipalities in the Greater Accra Region of Ghana. Using an explanatory sequential mixed methods approach, quantitative data were collected from 73 biology teachers across 31 schools, followed by qualitative observations and interviews with a subset of teachers. A convenience sampling technique was used to select 73 biology teachers for the study. The study examined teachers' biology content knowledge, pedagogical knowledge, technological knowledge, access to ICT tools, and how professional status impacts TPACK. Key findings indicate that while most teachers had strong biology content knowledge, they lacked adequate knowledge of modern digital technology for teaching biology. Most schools did not have modern ICT tools available for biology instruction. Most teachers relied on self-training for ICT skills rather than formal training. Overall, biology teachers demonstrated low levels of TPACK, with no significant difference found between qualified and unqualified teachers. The results suggest that despite strong subject matter expertise, many biology teachers struggle to integrate technology into their pedagogy effectively. Recommendations include providing more ICT training opportunities for teachers, encouraging the use of available digital devices, and considering students' prior knowledge when integrating technology. This study highlights the need to enhance biology teachers' technological pedagogical skills to meet 21st-century classroom demands.



CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter presents an outline of this research. It deals with the background to the study, statement of the problem, purpose of the study, research objectives, research questions, significance of the study, limitations, and delimitations of the study.

1.1 Background to the Study

The field of education has undergone a significant transformation in recent years, driven by rapid advancements in technology. In particular, integrating technology into teaching practices has become increasingly important to enhance the quality of education and engage students effectively. As a crucial stage in the education system, senior high schools have not been exempted from this technological revolution. Teachers in senior high schools are expected to possess sound content knowledge and the ability to integrate technology seamlessly into their pedagogical practices. According to Education World (2023), many schools are staffed with teachers who use outdated lesson plans, teaching strategies, and instructional methodologies, despite the availability of more current, research-based practices. This observation highlights the need for teachers to adapt to modern educational approaches, especially in the field of science. Science, the cornerstone of national progress, is an approach to understanding nature, a corpus of knowledge, and a method of investigation (Abimbola, 2013).

Within this broad domain, biology focuses specifically on the vital functions of living things. This branch of science explores all aspects of life's physicochemical makeup, offering a comprehensive understanding of organisms and their interactions with their environment.

However, the learning of science is often considered to be challenging, complex, and complicated to understand. It has become commonplace for students to pass the exam by memorising algorithms only while failing to build an understanding of scientific concepts and schemes in science learning (Dhanapal & Wan, 2014). The learning objectives for science subjects, which emphasise the mastery of concepts like scientific process skills, thinking skills, problem-solving abilities, and the capacity for higher-order thinking, stand in stark contrast to this method. Through active participation in the learning process, scientific instruction should stimulate students' critical and creative thinking abilities. To accomplish this, the scientific instructor must carefully consider which pedagogical elements are pertinent to the science material being taught. Additionally, scientific instructors must employ instructional resources that enable students to develop a thorough comprehension of the material.

Using technology in science education effectively is one way to overcome these issues. Science education places a strong emphasis on the application of technology (Guzey & Roehrig, 2009). When implemented properly, technology can significantly improve the teaching and learning environment (Crawford, 2000; Dilworth & Hueting, 2012). Therefore, rather than merely replacing current teaching strategies, the idea of utilising technology in scientific classes should be founded on the idea of problem-solving (Ghavifekr, Rosdy, & Wan Athirah, 2015). In order to tackle teaching and learning issues in the classroom and to enhance the content of science classes, technology use is crucial.

Students' learning is greatly impacted by the instructional decisions made by science teachers. While some of these choices may have an impact on the usage of technology in the classroom, others relate to curriculum adjustment. The main factor influencing

instructional tactics and approaches is the Technological Pedagogical and Content Knowledge (TPACK) of teachers. Teachers can become competent, adaptable, dynamic, and flexible in their use of technology to educate when they have a thorough understanding of each TPACK component (Koehler & Mishra, 2009). Teachers frequently think of technological knowledge as separate from subject knowledge, according to numerous earlier studies (Mohamad, 2010; Pamuk, 2012; Carpenter et al., 2020). Due to this belief, there hasn't been much of an attempt to change teaching methods in order to make the best use of technology and improve the quality of instruction.

Through the TPACK framework, teachers possess content knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), which allows them to develop effective instructional practices for various learners (Graham et al., 2009). Developing TPACK is a strategy to address challenges teachers typically face when aligning current demands in learning with subject content delivery (Mohamad, 2021). By strengthening their TPACK, teachers can use technology in the teaching and learning process efficiently (Cheng & Xie, 2018). Experts in teacher education appear to agree that teacher quality improvement is more beneficial than other approaches (Shulman, 1986). This is true because a teacher without proper training may ruin even the best curriculum and teaching methods. A highly skilled teacher is more likely to produce good students than an incompetent teacher through the efficient use of appropriate teaching tactics and materials.

To provide effective education in the classroom, a teacher must articulate and integrate multiple domains of expertise. This knowledge includes not only instructional and content knowledge but also technological competence in the context of teaching. While

Pedagogical Content Knowledge (PCK) remains important, a more contemporary and comprehensive framework is the Technological Pedagogical Content Knowledge (TPACK) model, which integrates technology into the traditional domains of pedagogy and content.

TPACK, conceptualised by Mishra and Koehler (2006), extends Shulman's (1987) foundational idea of PCK by including technology as a third critical component. This model recognises that effective teaching with technology requires an understanding that goes beyond the isolated mastery of technology, pedagogy, or content. Instead, it is the intersection of these three domains, Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK), that forms the foundation of effective technology-enhanced teaching.

According to Asempa (2020), there is a pressing need to address the academic performance of Ghanaian secondary school students, particularly in biology, where current results indicate significant room for improvement. One of the teacher-related characteristics that has been linked to poor performance is a lack of proficiency in TPACK. This means that teachers may struggle not only with teaching content effectively or using pedagogical strategies but also with how to meaningfully integrate digital tools into instruction in a way that enhances student understanding.

TPACK emphasises that simply knowing how to use technology (Technological Knowledge) is not enough. For technology integration to be pedagogically meaningful and content-relevant, teachers must understand how to adapt their teaching methods (Pedagogical Knowledge) and subject content (Content Knowledge) using appropriate digital tools. For example, a biology teacher needs to know how to use simulation

software to teach photosynthesis in a way that aligns with student learning goals, enhances conceptual understanding, and fits into a broader pedagogical plan.

Studies have shown that teachers with strong TPACK are more capable of designing innovative instructional activities, adapting lessons to students' diverse needs, and enhancing engagement and conceptual learning (Niess, 2013). The integration of ICT in classrooms has introduced a paradigm shift, requiring educators not just to teach with chalk and talk but to incorporate digital platforms such as virtual labs, interactive apps, online assessments, and multimedia tools.

Moreover, the accessibility and ubiquity of open-source and user-friendly ICT tools have further increased the urgency for teachers to upgrade their technological competence (Technology, Information, and Communication & Sustainable Development Goals, 2017). While this accessibility is a positive development, it also demands that teachers have the critical skill set to evaluate, select, and implement these technologies in alignment with curricular goals and students' needs.

In contrast to PCK, which primarily focuses on the fusion of pedagogy and content, TPACK highlights the *dynamic interplay* among technology, pedagogy, and content. This triadic interaction is essential in today's classrooms, where digital literacy is increasingly viewed as a fundamental competency. Teachers must be able to redesign content delivery, facilitate learner-centred environments, and assess student learning using technological tools, skills that are at the heart of the TPACK framework.

Thus, while traditional PCK remains a significant foundation of teaching expertise, the realities of 21st-century education necessitate that teachers develop robust TPACK capabilities. As Kyriakidou, Chrisostomou, and Banks (1999) and Yapici and

Hevedanli (2012) note, the inclusion of ICT is no longer optional but imperative for ensuring quality education. It is only through the effective integration of technology with sound pedagogy and deep content knowledge that teachers can meet the evolving needs of today's learners.

The use of technology in science education has been recognised by prominent educational organisations. Understanding the nature of technology is one of the standards-based areas that science teachers should assist their students in achieving in their science learning, according to the American Association for the Advancement of Science's 2013 Benchmark for Science Literacy. Technology is viewed as the means and the ends of curriculum design since it is a tool for the advancement of civilisation. Using technology to introduce students to the newest technical tools and equip them to deal with problems with those tools can make science education less burdensome.

Instead of only using tools, technology integration in science education seeks to enhance learning. The way teachers use technology to improve their science instruction is crucial to students' learning, even though it may appear that employing technology to teach science will benefit both the development of science literacy and technical literacy. (American Scientific Progress Association, 2013).

Several methods exist for teachers to incorporate technology into their classroom teaching. The teaching characteristics of an idea, together with the chosen ICT tool, determine several possible methods for technology integration into classroom instruction.

Teachers regularly encourage their pupils to complete coursework on computers and technical projects, which has led to a significant increase in technology-based educational activities (American Association for the Advancement of Science, 2013).

Modern-day life becomes incomplete when digital ICT is missing from the 21st century. Computer applications transform every part of daily human life across all social levels. Educational learning methods have fundamentally transformed classroom teaching strategies between teachers and students through instructional technology applications. New technology has made deep transformations within the educational system. Schools that integrate current digital technology improve education methods and enable students to have an interactive learning experience, according to Karasavvidis and Kollias (2014). The educational experience will result in deeper student understanding. Our analysis comes back to the original objective of maximising student achievement, especially in biological subjects, through teaching methods that combine excellent pedagogical content knowledge and technological proficiency. According to Hicks (2006), who researched seasoned teachers, the usage of modern digital ICT in education improves student learning opportunities. Angeli and Valanides (2015) maintained that modern educational technology implementations in teaching produce enhanced student achievement. Teachers need to master four essential areas, according to their statements: choosing subjects for educational technology use and understanding effective instructional approaches, as well as tool selection and adapting technology into classroom instruction.

Even though more and more teachers are using contemporary digital technology in the classroom, they often only do so in conjunction with more conventional teaching and learning strategies. This low uptake is often due to a variety of challenges teachers face.

According to Richmond Public Schools (2018), some of the contributing factors include a lack of teaching experience, negative attitudes toward technology, a lack of funding, a lack of time to complete the task of teaching with technology, and increased demands on students to use technology in the classroom.

Richmond Public Schools (2018) also identified other obstacles that prevent teachers from integrating technology into their instruction. These include the absence of adequate assessments that accurately reflect students' learning from technology-supported curricula and conflicting pedagogical beliefs from outside sources. However, it's important to note that most of these issues could potentially be resolved if teachers were more receptive to integrating technology into their lessons and focused on developing innovative ways that technology could support their classroom instruction. Researchers have developed several frameworks to address these issues and enhance educators' ability to integrate technology into their lessons effectively. Niess (2005) first proposed the idea of "technology PCK," while Angeli and Valanides (2009) proposed "ICT-related PCK" to describe the knowledge that teachers must possess to integrate modern ICT into the teaching and learning process. Eventually, these ideas developed into what is today referred to as TPACK, or technological pedagogical content knowledge.

Three essential components make up the comprehensive framework known as TPACK: technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK). Technological Pedagogical Knowledge (TPK), Pedagogical Content Knowledge (PCK), and finally TPACK itself are the products of the interaction between these basic forms of knowledge. According to Angeli and Valanides (2009), TPACK is a well-

defined, complex, multidimensional, integrative, and transformative concept that is crucial to comprehending and enhancing technology integration in the classroom.

Building on this concept, Mishra and Koehler (2006) further defined TPACK as the body of knowledge that teachers acquire while using technology to teach. This idea was developed on top of Shulman's 1986 theory of PCK, deepening our understanding of how different types of information actively interact to benefit instructors in their practice.

Numerous studies have been conducted as a result of the creation of TPACK, offering a better understanding of the relationship between teachers' knowledge and the pedagogical integration of digital technologies in educational settings. For determining and comprehending teachers' knowledge of TPACK, this research has produced some knowledge enhancement procedures (Mishra, 2012), measuring tools (Cavanaugh & Koehler, 2013; Chai, Koh, & Tsai, 2016), and empirical methodologies (Koehler, Shin, & Mishra, 2012; Archambault, 2016).

Acknowledging the significance of successful technology integration, Graham et al. (2009) observed that educators increasingly concur that merely knowing the fundamentals of using technological tools is not enough; mastering these tools is essential to improving students' meaningful learning. An emphasis on examining the pedagogical content of technology, Teachers of biology have learned as a result of this insight.

Accordingly, TPACK has been developed as a framework for the knowledge that teachers require to successfully integrate technology (Mishra & Koehler, 2006;

American Association of Colleges of Teacher Education, 2008; Koehler & Mishra, 2008a; 2008b).

The importance of effective teaching is underscored by Gess-Newsome (2002), who pointed out that a rising body of evidence demonstrates that teachers' effectiveness has a greater impact on students' accomplishment than factors such as students' colour, class, prior academic performance, or the school they attend. Furthermore, Gess-Newsome emphasised that the benefits of learning from excellent teachers add up very quickly. To be effective, a teacher must possess a range of knowledge types, including Technological Knowledge (TK), Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Content Knowledge (TPACK).

Scholars have investigated the potential of TPACK to reduce achievement discrepancies. Since younger generations are more tech-savvy, Koh, Chai, and Tsai (2015) claim that integrating contemporary digital technology into the classroom could greatly close the achievement gap between male and female pupils. They noted that even if female teachers might not be as skilled in TK, they learn better pedagogical content and understanding, which helps to bridge the knowledge gap. On the other hand, Shaharom & Faridah (2010) discovered that although male teachers lacked pedagogical and topic competence, their familiarity with technology compensated for these deficiencies.

The role of teacher qualifications and experience in developing TPACK has also been examined. Alazam, Bakar, Hamzah, and Asmiran (2013) identified teacher qualification as a key factor in determining student learning. They underlined that even

after earning their teacher education degree, educators must continue to develop their professional knowledge and skills. They also stressed that teachers need to be inventive, creative, and qualified in a certain field.

Gronseth et al. (2010) addressed pre-service teacher preparation and pointed out that most teacher preparation programs require pre-service teachers to take a single technology-focused course; however, some programs incorporate technology into other education courses. The problem of information transfer and application to classrooms in the future, however, might not be adequately addressed by this strategy. The need for ongoing research and enhancement of teacher preparation programs to boost TPACK development is highlighted by evidence that pre-service teachers still do not feel adequately prepared to use technology in the classroom (Polly, McGee, & Martin, 2010).

1.2 Statement of the Problem

In the last decade, the Government of Ghana has championed the use of technology in education to improve educational outcomes. According to Tagoe, Addae, and Amuzu (2020), The Education Strategic Plan (2003-2015) and (2010-2020) of the Ghana Education Service identified the need for technology in education to help achieve the objectives of the Education Strategic Plan, which are carved into Access, Quality, Gender and Inclusiveness, and Education Management. This initiative aligns with the global trend of integrating technology into educational systems to enhance learning experiences and outcomes.

Building on this foundation, the government of Ghana developed the ICT for Accelerated Development (ICT4AD) Policy (2003), which explicitly outlined the plans and strategies in a framework of how technologies can be used to facilitate the national

goal of "transforming Ghana into an information and knowledge-driven ICT literate nation" (Government of Ghana 2008, p.10). This policy demonstrates Ghana's commitment to harnessing the power of technology for national development, with a specific focus on education.

The ICT4AD policy consists of 14 cardinal pillars, with promoting ICT in education as the 2nd pillar, emphasising "the deployment and exploitation of technologies in education". To further this goal, the Ministry of Education launched the ICT in Education Policy in 2008, addressing the technological needs in education more comprehensively. This policy serves as a roadmap for integrating technology into Ghana's educational system at various levels.

In a practical implementation of these policies, the Ministry of Education, through Rlg Communications (rLG), an ICT company in Ghana, introduced the "One Teacher One Laptop and ICT project" in 2012. This initiative aimed to train teachers in ICT and provide them with laptops to aid in research, teaching, and learning across various subject areas, including biology. Additionally, the Ghana Science Association (GAS) (2014) has called for technology integration within science to transform the teaching and learning of science, recognising the potential of technology to enhance science education.

Asempa (2020) pointed out that teachers continue to be reluctant to incorporate technology into the classroom, even after the Ministry of Education implemented these ICT policies and gave teachers laptops to encourage the use of technology in the teaching and learning process. Realising the potential advantages of technology in education and achieving the objectives stated by the Ministry are seriously hampered by this reluctance.

A crucial question is raised by this apparent discrepancy between the application of policies and real classroom practice: Why are Ghanaian educators failing to include technology in their lesson plans? In order to solve this issue and gain a better understanding of the situation, the goal of this study is to examine the technical, pedagogical and content knowledge of biology teachers in Senior High Schools in the municipalities of Adenta, Ga-East, Ga-West, and La-Nkwantang. The study intends to identify potential obstacles to technology integration and provide guidance for future strategies for more successful implementation of educational technology policies in Ghana by looking at teachers' TPACK in these particular areas.

1.3 Purpose of the Study

The objective of this study was to investigate the technological pedagogical content understanding of biology teachers in senior secondary schools in the selected locations.

1.4 Objectives of the Study

The study aimed to achieve the following goals:

1. Examine biology teachers' Content knowledge in teaching biology in SHS in selected municipalities.
2. Find out the technological knowledge (TK) of Biology teachers in the teaching of biology in SHS in the selected municipalities.
3. Find out the Pedagogical knowledge (PK) of Biology teachers in teaching biology in SHS in the selected municipalities.
4. Investigate the technological pedagogical content knowledge (TPACK) of Biology teachers in the teaching of biology in the selected municipalities.

1.5 Research Questions

The following research questions guided the Study;

1. What is the Content knowledge of biology teachers in teaching biology in SHS in selected municipalities?
2. What is the technological knowledge (TK) of Biology teachers in teaching biology in SHS in the selected municipalities?
3. What is the Pedagogical knowledge (PK) of Biology teachers in teaching biology in SHS in the selected municipalities?
4. What is the technological pedagogical content knowledge (TPACK) of Biology teachers in teaching biology in the selected municipalities?

1.6 Research hypothesis

Research question 4 will be answered using the null hypothesis below. The null hypothesis will be tested at a 0.05 alpha level.

H₀: Professional and non-professional biology instructors in the chosen localities do not differ significantly in their technological pedagogical content knowledge (TPACK).

H₁: Professional and non-professional biology instructors in the chosen towns differ significantly in their technological pedagogical content knowledge (TPACK).

1.7 Significance of the Study

The study explores the technological pedagogical content knowledge of biology in-service teachers in some selected municipalities. The data collected from this discourse will provide information on critical issues like challenges faced by biology teachers in teaching biology concepts and the most effective ways to teach biology. This will inform the selected municipalities' education directorates on areas to consider when organising in-service training (INSET) for biology teachers on the teaching of biology.

It will also inform the directorate's decisions on policies that inform the posting of teachers who teach biology at senior high schools.

This study also required participants to answer tasks that required them to critically read and reflect on the scenarios of different teaching methods of biology. The conscious reflections and the tasks performed by participants made them identify the strengths and weaknesses of the lessons in the scenarios. This exposure will help them identify the best practices that elicit learning and will inform their own decisions on the choice of strategies to employ to teach topics in biology.

Policymakers and education administrators in the four municipalities can use this data to make informed decisions regarding curriculum development, resource allocation, and teacher training programs.

A well-informed approach to education policymaking can lead to more effective and efficient use of available resources and contribute to the overall improvement of the education system.

The study's findings will encourage biology teachers in the selected communities to improve their TPACK in order to boost their instruction's effectiveness and efficiency. This would improve students' biology knowledge and ability to do well on final external exams, like the West Africa Senior Secondary School Certificate Exams given by WAEC, NOV/DEC, and others.

When deciding where to host workshops and seminars on teacher training and retraining, the District Education Directorates in the selected municipalities may find this study to be very helpful. This study could be very helpful to education ministries in identifying areas that require curriculum changes.

This will introduce pre-service and in-service teachers to the use of pedagogical content knowledge in instruction. It will also serve as a launching pad for education researchers who want to learn more about this topic or similar topics. This study will help educational consultants understand how to incorporate technology integration and instruction, rather than technology implementation, into their teacher-educational materials and training programs.

It is anticipated that the results of this study will persuade the administrators and owners of schools in the selected locations to give teachers and students access to necessary contemporary digital ICT resources. The study's findings will be helpful literature and inspire researchers studying biology education to look more closely at biology teachers' TPACK.

1.8 Limitations of the study

This research study, while valuable, presents several limitations that should be considered when interpreting its findings. The narrow focus on biology teachers in selected Municipalities at the senior high school level restricts the generalizability of results to broader educational contexts. By concentrating solely on specific technological tools in biology instruction, the study may overlook important aspects of general digital literacy and technology use in other subjects.

The complete complexity of factors impacting technological pedagogical content knowledge (TPACK) may not be captured by the few variables evaluated, which mostly focused on teachers' professional standing, training, and knowledge.

Additionally, the exclusion of student perspectives and potential methodological constraints, such as self-reporting bias or time limitations, could impact the

comprehensiveness of the findings. Future research could address these limitations by expanding the geographical scope, including a wider range of subjects and grade levels, and incorporating diverse methodologies to provide a more holistic understanding of TPACK in educational settings.

1.9 Delimitations of the study

This study focuses on a specific subset of teachers: biology teachers in senior high schools within selected Municipalities. By narrowing its scope, the research aims to provide an in-depth analysis of technological pedagogical content knowledge (TPACK) within this particular context. The decision to concentrate on biology instruction at the senior high school level allows for a targeted examination of TPACK in a specific subject area and educational stage, though it necessarily excludes insights from other grade levels and disciplines.

The geographical limitation to selected Municipalities, while enabling detailed local analysis, means that the study does not encompass broader regional or national perspectives. This localised approach may offer valuable insights into the unique challenges and opportunities within these specific communities, but it also limits the generalizability of findings to wider educational contexts. In terms of technological focus, the study concentrates on the utilisation of specific tools and platforms within biology instruction. This targeted approach allows for a nuanced understanding of how technology is integrated into biology teaching, but excludes the exploration of general digital literacy or technology use in other subjects. By doing so, the research provides a detailed picture of TPACK in biology education while acknowledging that it may not reflect the full spectrum of technological integration across the curriculum.

The primary variables under consideration, teachers' knowledge, training, and professional status, form the core of the investigation into TPACK among biology teachers. This focus on teacher-centric factors provides a foundation for understanding the current state of technological integration in biology education within the study area. However, it's important to note that this approach may not capture all the complex factors that influence TPACK and educational technology use.

By maintaining this focused scope, the study aims to contribute valuable, specific insights to the field of educational technology in biology teaching. While its narrow focus limits its breadth, it allows for a depth of analysis that can inform targeted interventions and further research in this specific area of education.

1.10 Operational Definitions

Technological Knowledge (TK): Biology teachers use a variety of technical platforms in their classes, ranging from low-tech ones like pencil and paper to high-tech ones like the internet, digital video, interactive whiteboards, and many more.

Content Knowledge (CK): The understanding a teacher has of the biological ideas they teach. It covers the data about a subject.

Pedagogical Knowledge (PK): Understanding how various technology tools can be used to teach biology and having faith that technology can change how teachers modify their methods.

Technological Content Knowledge (TCK): Is the understanding of how technology may produce novel learning scenarios and/or representations for particular biology topics.

Pedagogical Content Knowledge (PCK): The integration of pedagogy and content to create more effective teaching methods for biology subjects is known as pedagogical

content knowledge, or PCK.

Technological Pedagogical Content Knowledge (TPACK): The information that educators need to incorporate technology into their biology lessons is known as Curricular knowledge is the culmination of a methodical, planned interaction between students and instructional materials, systems for assessing the achievement of educational goals, and instructional content.

Professional Teacher: A person who is certified and has at least a bachelor's degree in education is considered a professional teacher.

Non-Professional Teacher: A person without a degree in education is known as a non-professional teacher.

Experienced Teacher: An experienced teacher has taught biology subjects for at least ten years and possesses the necessary skills and expertise.

1.11 Organisation of the Study

There are five chapters in the study. The study's introduction was covered in Chapter 1. The study's background, problem statement, purpose, research objectives, research questions, and related hypotheses were all included. It also examined the study's organisation, limitations, delimitations, and importance.

Chapter Two involved a review of available literature relevant to the study, while Chapter Three focused on the methodology, which constituted the research design, population, sampling and sample size, research instruments for data collection, and procedure used for data analysis. Chapter four dealt with results and a discussion of the findings. Chapter Five involved the summary, key findings, conclusions, and implications for practice, recommendations, and suggested areas for further studies.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.0 Overview

This chapter covers several topics, including the nature and components of technological pedagogical content knowledge, the study's framework, models of technological pedagogical content knowledge and teachers' instructional use of ICTs, empirical studies on measuring and evaluating technological pedagogical content knowledge, the relationship between teachers' qualifications and technological pedagogical content knowledge, empirical studies on teachers' experience and pedagogical content knowledge, and an evaluation of the reviewed literature.

2.1 The Nature and Components of Technological Pedagogical and Content Knowledge

Teachers' attitudes toward the use of ICT in the classroom have been a big issue for the stakeholders, even though ICT is becoming more prevalent in schools and children are growing up with it more and more (Jimoyiannis, 2010; Polly et al, 2010). The reason for this fear is that integrating ICT into teaching and learning is one of the hardest things for many teachers to do (Shafer & Vovk, 2008; So & Kim, 2009).

Teachers lack a strong theoretical foundation and feel unprepared for the subject-specific use of ICT, which is a problem (Brush & Saye, 2009; Kramarski & Michalsky, 2010). To tackle this problem, a framework known as technological pedagogical content knowledge (TPACK) has been developed to direct research on teachers' use of ICT in problem-solving. Kramarski and Michalsky (2010) claim that TPACK was simpler to express than TPCK and that it more accurately portrays the interconnectedness of the three contributing knowledge domains (e.g., content

knowledge, pedagogical knowledge, and technology knowledge) (Mishra, personal communication). This framework offers an organised method for comprehending the intricate connection between pedagogy, content, and technology in the classroom.

In this study, the researcher employed the acronyms TPACK and TPCK interchangeably, acknowledging that the shift in terminology had not been universally embraced. Since its inception in 2005, the TPACK framework has significantly influenced the realms of teacher professional development and the integration of technology into educational settings. The growing scholarly attention towards TPACK necessitates a coherent understanding that encompasses both the conceptual growth of the framework and its real-world implications.

The metaphoric and representational associations within the TPACK framework are far from superficial; rather, they often serve as catalysts for transformative shifts within the discipline. Recognising the central role of technology in modern education highlights the urgency to develop pedagogically appropriate tools. This realisation underscores the importance of evaluating both the opportunities and limitations presented by technological tools when crafting educational content.

Consequently, selecting technological tools must align with the nature of the content to be taught, just as certain content choices may influence the appropriateness or functionality of specific technologies. This dynamic exchange between technology and content is essential to fully grasping the effective implementation of ICT in educational practice. While technology might constrain the forms of representation available, it simultaneously enables the creation of innovative and diverse forms of representation. Additionally, technological tools can enhance transitions between different forms, allowing for greater fluidity in teaching and learning processes (Alazam et al., 2013).

This interrelationship is captured in the concept of Technological Content Knowledge (TCK).

TCK refers to the interplay between technological tools and subject content, emphasising how each element shapes and influences the other. Educators must possess a deep understanding of the content they deliver, including the structure and presentation of that content, which may shift when particular technologies are introduced. Teachers also need to be knowledgeable about which technologies are best suited for specific content areas, acknowledging that content can influence the choice of technology, or vice versa (Alazam et al., 2013).

Technological Pedagogical Knowledge (TPK), which relates to comprehending how different teaching techniques can be improved or altered via the use of technology, is another essential element of the TPACK paradigm (Koehler & Mishra, 2008; Harris, Mishra & Koehler, 2009). TPK involves comprehending how instructional strategies adapt when particular technologies are employed in certain contexts. Developing TPK requires insight into the limitations and possibilities of technological tools and how these interact with different subject areas (Wetzel, Buss, Foulger, & Lindsey, 2014).

This knowledge can be supported by real-world classroom examples, like using whiteboards. For example, a whiteboard is usually placed at the front of the classroom and is largely under the teacher's control because of its fixed position, excellent visibility, and ease of adjustment (Wetzel et al., 2014). Since students often only interact with it when the teacher gives permission, this placement affects how the classroom's furniture is arranged and how the teacher and pupils interact.

However, assuming a singular mode of using whiteboards would be overly simplistic. In alternative settings, such as collaborative meetings in advertising firms or scenarios

involving digital whiteboards linked to graphics tablets, whiteboards take on a more interactive and democratic role. In these environments, the tool is shared, open to contributions from multiple participants, and becomes a central element for dialogue and meaning-making. This contrast highlights how the same technological tool can serve different purposes based on the context, thereby illustrating the nuanced interplay between content, pedagogy, and technology encapsulated in the TPACK model.

The relevance of Technological Pedagogical Knowledge (TPK) becomes increasingly evident when we recognise that most mainstream software tools are not inherently designed for educational use. Many popular applications, including Microsoft Office programs like Word, PowerPoint, Excel, Entourage, and communication tools such as MSN Messenger, cater primarily to corporate or business settings. Similarly, web-based platforms like blogs and podcasts are largely developed for leisure, interpersonal communication, and social networking. This makes TPK essential, as it calls for a thoughtful, imaginative, and open-minded approach to utilising technology, not merely for its presence, but as a means of enhancing students' comprehension and academic growth (Wetzel et al., 2014).

Expanding on the TPK concept, Polly and colleagues (2010) introduced TPACK, a sophisticated framework of teacher knowledge that integrates and transcends the three core elements of education: content, pedagogy, and technology. TPACK represents an evolved understanding that encompasses how technology can be strategically applied across various disciplines and instructional methods.

To put it another way, TPACK is a type of professional knowledge that results from the fusion of content, pedagogical, and technological skills. It involves more than just being familiar with each domain separately. TPACK encompasses the ability to

represent subject matter through technology, apply effective teaching strategies with technological tools, solve student-related challenges using tech-based solutions, assess students' existing knowledge, draw from epistemological theories, and build upon or reinforce knowledge using appropriate technologies (Polly et al., 2010).

In real classroom scenarios, educators enact TPACK continuously. Teachers proficient in this integrated knowledge draw on the interconnectedness of technology, pedagogy, and content every time they plan or deliver a lesson. Each instructional situation presents a unique configuration of these components, implying that there's no universal technological approach that suits all teachers, subjects, or teaching philosophies.

Successful implementation of TPACK hinges on an educator's ability to seamlessly shift among and combine the three domains. It is not enough to master content, pedagogy, or technology in isolation; what matters is the strategic and context-sensitive fusion of these elements. Misinterpreting them as discrete or failing to appreciate their interdependent nature often leads to instructional inefficiencies or breakdowns.

Teachers face unique challenges as a result of this complexity. In addition to developing depth in each subject, educators also need to foster the mental flexibility necessary to integrate them in a meaningful way. They must understand how contextual factors affect how technology, pedagogy, and content interact. TPACK is a sophisticated form of professional teaching knowledge because of this understanding, which is fluid, responsive, and strategic (Polly et al., 2010).

However, the integrated nature of TPACK also presents notable challenges. Viewing the three domains as tightly interwoven can make it difficult to isolate and address each one independently during instruction. Changes in any one area, be it technological

tools, pedagogical methods, or subject content, inevitably ripple through the others, necessitating compensatory adjustments to maintain instructional coherence (Mishra & Koehler, 2006).

This interdependence becomes especially clear when new technologies emerge. The introduction of unfamiliar digital tools often compels educators to revisit fundamental teaching principles and recalibrate the balance among content, pedagogy, and technology. Rather than aligning neatly with existing curricular aims, emerging technologies frequently disrupt conventional assumptions and require educators to rethink how content is presented and how students engage with both material and peers. For instance, the widespread adoption of the internet and the growth of online learning environments illustrate how new technologies can prompt educators to reconsider everything from content delivery methods to strategies for fostering student interaction and engagement (Peruski & Mishra, 2004).

Ultimately, the TPACK model underscores the dynamic and evolving nature of effective technology integration in education. It recognises that the interplay between content, pedagogy, technology, and instructional context is fluid and situational. Teachers must continually strive to establish, sustain, and reconfigure a functional balance among these elements.

Achieving this balance is influenced by numerous factors, including instructional goals, student needs, and the broader educational setting (Mishra & Koehler, 2006).

2.2 The Conceptual Framework

The application of TPACK, whether approached individually or collectively, plays a significant role in shaping teachers' decisions regarding the selection and deployment

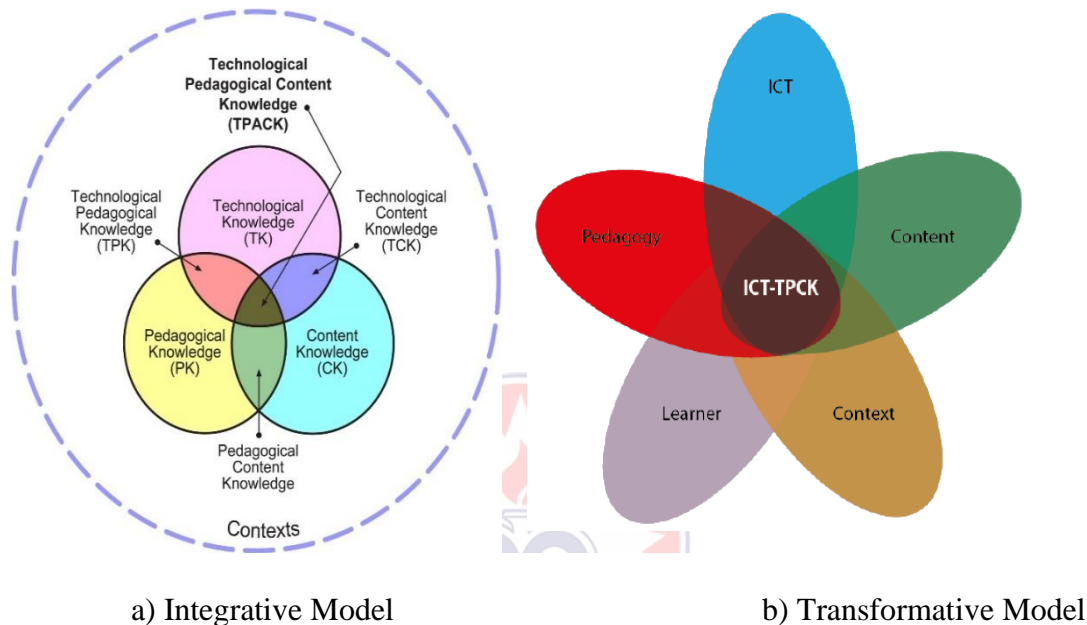
of both curricular materials and ICT-based tools (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). To effectively select and utilise educational resources, teachers must be equipped with a deep understanding of the available tools, insight into their characteristics, and the practical know-how to implement them effectively in classroom settings.

Educators are expected to have in-depth knowledge of specific hardware and software, allowing them to make informed choices tailored to distinct subject areas within the curriculum. This reflects their technological knowledge as well as their ability to connect it to content knowledge. A thorough grasp of the attributes of technology-enriched instructional tools is essential, as it helps teachers determine their suitability and craft targeted learning aids that support both teaching methods (technological pedagogical knowledge) and subject-specific educational goals (technological content knowledge).

Moreover, educators must understand how to integrate such ICT-based resources into their teaching strategies in ways that are pedagogically sound and aligned with the learning needs of specific content domains. This is the essence of technological pedagogical content knowledge (TPACK). In their reviews of TPACK-related literature, Jimoyiannis (2010) and Harris and Hofer (2011) support the idea of aligning TPACK development with particular academic disciplines. However, Voogt et al. (2013) highlight a significant gap in existing research, noting the limited exploration of TPACK with specific subject domains.

Currently, two prominent theoretical perspectives on TPACK dominate scholarly discourse: the integrative model and the transformative model. Mishra and Koehler (2006) introduced the integrative model, portraying TPACK as a fusion of

interconnected knowledge areas, namely, the relationships among pedagogy, content, and technology. In contrast, Angeli and Valanides (2009, 2015) advanced the transformative model, also referred to as ICT-TPCK, which treats the integration of technology, pedagogy, and content as a distinct and unified knowledge framework.



* **Knowledge needed for classroom teaching**

Figure 1: Representations of TPACK Models (Angeli and Valanides, 2009)

Research has consistently shown that many educators continue to resist incorporating modern technology into their teaching environments. Various underlying reasons contribute to this reluctance. Kathryn MacCallum, Lynn Jeffrey, and Kinshuk (2014) outlined several key influences on teachers' adoption of new technologies:

1. Educators' perceptions regarding the potential benefits of technology and the level of effort needed to become proficient in its use are commonly referred to as perceived "usefulness" and "ease of use."

2. The extent to which teachers possess the capabilities to apply digital tools effectively within instructional settings, which relates to their broader "digital literacy."
3. Teachers' confidence in their technological competence and the mindset they bring toward embracing technological tools.
4. The anxiety some teachers experience when faced with using information and communication technology (ICT) reflects a psychological barrier to integration.

These components play a crucial role in shaping a teacher's willingness to adopt technological tools for instructional purposes. The effectiveness of ICT implementation in education hinges largely on how teachers view the role of technology in their teaching practice. Their beliefs significantly impact their choices and instructional behaviour in the classroom.

For many years, the field of educational technology has grappled with defining its theoretical foundation (Graham, 2011). Crafting a comprehensive theory in this area proves challenging due to the complex and context-specific interactions among teaching variables. Studying causal relationships becomes especially complicated when factors such as teacher experience, classroom dynamics, educational policies, and curriculum goals vary widely (Mishra & Koehler, 2006).

Khaddage and Knezek (2013) noted a growing global interest among educational technology scholars in matters related to technology integration. Consequently, modern scholarly investigations have relied more on the Technological Pedagogical Content Knowledge (TPACK) paradigm (Graham, 2011).

Recognising the complexity of teaching, it is essential to acknowledge that it draws upon multiple dimensions of knowledge. Historically, teacher education placed a strong emphasis on subject-specific knowledge. In more recent years, the focus has shifted toward general pedagogical strategies that are not tied to specific subject matter, often at the cost of deep content understanding. This shift created a divide in teacher education, emphasising either pedagogical (P) or content (C) knowledge (Mishra & Koehler, 2006).

Shulman's foundational work in the 1980s on pedagogical content knowledge (PCK) laid the groundwork for what would later evolve into the TPACK framework. This model integrates a third dimension of technological knowledge into the existing pedagogical and content knowledge structures (Graham, 2011).

A common visual representation of the TPACK framework is a Venn diagram with three intersecting circles, each denoting one of the essential knowledge domains for educators. TPACK has increasingly become a prominent analytical tool in understanding the types of knowledge teachers require and has been applied extensively in recent studies on teaching practices (e.g., Ozgun-Koca, Meagher, & Todd, 2010; Syh-Jong & Kuan-Chung, 2010; Han, Eom, & Shin, 2013).

The TPACK and ICT-TPCK frameworks are illustrated using a Venn diagram to highlight both the separation and interconnection among the various knowledge domains. At the centre of the diagram, where technological, pedagogical, and content knowledge converge, is the integrated understanding of TPACK and ICT-TPCK. This central overlap represents a holistic knowledge system, functioning collaboratively (see Fig. 4). This integrated model empowers educators to navigate and manage the intricate interplay between these three foundational areas of knowledge. The framework

elucidates the multifaceted nature of teaching in a technology-enriched environment (Hasniza, 2014).

TPACK is a crucial conceptual model for analyzing, interpreting, and evaluating the fundamental skills teachers require to successfully integrate technology into their teaching practices, as well as how this body of knowledge may be developed, claim Wang, Jin, and Schmidt (2018).

Their results also imply that assessing teachers' technology pedagogical expertise may have an impact on the design of pre-service and in-service teacher professional development programs. It is widely accepted that TPACK is a unique and thorough type of professional knowledge that complements content-driven technology integration in the classroom. It incorporates the overlapping realms of curriculum expertise, general teaching methods, technological tools, and context-sensitive learning (Harris & Hofer, 2011). Numerous scholars recognise the expansive utility and potential of this model (Graham, 2011).

Of particular relevance is the idea of pedagogical content knowledge, which emphasises how teaching draws upon unique and intersecting bodies of understanding. This knowledge domain captures how subject matter and instructional strategies are interwoven in ways that adapt complex topics into teachable concepts, sensitive to learners' cognitive needs and interests.

The TPACK structure encourages adaptive, responsive teaching strategies that promote instructional effectiveness (Junnaina & Hazri, 2014). As Hasniza (2014) points out, employing the TPACK model provides notable benefits, such as:

- Facilitating comprehension of challenging concepts for educators.

- Enhancing teacher proficiency in developing rich instructional materials that blend pedagogical and technological knowledge.
- Assisting educators in formulating student-centred teaching strategies.
- Supporting the seamless incorporation of technology in content delivery.
- Strengthening teachers' capabilities in using technology effectively during instructional design.
- Guiding the development of content-driven lessons with diverse ICT tools.
- Shifting instructional focus from casual use of digital platforms to more pedagogically meaningful applications of these tools.

Many quantitative inquiries have focused on refining instruments used to assess teachers' TPACK competencies. Despite the recognised value of TPACK, there remains a critical need to improve the validity of these assessment tools. Some notable limitations include the lack of discipline-specific frameworks, ambiguous item language, unclear definitions and examples of TPACK components, insufficient item counts per construct (fewer than three items), and inadequate sample sizes (Cox & Graham, 2009; Chai, Koh, & Tsai, 2016).

The breadth of instructors' expertise is a major obstacle to effective technology integration (Mishra & Koehler, 2006; Hew & Brush, 2007). The ongoing discussion around what technological understandings teachers must possess for effective classroom use has intensified in recent years (ISTE, 2002; Zhao, 2003). Simply introducing digital tools into the learning environment does not ensure success; rather, it is the meaningful use of these tools that determines their impact (Mehan, 1989). Similarly, Koehler and Mishra (2005) argue that the presence of new technologies does not inherently improve instructional quality. Instead, understanding the specific

knowledge teachers require about technology is essential for enhancing classroom practice (Mishra & Koehler, 2006).

Therefore, developing a solid foundational knowledge base for educators is indispensable for the effective application of digital tools in instruction. Teachers must be well-prepared to integrate technological education into their subject areas. One of the crucial elements within the TPACK model is teacher preparation and development (Maor & Roberts, 2011). Pre-service teachers' (PTs') understanding of TPACK is greatly influenced by their coursework and hands-on teaching experiences in teacher preparation programs. Research has been done in a number of fields, such as social studies, science, and math, to examine how varied teaching experiences affect PTs' TPACK development.

Cavin (2007), for instance, investigated how six PTs in the science and math fields created TPACK by taking part in a microteaching lesson study (MLS). The lecturer used PTs to act as learners during the 40 MLS sessions to showcase technology-integrated teaching. PTs documented their reflections after each session, designed and taught lesson plans incorporating technology, and participated in group discussions. Analysis of audio and video recordings, interviews, and reflective writings indicated that PTs started recognising the interdependencies among content, pedagogy, and technology. Their teaching approaches shifted as they began to intentionally align these domains to improve lesson outcomes.

In another study by Mahdum (2015), efforts were made to foster TPACK development among 74 PTs through a course focused on using interactive whiteboards (IWBs). The research adopted a structured three-phase instructional model: (1) faculty-led demonstrations of the IWB, (2) technical skill-building coupled with pedagogical

modelling, and (3) practical application in instructional design. PTs' attitudes and confidence levels were measured by pre- and post-surveys, and end-of-course reflections yielded qualitative information.

Findings showed a marked improvement in PTs' ability to integrate IWBs effectively, along with a consistently positive perception of the technology. Although TPACK itself was not explicitly emphasised in PTs' reflections, a notable shift occurred, from an initial focus on technological knowledge (TK) to a later emphasis on technological pedagogical knowledge (TPK). The overall TPACK competency of PTs demonstrated significant progress during the course. While their lesson plans reflected solid understanding of TPACK principles, a slight decline in scores was noted during the student-teaching semester. Nonetheless, PTs' reflective writings confirmed their growing awareness of how to incorporate technology in a pedagogically sound manner. This study contributes to the expanding body of knowledge regarding how TPACK can guide the development of competent, tech-savvy educators.

More specifically, a recent mixed-methods investigation aimed to analyse how Turkish PTs of English developed TPACK as they engaged in an initiative shaped by the Learning Technology by Design framework. Additionally, it assessed how this emerging knowledge was applied in their lesson plans. Given the rapid evolution of technology, it is vital to continually assess its impact on education and teachers' pedagogical beliefs (Margerum-Leys & Marx, 2002).

Mishra and Koehler (2006), in expanding upon Shulman's (1986) concept of pedagogical content knowledge, introduced the integration of technological knowledge. As illustrated in Figure 2.1, the resulting model encompasses three

fundamental knowledge areas: technology, pedagogy, and content and highlights the significance of their interconnectedness.

Technological Pedagogical Knowledge (TPK) refers to teachers' understanding of general teaching strategies that include technology utilisation (Margerum-Leys & Marx, 2002). It entails comprehending the ways in which particular technological applications might alter and impact the processes of teaching and learning. This knowledge encompasses the effective combination of technological resources with instructional strategies by recognising their capabilities and limitations. While most commonly available software programs are designed primarily for business, communication, entertainment, or social networking purposes (Koehler & Mishra, 2009), educators are expected to transcend these general functionalities and apply such technologies meaningfully within instructional settings.

According to Koehler and Mishra (2008), teachers' technological competencies in the classroom span multiple facets, which should be integrated for effective learning outcomes. In efforts to conceptualise a framework that captures the success of implementing educational technologies, there is a recognised need to combine three essential domains of teaching expertise: technological knowledge, pedagogical knowledge, and content knowledge. The dynamic interplay among these domains produces a range of skillsets, with their intersection representing the highest form of instructional capability. This is where Technological Pedagogical Content Knowledge (TPCK) emerges as a core construct.

Technological Content Knowledge (TCK) enables educators to visualise and create opportunities for embedding technology within subject-specific teaching (Margerum-Leys & Marx, 2002). A practical instance of this would be the use of computer

simulations in disciplines like physics and mathematics to deepen students' understanding (Koehler & Mishra, 2009). This knowledge base demonstrates the mutual reinforcement between technological tools and subject matter, requiring teachers to be knowledgeable about both their discipline and the technologies that can support and enrich student learning.

Pedagogical Content Knowledge (PCK) refers to the instructional strategies tailored to teaching specific content areas effectively (Harris et al., 2007). It involves the ability to adapt and present subject matter through various teaching methods to suit diverse learner needs, thereby connecting curriculum design, instructional delivery, and student assessment. As a critical intersection within the broader framework, PCK emphasises the transformation of content into teachable formats.

Technological Pedagogical Content Knowledge (TPACK), as articulated by Ferdig (2006), is an educational framework that combines content knowledge with pedagogically informed use of technology. Mishra and Koehler (2006) particularly highlighted the synergy between the three domains: technology, pedagogy, and content. Mastery of TPACK implies that educators can effectively deliver instruction by understanding how to represent ideas and concepts using technology, employing strategies that facilitate meaningful learning, and identifying challenges students may face. It also requires insight into how learners' prior knowledge interacts with new technological tools, and how these tools can enhance both existing and emerging ways of knowing (Koehler et al., 2007).

As an approach to teaching, TPACK is seen as a means of achieving educational effectiveness through technology integration. Angeli and Valanides (2009) described TPACK as inherently stable, intricate, multi-dimensional, integrative, and capable of

transforming instructional practices. Successful classroom implementation relies heavily on a teacher's ability to interconnect technology, pedagogy, and subject matter knowledge (Koehler et al., 2007). Teachers run the risk of reducing technology to a supporting or auxiliary role if they do not view it as an integral component of the learning process. Pierson (2001) asserts that meaningful intersections between these disparate knowledge areas are necessary for true integration to occur.

The foundational elements of the TPACK framework include content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). Their various combinations give rise to pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and ultimately, TPACK. Scholars such as Manfra & Hammond (2008), Angeli & Valanides (2009), Harris et al. (2009), and Koehler & Mishra (2009) have consistently described TPACK as complex, integrative, and capable of reshaping instructional practices.

As a theoretical framework, TPACK has been widely utilised in analysing technology-integrated lessons, guiding teachers' use of ICT, informing curriculum development in teacher education, and organising literature related to digital technology in education (Polly, McGee & Martin, 2010). Ultimately, TPACK provides a robust structure with significant potential for guiding both research and practical advancements in the integration of ICT in educational contexts.

2.3 Confusion about TPACK constructs

Owing to the interconnected nature of the framework, scholars like Cox and Graham (2009) have raised concerns about the ambiguity surrounding its constructs. This issue has also been a focus for researchers examining how teachers perceive their self-assessment of TPACK (Archambault & Barnett, 2010; Lee & Tsai, 2010). Cox and

Graham (2009) emphasised the necessity of treating each knowledge domain as distinct when organising the framework's categories. For instance, when evaluating Technological Pedagogical Knowledge (TPK), such as understanding how to utilise online discussion forums, any reference to Content Knowledge (CK) should be excluded. Their perspective offers valuable guidance for scholars aiming to clarify the constructs within the model. Nonetheless, some inconsistency in the use of terminology remains evident across various academic works.

Additionally, there is a need for greater clarity regarding components like Technological Knowledge (TK) and Technological Content Knowledge (TCK). Although recognising how to use older instructional tools, such as overhead projectors, is considered part of technological knowledge (Schmidt et al., 2009), within TPACK-related inquiries, including such examples may detract from the central focus. It is more fitting to confine TK to encompass only the skills and expertise related to computer-based technologies (Cox & Graham, 2009). This stance is reinforced by the collective insights drawn from the works of Cox and Graham (2009), Koehler and Mishra (2009), and Mishra and Koehler (2006).

2.4 Knowledge Base of Biology Teachers

Each professional is characterised by a unique body of knowledge that sets them apart from non-experts. In the case of teaching, this means educators are expected to possess a distinct set of knowledge tailored to the instructional field. This specialised expertise, often referred to as professional or teacher knowledge, encompasses understanding how schools operate, the responsibilities of educators, and the processes through which students learn (Dasare et al., 2023). According to Tepner et al. (2012), this knowledge

is a foundational component of effective teaching and serves as a benchmark for teacher proficiency and training standards.

Shulman's seminal studies in 1986 and 1987 brought clarity to the components of teacher knowledge by identifying seven primary categories that influence instructional practice. Baumert et al. (2010) expanded on this by detailing areas such as subject content knowledge, understanding of student characteristics, pedagogical and pedagogical content knowledge, curriculum familiarity, contextual awareness in educational settings, technological content knowledge, and awareness of educational goals. Among these, Shulman emphasised TPACK as a particularly significant domain that integrates the core elements of effective teaching.

In biology education, teachers who exhibit deep expertise in both pedagogical methods and subject-specific practices are considered professionals. They are capable of fostering student development across emotional, intellectual, and academic dimensions (Conklin, 2015). Ben-Peretz et al. (2010) argue that a competent biology teacher's TPACK includes both deliberate and intuitive modelling and instructional roles that enhance student engagement. The ongoing discourse on what defines a biology teacher's professional foundation (Connelly & Clandinin, 2004; Moallem, 1998; Barnett & Hodson, 2001) has led Fischer et al. (2012) to suggest that biology teaching knowledge is based on three pillars: content knowledge (Krauss et al., 2004), pedagogical understanding (Bromme, 2005), and technological pedagogical content knowledge (Baumert et al., 2010). However, identifying which elements of TPACK are most relevant depends greatly on teachers' insights into student learning (Shulman, 1987).

Therefore, this study reviews literature focused on four core domains of professional knowledge essential for biology education: content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), and TPACK. The following sections explore the importance of each domain and how biology educators acquire them.

2.5 Technological Pedagogical Content Knowledge in Biology Teaching

Blomeke and Delaney (2012) regard TPACK as an intellectual competency that contributes to overall teaching effectiveness. For biology educators, this competency is critical in facilitating impactful learning. As Guerriero (2017) explains, TPACK represents the complex knowledge educators employ to construct supportive and engaging instructional environments for students across different content areas. It reflects their capability to teach in ways that resonate with diverse learning needs. Montrose (2019) adds that such knowledge extends beyond teacher education and includes dynamic expertise gained through professional experiences.

Kraus et al. (2008) describe TPACK as both declarative and procedural, helping teachers manage lessons, create conducive classroom environments, and apply practical teaching strategies. In this context, a biology teacher's mastery lies in knowing how to navigate and orchestrate instructional processes effectively.

Ozden (2008) frames it as the "science of teaching and training," while Penso (2002) simplifies it as the essential knowledge every teacher should possess. This includes understanding what content to teach and how to design strategies that enhance student comprehension (Ball et al., 2001; Loughran et al., 2012). These strategies typically involve lesson planning, encouraging discussion, and organising collaborative learning experiences (Ije, 2012).

Drawing from empirical insights, the professional knowledge (PK) base of biology educators generally encompasses three overlapping domains: instructional strategies (e.g., teaching styles, classroom structuring, and behavior management), understanding how students learn (e.g., their cognitive, motivational, and emotional profiles), and assessment strategies (e.g., evaluation and diagnostic practices) (Guerriero, 2017; Montrose, 2018). PK serves as a vital bridge that connects subject matter expertise to actual classroom instruction (Abd-El-Khalick, 2006). Jutner and Neuhaus (2012) caution that high school biology teachers with limited pedagogical knowledge may struggle to deliver effective instruction despite subject expertise.

However, the current teacher preparation system often results in graduates with an inadequate understanding of how to teach biology conceptually (Eshun, 2014; Heywood, 2005). Many of these teachers rely heavily on traditional, lecture-based methods because of their long-standing exposure to outdated pedagogical styles during their training. As a result, they encounter challenges in sequencing instruction in ways that promote student understanding. Heywood (2005) advises a shift in training emphasis from mere knowledge acquisition to addressing conceptual learning difficulties.

2.6 Nurturing Biology Teachers' TPACK

Montrose (2018) emphasises that advancing the standard of teacher education and maintaining ongoing professional development (CPD) throughout educators' careers can greatly enhance student outcomes by promoting more effective instructional practices. Within the realm of biology education, this highlights the crucial necessity of structured opportunities and consistent support for the professional growth of biology teachers, especially in strengthening their Technological Pedagogical Content

Knowledge (TPACK). Studies have shown that numerous biology educators frequently struggle with employing effective instructional strategies suited for specific biology topics (Friedrichsen, Abell, Pareja, Brown, Lankford, & Volkmann, 2009; Henze, van Driel, & Verloop, 2008). This observation reflects a pressing requirement for focused training programs that bring together subject mastery, pedagogical expertise, and technological fluency.

Magnusson et al. (2001) argue that the methods used to teach various biology topics are central to a teacher's pedagogical content knowledge (PCK), and in the modern, technology-driven context, these must be broadened to incorporate digital tools and methods. Effective teaching strategies in biology often rely on instructional representations like models, analogies, demonstrations, and hands-on activities, which must be carefully adapted to suit the intricacies of each topic. According to Coll, France, and Taylor (2005), there are diverse ways to present biological concepts, and skilled teachers must be capable of identifying the most suitable resources, including technological aids, to facilitate deep and meaningful student understanding. Juttner, Boone, Park, and Neahaus (2013) support this view, asserting that the selection of such instructional tools should be informed by a teacher's comprehensive grasp of content, pedagogy, and the technological options at their disposal.

Scholarly literature also suggests that a biology teacher's pedagogical development, particularly in the context of TPACK, is closely linked to the strength of their content knowledge (CK) (Kapyła, Heikkinen & Asunta, 2009; Magnusson et al., 2001; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). For instance, Kapyła et al. (2009) discovered that teachers with academic backgrounds in biology addressed advanced topics like photosynthesis and plant growth with fewer misconceptions and

used more practical, field-based instructional methods than those without such specialisation. Similarly, Rollnick et al. (2008) noted that chemistry teachers with inadequate mastery of the mole concept also faced challenges in applying effective teaching strategies for it, thereby underscoring the interrelated nature of CK and PCK. Moreover, the body of knowledge that informs biology teachers' practice, encompassing content, pedagogy, and technology, is continually evolving (Hattie, 2009; Guerriero, 2017). Innovative teaching strategies, frequently enabled by advancements in technology, are emerging from ongoing research and collaborative professional learning initiatives. Biology educators must therefore be equipped to access, evaluate, and implement this dynamic knowledge in their teaching practices (Guerriero, 2017). As a result, participation in CPD activities, such as in-service training (INSET), is crucial for educators to remain current and effective. Eshun (2014) affirms that CPD plays an essential role in refreshing teachers' pedagogical competencies, while Omar (2014) adds that in-service programs are designed to support educators in acquiring new insights that enhance their teaching, particularly in integrating technology into instruction.

Magnusson et al. (2001) also point out that actual teaching experience and reflective classroom practices contribute significantly to the refinement of instructional strategies. Seasoned educators, through reflective engagement, tend to possess deeper content knowledge and are generally more adept at incorporating relevant technological tools into their teaching than beginners. Nonetheless, subject expertise alone does not ensure the proficient application of teaching methods or digital tools; it is the interplay of practical experience and reflective action that cultivates these capabilities.

The cultivation of TPACK among biology teachers can evolve gradually through teaching experience (Brown, Friedrichsen & Abell, 2013; De Jong, 2010; Henze et al., 2008), or it can be deliberately nurtured through comprehensive professional development initiatives that aim to simultaneously build content knowledge, pedagogical understanding, and technological competence in a cohesive and well-integrated manner (Drechsler & Van Driel, 2008; Ijeh & Onwu, 2012). When choosing representations such as analogies, examples, or illustrations, biology educators must thoughtfully align scientific content with pedagogical techniques and suitable technological tools, ensuring these selections are developmentally appropriate and contextually relevant. This reinforces the pivotal role that an understanding of learner characteristics plays in delivering effective biology instruction through the TPACK lens.

2.7 Biology Teachers' Understanding of Students

Research in science education emphasises that students often enter classrooms with pre-existing ideas shaped by their daily lives, personal observations, and exposure to media (Juttner & Neuhaus, 2012; Morrison & Lederman, 2003; Treagust & Duit, 2008). Educators need to recognise that students vary significantly from one another across multiple dimensions (Asempa, 2020). This underscores the importance of Shulman's (1987) inclusion of "knowledge of learners" as a vital aspect of a teacher's professional knowledge base. Biology educators, in particular, benefit from this understanding to effectively identify and adapt to individual learner characteristics during instruction.

According to Shulman (1986; 1987), students bring into lessons a set of pre-existing understandings, including alternative and sometimes incorrect conceptions, which he

categorises as prior knowledge. These preconceptions often conflict with scientifically accepted explanations (Juttner & Neuhaus, 2012; Treagust & Duit, 2008), potentially obstructing meaningful learning. Abell and Lederman (2007) support this view, stating that significant disparities between scientific reasoning and students' everyday thinking can make certain science topics especially difficult for both teaching and learning. Consequently, educators must be able to identify and understand these prior notions to align their instruction accordingly and facilitate better comprehension and academic outcomes (Juttner & Neuhaus, 2012; Morrison & Lederman, 2003; Penso, 2002).

Shulman (1987) elaborates that a teacher's awareness of learners includes knowing the prerequisites for grasping specific concepts, recognising common student misconceptions, understanding how students learn, and identifying challenges they might face. Furthermore, Shulman (1986) emphasises that this knowledge enables teachers to select the most suitable content knowledge (CK) and pedagogical knowledge (PK) to support student learning. Penso (2002) notes that an educator's insight into their students enhances their ability to interpret students' behaviours and ideas, plan strategically, and establish a classroom environment that supports students in forming accurate scientific understandings. Supporting this view, Juttner and Neuhaus (2012) advocate for teachers to comprehend students' ideas and learning obstacles to adapt instruction that matches learners' needs and learning profiles.

Juttner and Neuhaus (2012) further divide knowledge of learners into two components: empirical and cognitive. Empirical knowledge refers to a teacher's awareness of age-specific student behaviour, social dynamics, learning interests, contextual influences such as unexpected classroom events or weather conditions, and how these factors affect student performance and the teacher-student relationship. On the other hand,

cognitive knowledge encompasses an educator's grasp of child development theories that inform their practice, along with the necessary skills and strategies to address varying levels of student ability through differentiated instruction.

Despite its significance, several studies have revealed that many biology teachers often lack an adequate understanding of students' prior conceptions and common learning challenges, which negatively impacts their pedagogical content knowledge (De Jong, 2012; Ijeh, 2012; Juttner & Neuhaus, 2012; Morrison & Lederman, 2003). For instance, Morrison and Lederman (2003) discovered that while teachers acknowledged the value of knowing students' prior understanding, they frequently did not possess sufficient methods or tools to effectively uncover students' thinking. This study, therefore, investigates the extent of senior high school biology teachers' understanding of their learners.

Penso (2002) categorised sources of students' learning challenges into four main areas. The first involves learners' cognitive and emotional characteristics, particularly when there is a lack of foundational knowledge or when negative experiences reduce motivation and focus. The second area pertains to instructional shortcomings, such as overwhelming content or disorganised delivery. The third deals with the inherent complexity or abstractness of the subject matter (Magnusson et al., 2001). Lastly, the fourth area relates to classroom climate, including discipline issues and how the lesson is structured. This research explores how well biology teachers understand these factors, especially students' pre-existing ideas and learning barriers, in the context of biology instruction.

2.8 Development of Biology Teachers' Knowledge of Learners

Magnusson et al. (2001) state that a biology teacher's subject-matter expertise determines how well they understand their students' preconceptions and learning challenges. For example, Ijeh (2012) employed semi-structured interviews to ascertain the KL of teachers and concluded that each teacher enhanced their KL by expanding their understanding of the subject matter through formal education programs and using topic-specific textbooks and other publications as instructional resources. This suggests that a biology teacher's practical pedagogy choices are influenced by their level of content knowledge of biology topics, and that teachers' understanding of their students is influenced by the pedagogy they employ.

Classroom teaching experience is also mentioned by De Jong (2010) and Henze et al. (2008) as a factor that affects teachers' understanding of students.

2.9 Pedagogical Content Knowledge of Biology Teachers

It is evident from the talks in this chapter about the professional knowledge of biology teachers and the conceptual framework of Pedagogical Content Knowledge (PCK) that there isn't a single, widely recognised definition of PCK.

This absence of a shared understanding is supported by several reviews of PCK conducted in prior research (Ekis, 2012; Schmelzing et al., 2013; Mthethwa-Kuene, 2014). Nevertheless, the majority of studies focusing on PCK in biology education tend to adopt the integrative model, which is also utilised in this research. This model allows for the individual assessment of distinct PCK components as well as their combination into a comprehensive framework (Lee & Luft, 2008). In the present study, the PCK levels of senior high school biology educators were evaluated using this integrative approach, with pedagogical knowledge (PK), content knowledge (CK), and knowledge

of learners (KL) identified as key elements comprising the integrated PCK of biology teachers.

Contemporary biology education operates in a landscape where the benchmarks demand a transformation in instructional approaches from merely conveying factual information to enabling students to actively construct explanations for scientific phenomena (Reiser, 2013). PCK represents the specialised knowledge that differentiates biology teachers in their instructional role from scientists. This distinction does not imply that biology teachers possess inferior content knowledge compared to scientists; rather, it highlights that teachers arrange and apply their subject matter expertise in ways designed specifically to promote student learning (Kang, Donovan & McCarthy, 2018). Davis and Krajcik (2005) further emphasised that the aspect of PCK related to biology disciplinary practices constitutes a unique component of PCK. They asserted that such knowledge equips teachers to guide students in engaging with scientific practices, including formulating questions, planning investigations, and developing explanations grounded in evidence.

The central responsibility of science teachers lies in the interpretation and adaptation of scientific content with the goal of enhancing student understanding. Consequently, the effectiveness of PCK can be gauged by the degree to which it positively influences student learning outcomes (Kind & Chan, 2019; Kang et al., 2018).

2.9.1 Growth of Pedagogical Content Knowledge Among Biology Teachers

Extensive research has examined how biology teachers develop their pedagogical content knowledge (PCK), focusing on both those preparing to enter the profession and those already teaching, particularly concerning biology or specific scientific topics (Arzi & White, 2008; Brown et al., 2013; De Jong, 2010). Kind and Chan (2019) affirm

that both teacher education programs and ongoing professional development play crucial roles in fostering PCK growth across biology educators at varying stages of their careers.

Research investigating PCK development typically follows two main methodologies. The first involves longitudinal studies tracking teachers' PCK progression over extended periods (e.g., Brown et al., 2013; De Jong, 2010; Appleton, 2008). These studies suggest that teachers' mastery of content knowledge combined with accumulated teaching experience significantly drives the evolution of PCK (De Jong, 2010; Miller, 2007). Furthermore, Dreschsler and Van Driel (2008) emphasise that PCK deepens as educators reflect on their instructional practices and the challenges students encounter. Loughran et al. (2012) similarly highlight reflective practice as vital to PCK advancement. Additional elements contributing to PCK development include participation in professional development sessions or workshops, exposure to curriculum frameworks, the use of textbooks, and collaboration with colleagues within schools (De Jong, 2010; Appleton, 2008; Kind, 2009).

The second approach to studying PCK development centres on how teachers enhance or refine their existing PCK. Investigations by Kind (2017), Pitjeng-Mosabala and Rollinick (2017), Dreschsler and Van Driel (2008), and Ijeh (2012) exemplify this perspective. For instance, Dreschsler and Van Driel (2008) explored chemistry teachers' processes of improving their PCK in teaching the topic of acids and bases, focusing on their pedagogical understanding and awareness of students' learning difficulties. Their findings revealed that changes in PCK were motivated by reflections on student challenges, professional dialogue among peers, engagement with research,

consideration of teaching experiences, use of textbooks, media resources, and conducting simplified experiments.

Comparing these two research strategies, it is clear that identifying the factors influencing biology teachers' PCK development is most comprehensively addressed through longitudinal studies. Nonetheless, due to constraints related to time and resources, this particular study opted for the second method. It specifically examined the technological pedagogical content knowledge (TPACK) of senior high school biology teachers currently practising in the classroom.

Based on the reviewed literature, it was posited that various influences, such as teaching experience, participation in professional growth activities, environmental challenges, and collaboration with fellow educators, may have contributed to shaping the extent of PCK development among senior high school biology teachers responsible for delivering biology content.

2.9.2 Impact of Biology Teachers' Traits on Their TPACK

A crucial aspect of TPACK lies in its effect on students' academic success. Nonetheless, maximising the teaching and learning environment in schools to reach its full potential remains a significant challenge (Hendriks, Kuyper, Lubbers, & Van der Werf, 2011). A particular difficulty arises from how teachers perceive classroom dynamics and students' abilities or behaviours within specific contexts (Kikas, Silinskas, & Soodla, 2015). Research by Hansen (2016) and Kikas et al. (2015) highlights that contextual factors, including the composition and size of classes, teachers' beliefs, prior experiences, gender, and the objectives of a given task, can influence the pedagogical content knowledge (PCK) applied during teaching and learning situations. These elements warrant close examination since teachers

continually evaluate their instructional approaches, shaped by these perceptions, while simultaneously monitoring students' cognitive and social development on a day-to-day basis through interactions, instruction, and assessments (Retelsdorf, Schwartz, & Asbrock, 2014).

For example, a teacher's PCK has been linked to student academic outcomes (Cho, 2012; Antecol, Ozbeklik, & Eren, 2015; Helbig, 2012; Holmlund & Sund, 2008), with some research indicating that having teachers of the same gender as their students can also impact academic performance (Ammermuller & Dolton, 2006; Dee, 2007). In particular, findings from certain studies reveal that teacher gender statistically affects how the academic achievements of boys and girls are assessed. This underscores the role gender plays in the evaluation process within instructional contexts. Since assessment is a vital component of pedagogical knowledge, integral to a teacher's PCK, it follows that gender is a factor influencing PCK.

Although the magnitude may not be large, extensive research confirms that teaching experience positively affects instructional practices and student achievement (Jepsen & Rivkin, 2002; Rockoff, 2004; Clotfelter, Ladd, & Vigdor, 2006). Specifically, biology teachers' PCK benefits from their accumulated teaching experience (Abell, 2008). Through ongoing reflection and participation in professional development opportunities, teachers progressively cultivate specialised content strategies, such as employing illustrations, models, analogies, experiments, and practical activities, to effectively deliver complex biological topics (Parker, Osei-Himah, Asare, & Ackah, 2018).

The reviewed literature consistently indicates that the individual characteristics of biology teachers shape their classroom perceptions, which in turn influence

instructional decisions, ultimately affecting the development and application of their TPACK.

2.9.3 Teaching and Learning Biology

Shulman first proposed the idea of TPACK, which states that in order to promote student achievement, teachers need to have adequate technology knowledge (TK), pedagogical knowledge (PK), content knowledge (CK), and pedagogical content knowledge (PCK). Based on this framework, Shulman proposed several broad principles essential for effective teaching (Krepf, Ploger, Scholl, & Seifert, 2018). A variety of scholarly works have examined the validity and impact of these principles (for example, Drechsler & Van Driel, 2008; Fraser, 2016; Kinnersley, 2019). Nevertheless, these studies often concentrated on a limited subset of these principles, predominantly emphasising only four of them (Krepf et al., 2008).

To offer a more detailed and inclusive representation of Shulman's principles of effective teaching, Krepf et al. (2008) compiled ten core principles derived from extensive meta-analyses covering research from the past thirty-five years. These principles delineate teacher behaviours that have a positive correlation with student achievement. The principles are: (1) providing opportunities to learn and ensuring sufficient time on task; (2) maintaining clear goal orientation; (3) effective lesson structuring; (4) promoting clarity in instruction; (5) encouraging cognitive activation and motivation; (6) linking cognitive activities to students' prior knowledge; (7) offering timely and constructive feedback; (8) adapting instruction based on student needs; (9) emphasizing the application of knowledge; and (10) fostering a positive classroom climate. These principles represent general pedagogical knowledge that every teacher should master, regardless of their subject area. Yet, when teaching

biology, these principles must be contextualised, especially when a teacher integrates them with pedagogical content knowledge and a substantial grasp of technological pedagogical content knowledge (TPACK) to effectively engage students in biology topics (Krepf et al., 2008).

Over the past twenty years, research has indicated that biology teachers initially operated within a “transformative” teaching model, in which teachers were seen as the sole holders of knowledge, and students were regarded as passive recipients of information delivered through lectures and verbal explanations (Blumenfield, Marx, Patrick, Krajcik, & Soloway, 1997). Due to consistently low student achievement levels, recommendations have urged biology teachers to adopt more student-centred teaching methodologies. These include inquiry-based learning, guided discovery, constructivist approaches, activity-focused lessons, hands-on and minds-on engagement, as well as project-based learning (Luera, Otto, & Zitzewitz, 2005).

Anderman, Sinatra, and Gray (2012) observe a persistent disconnect between the knowledge acquired by biology teachers during their training and how they implement this knowledge to enhance students’ comprehension. This gap is also evident among secondary school biology teachers in Ghana (Eshun, 2014). Marschall and McKee (2002) highlight the need for educational reforms to address shortcomings in the preparation of biology teachers, aiming to improve teaching effectiveness and student learning outcomes in senior high schools.

Brunner (1986) emphasises that “knowing” is an ongoing process rather than a final product. The senior high school stage represents a crucial phase for biology education, where targeted interventions should focus on fostering better student attitudes, raising achievement levels, and broadening access to quality biology instruction (Abell, 2007).

Adebayo and Dorcas (2015) underline that students' future careers in science-related fields heavily depend on their performance in senior high school biology. Consequently, Ghana's national goal of advancing scientific and technological capabilities relies on the quality of biology education at this level. According to Jung, Kim, and Park (2021), students' academic success and development of positive attitudes and values in science are largely influenced by their teachers. Teachers must possess a deep understanding of scientific concepts and demonstrate enthusiasm for biology to facilitate meaningful learning. Unfortunately, many teachers struggle to implement effective teaching strategies due to a lack of interest and insufficient pedagogical and content knowledge presented in ways that students can easily grasp, thus hindering positive learning outcomes in biology.

As Shulman originally posited, the effectiveness of a biology teacher is ultimately reflected in students' academic achievements. To be truly effective, biology teachers must skillfully integrate content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), and pedagogical content knowledge (PCK), making scientific ideas accessible, relevant, and understandable to students. This blend of expertise, known as TPACK, is what differentiates biology teachers from subject-matter experts who may lack pedagogical insight.

However, Eshun (2014) points out that the integrated TPACK model is not yet embedded within the Ghanaian education system for pre-service biology teachers. Instead, the current teacher education curriculum separates content knowledge development through biology courses from pedagogical knowledge training delivered via teaching methods courses. This division runs counter to Shulman's original TPACK concept, which advocates for the intertwined development of content and pedagogical

knowledge (Eshun, 2014; Krepf et al., 2018). It is suggested that biology teaching should inherently include the relevant pedagogical knowledge and skills required to enhance student learning.

From this analysis, it can be inferred that the underperformance of students in biology is linked to the way teachers are prepared in Ghanaian senior high schools. Teachers who possess a well-rounded TPACK framework tend to promote better student outcomes. Eshun (2014) argues that “poor learner performance in biology is likely a reflection of a lack of conceptual understanding. Although multiple factors may contribute, it is crucial to address the primary issue of teacher incompetence arising from inadequate foundational knowledge for effective teaching” (p.47). This implies that among various challenges, a significant reason for students’ difficulties in biology lies in the deficiency of essential knowledge bases for effective teaching. Other obstacles faced by biology teachers will be explored in subsequent discussions.

2.9.4 Teachers' Use of ICT in Instruction and Technological Pedagogical Content Knowledge Models

In order to meet the demands of 21st-century education, teachers are tasked with continually updating their expertise to keep pace with ongoing developments in their fields. The rapid progress of technology, along with shifts in the learning environment and curriculum content, as well as the integration of information and communication technologies (ICT) into classroom instruction, present ongoing challenges for educators (So & Kim, 2009). Alongside these digital tools, technical skills have become increasingly important, necessitating a thorough understanding and ability to employ technology effectively to facilitate comprehensive learning experiences.

Many educators, however, often lack adequate resources and a structured framework for delivering their subject matter effectively (Kramarski & Michalsky, 2010). The Technological Pedagogical Content Knowledge (TPACK) framework addresses the issue of overemphasising technological knowledge in isolation from teachers' subject-specific expertise by highlighting the importance of understanding the distinct nature of knowledge and inquiry within various disciplines (Papanikolaou, 2014).

TPACK has gained recognition among educational technology experts as a model that integrates the pedagogical application of technology with specific content areas. For example, the expertise required to integrate technology into a science curriculum differs significantly from what is needed in social studies instruction. According to research by Papanikolaou (2014), blended learning programs assist teachers in better understanding and utilising technology in the classroom and, to a lesser extent, in adapting excellent teaching resources to their particular contexts. According to Kazua (2014), teachers typically have high opinions of their material, pedagogy, and technological knowledge and are aware of the efficient interactions across these areas of knowledge. It is evident that educators are aware of the specific knowledge necessary to incorporate technology into teaching and can develop these skills over time.

Lee (2010) proposed that an interdisciplinary team comprising expertise in braille, educational technology, and systems development can collectively contribute to content, pedagogical, and technological dimensions of educational systems. Alazzam et al. (2012) noted that a primary concern among teachers remains the challenge of effectively integrating ICT into their instructional practices. Jimoyiannis (2010) further emphasised that the development of teachers' TPACK necessitates ongoing, authentic

learning experiences that allow for practical classroom application, accompanied by opportunities for reflection and feedback.

Despite these advancements, TPACK still holds potential to bridge existing gaps in educational technology integration and drive substantial improvements in teaching practices. Lee (2010) and Jimoyiannis (2010), for example, assessed teachers' basic ICT knowledge and abilities with the presumption that all instructors, regardless of discipline, must develop these competencies. Prior research has highlighted the critical role of ICT proficiency in preparing teachers to incorporate technology into their instruction, forming the basis of conceptual frameworks related to teacher knowledge. The application of ICT in education can manifest in various forms, including information networks, digital content, websites, multimedia tools, mobile technologies, collaborative software, and virtual environments, among others.

Successful ICT integration involves teaching with technology in ways that enhance learning. This demands knowledge about how to represent and organise concepts using technological tools, combined with pedagogical skills to effectively employ these tools in subject-specific instruction, a synthesis captured by the intersection of technological, pedagogical, and content knowledge (Mishra & Koehler, 2006). The TPACK framework identifies seven distinct categories of teacher knowledge, with TPACK itself at the centre. This core represents the capacity to use technology to support content-specific teaching strategies, such as leveraging technology to facilitate inquiry-based learning in science classrooms.

The model's seven components include the foundational areas of Technology Knowledge, Pedagogical Knowledge, and Content Knowledge. Considering these three individually provides a basis for understanding how they can be combined.

Technology Knowledge entails familiarity with how to operate and reason about various technologies, tools, and resources. It encompasses a general understanding of information technology sufficient for productive use both professionally and personally, the ability to discern when technology aids or hinders objectives, and the flexibility to adapt to ongoing technological changes (Koehler & Mishra, 2009).

Pedagogical Knowledge refers to a teacher's deep understanding of educational processes and methods, including general instructional aims, values, and teaching strategies. This knowledge includes awareness of how students learn, classroom management techniques, lesson planning, and assessment methods (Koehler & Mishra, 2009). Content Knowledge involves mastery of the subject matter itself. The specifics vary widely, from middle school science curricula to advanced university courses in diverse fields such as art or astrophysics. Shulman (1986) described this knowledge as encompassing concepts, theories, ideas, organisational structures, evidence, proof, and established practices related to a discipline (Koehler & Mishra, 2009).

Building upon these three pillars, the TPACK framework synthesises them into integrated forms: Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and ultimately the comprehensive TPACK. According to Mandinach and Cline (2012), teachers progress through four developmental stages in their use of technology (illustrated in Figure 2).

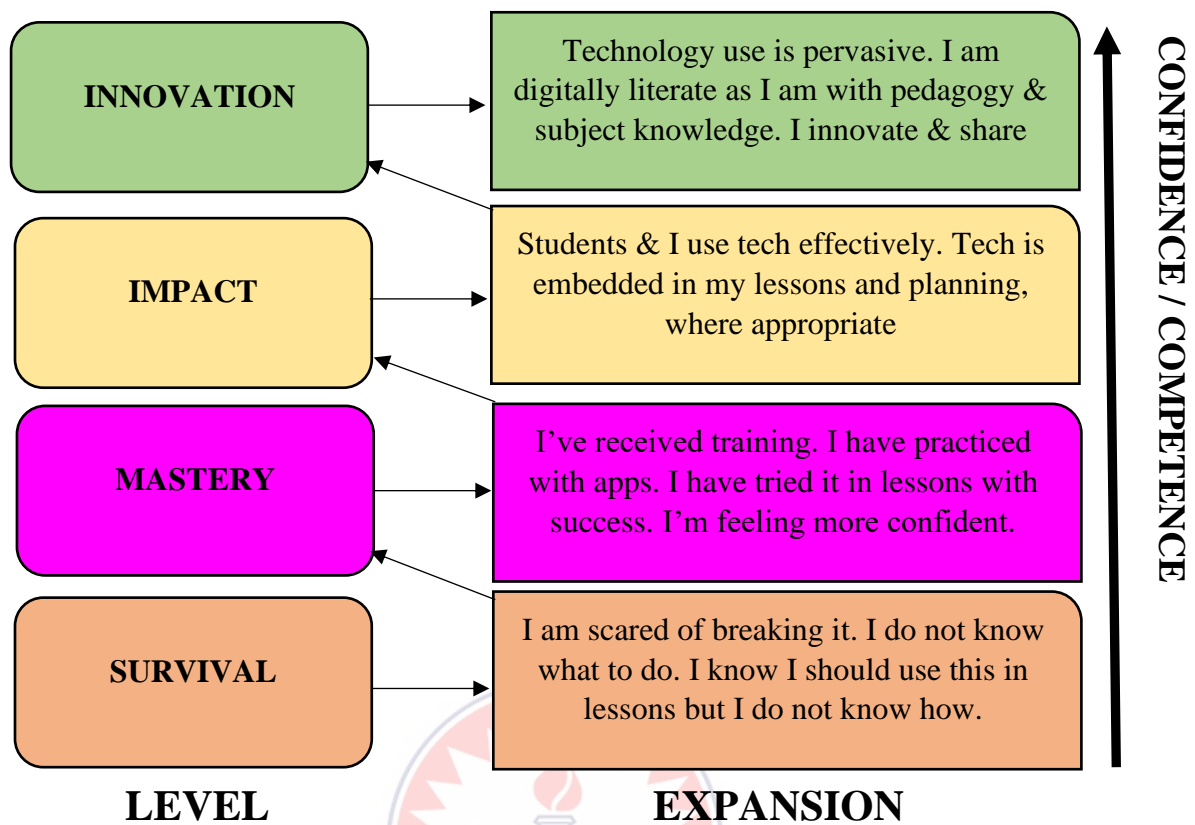


Figure 2: Teacher Confidence in the Use of Technology

Source: Mandinach and Cline (2012)

A variety of technological tools can be employed to support and enhance the educational process. These technologies include everything from digital video production and multimedia content to laptop computers and portable devices, all of which have found application within educational settings. Moreover, novel technological applications such as podcasting have recently begun to emerge and gain traction in classrooms (Clare, Dharamshi & Menna, 2019). The spectrum of technology accessible in today's learning environments ranges widely, from basic software applications like word processors to extensive online databases containing scientific information. Closed-circuit television systems, interactive two-way distance learning

settings, handheld computers, and primary source historical archives are further examples.

Prensky (2013) posited that even mobile phones, which many students carry regularly, can be effective learning tools. The research conducted by Lei and Zhao (2006) further underscores that distinct technologies serve different functions in the educational experience of students, challenging any notion that the impact of technology can be generalised or treated as uniform. For researchers, it becomes crucial to identify which technologies are in use within classrooms and understand their intended educational roles. Two main distinctions become apparent: computers can function as tutors that help students develop foundational knowledge and skills, or they can be leveraged to meet a variety of instructional goals, fostering higher-order cognitive abilities, creativity, and research competencies (Ringstaff & Kelley, 2002).

Discrete Educational Software (DES), Integrated Learning Systems (ILS), Computer-Assisted Instruction (CAI), and Computer-Based Instruction (CBI) are some of the terms used by Murphy, Penuel, Means, Korbak, and Whaley (2001) to classify technological applications in education. These terms represent the fundamental ways in which students learn through technology. These software categories, along with tools like word processing programs, have been prominent in educational settings for over two decades and have contributed significantly to teaching and learning improvements (Becker, Ravit & Wong, 1999). Murphy et al. (2001) explain that the role of DES has evolved beyond merely supplementing lessons to becoming a primary method for introducing new material, facilitating independent study, and providing access to concepts otherwise difficult for students to grasp.

The growth of information and communication technology that students may now easily access at home and in schools is a major factor driving this change. These personal gadgets give educators and students new ways to improve student performance and meet the needs of developing 21st-century skills (Zhang, 2005). At this point, it is important to recognise three principal pedagogical approaches toward ICT usage that teachers typically adopt, as outlined by UNESCO (2004).

The first approach, known as the Integrated approach, involves the deliberate incorporation of ICT within specific subject areas to develop particular concepts and boost academic performance. This method requires a thorough and critical evaluation of the curriculum to select appropriate technological resources that align with curriculum goals and then seamlessly integrate them into lesson plans. The second method, termed the Enhancement approach, focuses on improving existing topics by introducing an ICT element into lessons and activities. For instance, a teacher might connect a computer to a projector to visually present theoretical content, thereby enriching class discussions and helping students visualise complex problems.

The third, Complementary approach uses ICT as a supplementary tool to support student learning, such as enabling students to type notes, submit assignments via email, or use word processors for homework. All three methods have the potential to improve educational outcomes. The integrated approach challenges students' prior knowledge and deepens their comprehension of the subject matter. The enhancement approach presents information in innovative ways that encourage discussion and require students to articulate their understanding. The complementary approach reduces the monotony of repetitive tasks like handwriting essays, allowing learners to concentrate more on substantive content (UNESCO, 2004).

Each of these approaches demands that educators possess a comprehensive understanding of ICT and the capability to integrate it effectively, whether by adapting their current teaching methods or by expanding their pedagogical expertise to accommodate technological tools in their instruction.

2.9.5 Evaluating Technological Pedagogical Content Knowledge through Empirical Research

Technological Pedagogical Content Knowledge (TPACK), which teachers often hold unconsciously, has sparked significant inquiry regarding the most effective ways to evaluate this multifaceted knowledge encompassing its seven core components. Shulman (2009) initially identified the foundational elements, Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK), alongside the intersecting domains: Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and the integrated TPACK. Building on this framework, Matt Koehler and Punya Mishra refined these concepts, and in 2007, the term TPACK evolved into TPACK to better emphasise the interplay among these three knowledge domains. Further, in 2008, the contextual dimension was incorporated to acknowledge that effective technology integration within teaching must always consider the specific educational environment (Mishra et al., 2012).

Since its inception, TPACK has become the predominant framework for defining the knowledge and skills required for the successful incorporation of information and communication technologies (ICT) into instructional practices. Consequently, this framework has prompted the need to develop methods for determining whether educators possess adequate TPACK and for tracking their development over time. This

overview first explores perspectives from both researchers and teachers on TPACK and then reviews the instruments designed for its measurement. It also discusses the techniques for applying these tools and the potential for fostering a unified understanding of TPACK (Mishra et al., 2012).

A variety of tools have been utilised to assess TPACK, with research distinguishing primarily between two categories: self-report surveys and performance-based evaluations. The former typically involves teachers' self-assessments of their confidence in the seven domains of TPACK, while the latter focuses on practical demonstrations such as lesson planning, classroom implementation, or task-specific performance. The TPACK Survey, created by Denise Schmidt and associates, is a popular self-assessment instrument. Using a five-point Likert scale, this survey asks pre-service and in-service teachers to score their level of confidence about each of the seven TPACK domains (Petra, Joke, Johan, & Jo, 2015).

For example, in the context of teaching mathematics, survey items could include statements like: "I keep up with important new technologies" (TK), "I can adapt my teaching style to accommodate a variety of learners" (PK), "I understand mathematics well enough" (CK), "I can identify the best ways to teach students to think mathematically" (PCK), "I know about technologies that help students understand and practice math" (TCK), "I can select technologies that improve student learning in class" (TPK), and "I can deliver lessons that seamlessly integrate mathematics content, technology, and pedagogy" (TPACK). Many researchers favour this survey because it reliably captures teachers' self-perceptions of their TPACK competencies. Moreover, the instrument can be adapted to emphasise particular technologies, pedagogical strategies, or knowledge domains as needed (Petra et al., 2015).

Despite its popularity, the use of self-assessment surveys to quantify the seven knowledge domains of the TPACK framework has sparked debate.

Some studies employing factor analysis report clear, distinct factors corresponding to the knowledge domains, while others find the domains difficult to differentiate statistically. Recent investigations suggest strong correlations, particularly among the technology-related domains, TK, TPK, TCK, and TPCK, indicating these areas may extend beyond simple combinations. The second main approach to assessing TPACK relies on performance-based measures.

Assessing teachers' TPACK may also involve instruments beyond self-report questionnaires, including performance-based evaluations and voluntary self-reflections, which aim to capture the extent to which teachers integrate technology effectively. Research into technology integration underscores that beyond knowledge and skills, teachers' attitudes toward technology and their pedagogical beliefs significantly influence successful adoption. Teachers may possess what is termed "adopted TPACK," meaning they understand and can articulate sound pedagogical technology integration conceptually, yet this does not necessarily translate into actual practice.

"In-use TPACK" describes the condition when teachers effectively transform their conceptual understanding into the practical design and delivery of technology-enhanced lessons tailored to specific content areas. Achieving this level requires not only knowledge and skills but also appropriate attitudes and professional reasoning capabilities (Petra et al., 2015).

This highlights the importance of professional development programs that address not only knowledge and skills but also teachers' beliefs, attitudes, and ability to engage in reflective professional thinking when integrating technology. While self-assessment surveys can be complemented with existing scales measuring attitudes and pedagogical beliefs, more comprehensive evaluation methods might include expanded rubrics or observational protocols to assess these more nuanced dimensions. Given the complexity and effort involved in such detailed assessments, expert observation of professional discourse may sometimes serve as a practical alternative. Furthermore, self-assessment instruments can be tailored to examine the influence of gender on teachers' TPACK.

2.9.6 Technological Pedagogical Content Knowledge and Teachers' Qualification

The credentials of teachers are very important in the context of teaching and learning. To successfully meet the needs of the educational system, educators must exhibit a blend of creativity, innovation, awareness, and subject-matter expertise. Pre-service teachers have been the focus of a large portion of the research that has been done on Technological Pedagogical Content Knowledge (TPACK). For example, Chai et al. (2011) highlighted that teacher education programs frequently restrict their focus to skill-specific, technology-related courses. Similarly, Lux (2010) pointed out that teachers need to be able to integrate technology with both pedagogy and subject matter for it to be successfully integrated into instructional practices. Graham, Borup, and Smith (2012) further support this viewpoint by emphasising the value of exploring the fundamental knowledge that underpins teachers' use of technology in the classroom. They did admit, though, that this element frequently goes unnoticed, particularly when taking into account both pre-service and in-service teachers.

Investigations pertaining to TPACK have been conducted widely in the United States and have progressively spread into the Mediterranean and Asian areas, encompassing nations like Vietnam, Singapore, China, Turkey, and Malaysia. However, as Koh et al. (2011) note, a wider range of research conducted outside of the United States is still necessary to ascertain how cultural factors may affect teachers' comprehension and use of TPACK. A noteworthy longitudinal study by Niess (2013) focused on Mathematics educators for three years. Niess utilised a five-stage developmental model to characterise the progression of Mathematics teachers' TPACK, which included the stages of recognising, accepting, adapting, exploring, and advancing.

During the initial recognising stage, educators demonstrated familiarity with spreadsheet software and acknowledged its potential as a mathematical instructional tool. In the accepting stage, they began to see spreadsheets as beneficial for both problem-solving and facilitating specific mathematical topics. By the adapting stage, teachers were actively involving students in spreadsheet-based activities, albeit as supplementary exercises to reinforce previously taught concepts. In the exploration phase, educators consistently employed spreadsheets as integral components of their lesson plans, signifying a deeper engagement with instructional technology. At the advanced stage, teachers effectively translated mathematical ideas into spreadsheet-based learning activities designed to enhance student comprehension and critical thinking. Moreover, throughout these stages, educators remained committed to refining their planning, delivery, and assessment strategies through continuous exploration of spreadsheet applications.

From the above studies, it becomes evident that TPACK has evolved through substantial development and has proven useful both as a research model and as a guide

for instructional practice. Research has heavily focused on the domains of Mathematics and Science, possibly due to the abstract nature of these subjects, which necessitates the support of digital tools to convey concepts effectively. Conversely, the application of TPACK within English as a Foreign Language (EFL) instruction has received relatively limited attention, as indicated by Lux (2010).

Exploring TPACK in the EFL domain is particularly compelling, given that EFL instruction, much like Mathematics and Science, often involves standardised testing and conceptual challenges. Wu and Wang (2015) investigated the TPACK levels of 22 in-service EFL teachers in Taiwan, one of the few research in this field. Furthermore, Tseng (2014) presented a technique for assessing EFL teachers' TPACK from the viewpoint of their students, and Baser, Kopcha, and Ozden (2015) created a TPACK framework specifically for EFL teacher training. According to this research, the participating teachers' TPACK was generally of excellent quality. Using a self-assessment questionnaire, Mahdum (2015) examined the use of TPACK by senior high school EFL teachers in Pekanbaru, Indonesia, in another pertinent study. Despite these efforts, the existing body of literature indicates that no thorough investigation of EFL instructors' professional growth within the TPACK framework has yet been conducted.

2.9.7 Teachers' Experience and Technological Pedagogical Content Knowledge

One important factor that warrants consideration when analysing the obstacles to successfully integrating ICT into classroom education is the breadth of instructors' instructional expertise, which is a crucial part of the TPACK knowledge base. Prensky (2005) investigated nine experienced chemistry teachers' Pedagogical Content Knowledge (PCK). In addition to using instructional models to teach electrochemistry,

redox processes, and acid-base reactions, these teachers received professional development that concentrated on the typical difficulties that students encounter.

As part of the study, the teachers participated in interviews that explored their Pedagogical Content Knowledge in two main areas: first, their understanding of the difficulties students typically encounter in acid-base chemistry, and second, the strategies they employed to teach the concepts of acids and bases. Additionally, the educators were asked to assess the accuracy of student responses from a prior investigation that involved interviews with students about their conceptual understanding of acids and bases.

The study also required the teachers to develop narrative storylines to visually depict their levels of satisfaction with how they taught acid-base chemistry (Prensky, 2013). Findings revealed that although all participants recognised certain common student misconceptions, particularly confusion among different scientific models, only a small number emphasised the need to address the diverse conceptual frameworks of acids and bases explicitly. Most teachers believed it was sufficient to distinguish between the macroscopic or observable aspects and the microscopic or particle-level explanations. Moreover, the nature of the teachers' reflective practices varied: while some focused their reflections on identifying and addressing student learning challenges, others were more preoccupied with evaluating their teaching outcomes and overall performance (Prensky, 2013).

2.9.8 Identified Gaps in the Literature

A substantial body of scholarly work has examined the Technological Pedagogical Content Knowledge (TPACK) of both pre-service and in-service science educators. Since Shulman (1987) introduced the foundational concept, extensive research has

emerged aiming to explore and evaluate various aspects of teachers' knowledge (Magnusson et al., 1999). Globally, investigations into TPACK span across multiple academic fields, including mathematics (Hill, 2011; Kilic, 2009) and science (Rohaam et al., 2009).

Although relatively few, studies conducted within the Ghanaian context have also explored TPACK in various disciplines. For example, research has been carried out in science (Eshun, 2014; Siemoh, 2015), social studies (Siaw-Marfo, 2011), mathematics (Agyei, 2013), and English (Addy & Ofori-Boateng, 2015). Eshun (2014) examined science teachers' pedagogical content knowledge (PCK) and how it was manifested in instructional settings. She employed a quasi-experimental methodology, gathering data from a strategically selected sample of senior high school science teachers, and implemented a workshop-based intervention to enhance the PCK of the treatment group. Similarly, Siemoh (2015) undertook a mixed-method study that centred on the TPACK of science teachers, examining its perceived influence on student academic performance at the SHS level.

This current research is particularly relevant as it zeroes in on the discipline-specific dimension of TPACK. By focusing specifically on biology education, the study extends existing literature both within Ghana and globally. It aims to provide comprehensive insights into the TPACK competencies that senior high school biology teachers possess, particularly about teaching biology concepts, and how these competencies affect student learning outcomes. Moreover, it seeks to shed light on the specific difficulties biology teachers face when attempting to integrate their TPACK into effective instructional practices at the SHS level.

2.9.9 Evaluation of the Reviewed Literature

The TPACK framework emerged in response to the need for a cohesive concept guiding the integration of technology in teaching (Archambault & Barnett, 2010). Conceptualised by Koehler and Mishra (2005; 2006), this framework extends Shulman's (1986) notion of pedagogical content knowledge, which underscored the specialised knowledge necessary for effective teaching.

In the educational setting, TPACK comprises seven interrelated components: Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPCK). Each construct represents a critical aspect of the teacher's professional knowledge base.

Pedagogical Knowledge (PK), as theorised by Shulman (1987), pertains to educators' grasp of foundational educational philosophies and strategies for classroom management and organisation. It also encompasses their understanding of the nature of teaching and learning (Abbitt, 2011), as well as their instructional beliefs, practices, and philosophies (Grossman, 1990). Content Knowledge (CK), on the other hand, refers to a teacher's mastery of the concepts, theories, and structures within a particular subject area.

The TPACK model, as detailed by Koehler and Mishra (2005; 2006), highlights the intersections among TK, PK, and CK, which yield four compound constructs: PCK, TCK, TPK, and TPCK. Within this framework, Pedagogical Content Knowledge (PCK) integrates pedagogical strategies with subject matter expertise, emphasising how subject content can be organised and presented for effective instruction (Shulman,

1986). PCK goes beyond simply knowing content or pedagogy in isolation; it represents their dynamic integration.

Technological Content Knowledge (TCK) involves recognising how content is influenced by technological tools and how emerging technologies can be harnessed to represent specific content concepts (Cox & Graham, 2009). Technological Pedagogical Knowledge (TPK), by contrast, addresses the understanding of how technological tools can transform instructional practices and enhance the teaching and learning experience. The capstone of the framework, Technological Pedagogical Content Knowledge (TPCK), arises from the intricate interplay among TK, PK, and CK. It embodies a comprehensive understanding of how these domains coalesce to support meaningful, technology-enhanced instruction (Koehler & Mishra, 2009). The TPACK framework posits that these components should not be examined in isolation, as their interdependency is crucial for effective teaching. As such, for teachers, particularly biology teachers, technology, content, and pedagogy must be viewed as interconnected domains, rather than separate areas of expertise.

Despite the growing body of research grounded in the TPACK model (Voogt, Fisser, Pareja Roblin, Tondeur, & Van Braak, 2013), some scholars have critiqued its theoretical foundations. Graham (2011) argued that while the framework may appear straightforward, it conceals a substantial level of complexity. This complexity has led to debates over the distinctiveness and clarity of the individual constructs (Archambault & Barnett, 2010; Graham, 2011).

Even though the precise definitions of some constructs remain debatable (Graham, 2011), TPACK continues to offer valuable insights into the knowledge base teachers require for effectively incorporating technology into their instruction. It has evolved

into a recognised conceptual model for understanding how teachers can successfully teach with technology (Cox & Graham, 2009; Niess, 2012; Chai et al., 2016). Literature on the subject appears to favour a transformative rather than integrative perspective (Angeli & Valanides, 2009), thus supporting the idea that TPACK constitutes a unique body of knowledge essential for teaching in the digital age.

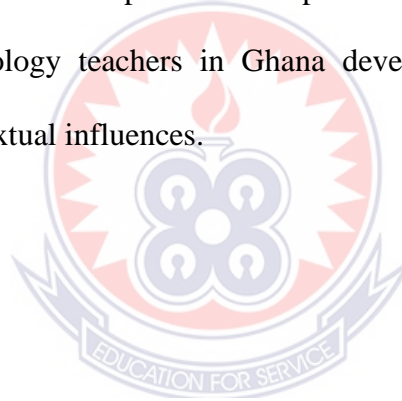
Niess (2012) introduced a developmental trajectory for TPACK, identifying five stages: recognising, accepting, adapting, exploring, and advancing. These stages capture the progression of teachers' proficiency with TPACK and are associated with distinctive characteristics that influence how educators use technology in their classrooms.

Because TPACK is shaped by contextual influences and its application is dynamic, teachers' levels of TPACK may vary according to the specific teaching environment and circumstances (Niess, 2012). The reviewed literature illustrates the increasing scholarly attention TPACK has garnered since its introduction. Research on the framework spans a variety of methodologies and educational settings. For instance, Koehler et al. (2012) and Voogt et al. (2013) documented over 200 studies that referenced, measured, or adopted TPACK as a foundational framework.

Numerous studies have focused on assessing the TPACK levels of preservice teachers (Chai et al., 2011; Horzum, 2013), while others explored its use among in-service teachers (Graham et al., 2009). Findings from some of these investigations highlighted the significant influence of TPK and TCK in the development of TPACK (Chai et al., 2011; Horzum, 2013; Pamuk & Marino, 2013). These findings suggest that fostering TPACK requires emphasising the synergies among the knowledge domains rather than treating TK, PK, and CK as independent constructs.

While there has been growing interest in TPACK, only a limited number of studies have been conducted in the Ghanaian context. Specifically, three studies, Orlando (2013), Niel (2014), and Ayoub (2015), have explored TPACK in Ghana, focusing respectively on mathematics education, social studies instruction, and pre-service teacher training. None of these investigations addressed TPACK in the context of biology education.

Consequently, there is a noticeable research gap regarding biology teachers' TPACK in Ghana. Furthermore, despite widespread recognition that contextual variables affect TPACK integration, few studies have examined how these factors shape teachers' application of the framework in practice. The present study aims to address this void by exploring how biology teachers in Ghana develop and utilise their TPACK, particularly with contextual influences.



CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Overview

The research techniques that were employed to conduct the study are described in this chapter. Research Methods, Research Design, Setting, Population, Sample, Sampling Methods, Research Instruments, Research Tool Validation, Data Gathering Methods, Data Analysis Methods, and Ethical Considerations.

3.1 Research Approach

The pragmatic paradigm is maintained in this study due to the impact of the research technique. As per the findings of Biesta (2010) and Alise and Teddlie (2010), the pragmatist paradigm maintains that a single paradigmatic perspective in research is insufficient. They contend that, practically speaking, a methodology ought to permit the combination of techniques that, when used in concert, could provide insight into participants' actual behaviours, the beliefs that underlie those behaviours, and the outcomes that such behaviours are likely to produce. According to Kivunja and Kuyini (2017), the positivist and interpretivist paradigms are two completely different paradigms that were combined to create the pragmatist paradigm.

The positivist paradigm holds that knowledge can only be discovered by experimentation and observation. Accordingly, reality is steady and amenable to observation or objective description (Levine, Sober & Wright 1987; Rahi, 2017). This paradigm-based research employs logical reasoning, hypothesis development, and testing. Providing mathematical formulas, computations, extrapolations, and expressions along with operational definitions to conclude (Kivunja & Kuyini, 2017).

Conversely, the interpretative or constructive paradigm is based on the idea that people should be able to give their subjective interpretation of what they see or think to be true.

Kivunja and Kuyini (2017) also note that research works that apply this paradigm endeavour to “get into the head of the subjects being studied” to comprehend and deduce what the subject is thinking or the meaning s/he is making of the context. The nature of this study demands the use of both paradigms to be able to understand and interpret the actions of research participants, hence the use of the pragmatist paradigm. Their emphasis is on obtaining an in-depth understanding of a concept and exploring the understanding of the world in which they live (Rahi, 2017).

3.2 Research Design

According to Creswell (2012), a research design is a comprehensive plan outlining the steps involved in conducting a research inquiry, including determining, testing, or evaluating variables for analysis, choosing a study sample, gathering data for hypothesis testing, and analysing findings. Akhtar (2016) further emphasises the importance of research design, describing it as the "glue" that holds together every component of a research endeavour.

According to Creswell (2014), the explanatory sequential mixed method is a research design that combines quantitative and qualitative methods in a two-phase approach. Teddlie (2010) further emphasises that by integrating multiple methods, researchers can demonstrate a more rigorous and systematic approach, enhancing the study's credibility.

Data on the degree of TPACK of biology teachers in teaching biology ideas was gathered using the explanatory sequential mixed approach in order to adequately address the research issues. Because both qualitative and quantitative research methods have their forms of strengths and weaknesses, a mixture or a blend of their data collection procedures provides a better bid to fortify the strengths each method possesses and numbs the weaknesses each method may hold, hence, the mixed methods approach (Cresswell, 2014). Cresswell (2012; 2014) further indicates that in the application of the explanatory sequential mixed-method design, quantitative data will be collected and analysed, followed by qualitative data. In this study, questionnaires were initially used to collect quantitative data about teachers' TPACK levels and the challenges they face in teaching biology topics. This was followed by the use of interviews and observations to collect qualitative data about biology teachers' exhibition of the TPACK components of CK, PK, and KL, as well as the challenges they faced in teaching biology concepts.

3.3 Study Area

The study areas for this research encompass four municipalities in the Greater Accra Region of Ghana: Ga-East Municipal, Ga-West Municipal, La-Nkwantanang Municipal, and Adenta Municipal. Each of these areas has its unique characteristics and demographics that contribute to the overall educational landscape of the region.

The Ga-East Municipal, located in the northern part of the Greater Accra Region, is one of sixteen districts in the region, covering a land area of about 85.7 square kilometres with its capital at Abokobi. According to the 2021 Population and Housing Census, the municipality has a population of 283,379, representing 3.68 percent of the region's total population. The population is almost evenly split between males (49.4%)

and females (50.6%), with a high urbanisation rate of 93.8%. Notably, the municipality has a relatively mature population, with less than half (40.3%) below 20 years of age. Education plays a significant role in Ga-East Municipal, with a high literacy rate of 93.6% among the population 11 years and above. Interestingly, male literacy (96.7%) surpasses female literacy (91.1%).

A majority of the literate population (59.3%) can read and write in both English and a Ghanaian language. The municipality boasts six privately owned Senior High Schools and one public senior high school at the time of this study, serving its educational needs. Moving to the Ga-West Municipality, we see a larger population of 314,299 as of the 2021 census, with a slightly higher proportion of females (158,756) compared to males (155,543). Unlike Ga-East, Ga-West has a more youthful population, with 33.4 percent aged below 15 years. The literacy rate in Ga-West is also high at 92.3% for those 11 years and above, with 56.3% of the literate population able to read and write in both English and a Ghanaian language.

Education statistics in Ga-West Municipality reveal that out of the population aged 3 years and older, 6.7 percent have never attended school, while 55.9 percent have attended in the past, and 37.4% are currently attending. The distribution across education levels shows a concentration in primary education (41.3%) and a smaller proportion (6.2%) at the tertiary level.

Shifting focus to the Adenta Municipality, located in the central part of the Greater Accra Region, we find a population of 237,546 as of the 2021 census. Adenta is notable for its natural resources, including several rivers and dams that facilitate farming and agricultural activities. Educationally, Adenta presents an interesting case with 13 public basic schools, 135 private basic schools, and nine private Senior High Schools.

However, the absence of a public SHS in the municipality forces students to move to other districts for senior high education.

Lastly, the La-Nkwantanang Municipal, created in 2012 to deepen decentralisation, has a population of 244,676 according to the 2021 census.

The municipality shows a slight gender imbalance with females constituting 51.5 percent of the population. Education-wise, La-Nkwantanang boasts a literacy rate of 91.3% among those 11 years and above, with males (95.4%) showing higher literacy compared to females (87.5%). Notably, 55.4% of the literate population can speak and write in both English and Ghanaian languages.

These four municipalities, each with their unique demographic and educational profiles, provide a diverse backdrop for the study of technological pedagogy and content comprehension among biology instructors in senior high schools. The varying literacy rates, school distributions, and population characteristics across these areas offer rich ground for comparative analysis and insights into the educational landscape of the Greater Accra Region.

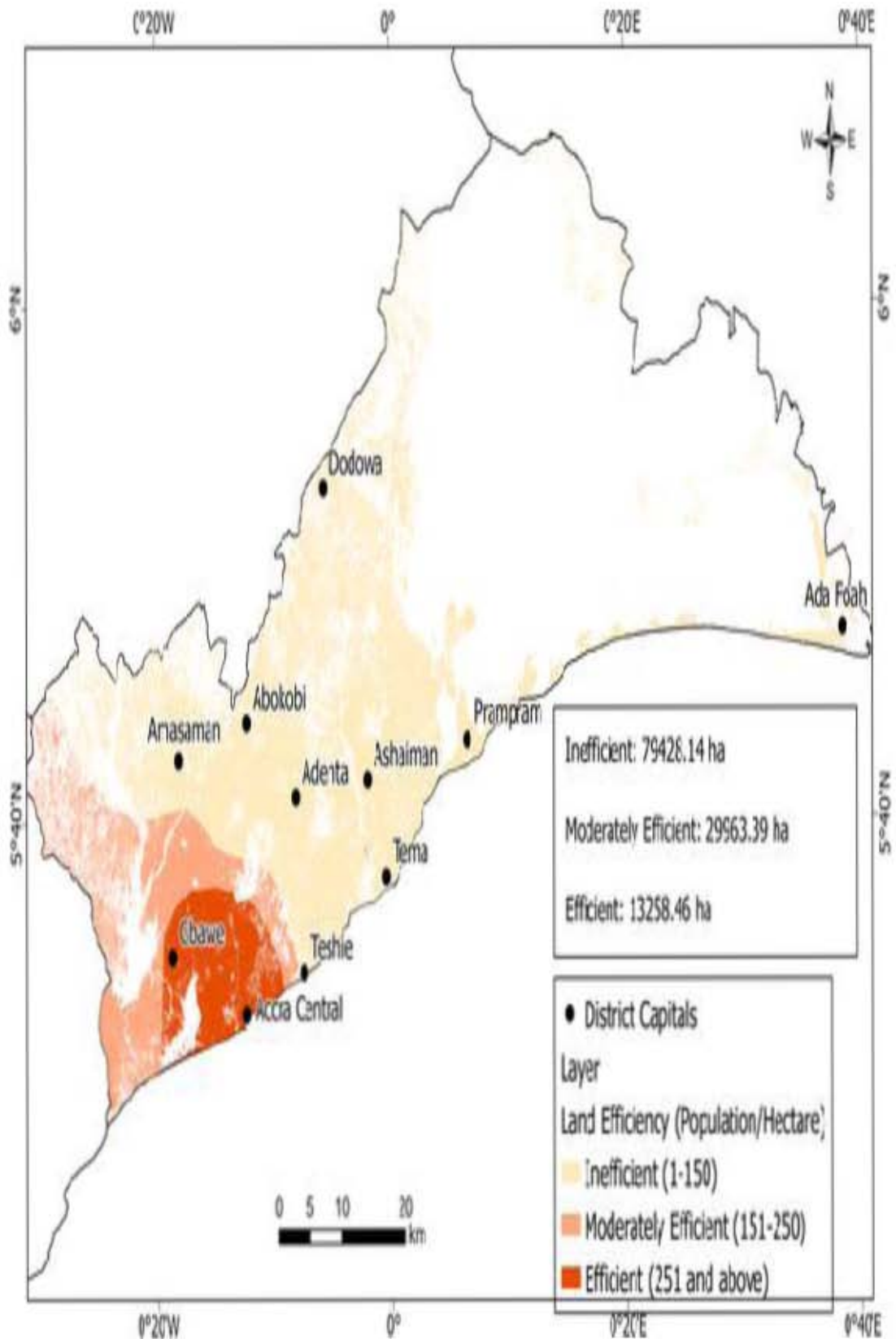


Figure 3: Map of Research Area (Greater Accra Region)

Source: Ghana Statistical Service (2010)

3.4 Population

The concept of population is crucial in research methodology and sampling. The Oxford English Dictionary (OED) (2018) provides a comprehensive definition, describing a population as a real or hypothetical totality of objects or individuals under consideration, of which the statistical attributes may be estimated by the study of a sample or samples drawn from it. Expanding on this definition, Subbey (2017) added that the term population refers to a collection of people, items, or events about which you want to make inferences.

Understanding the nature of populations is essential because it's often impractical or impossible to examine every member of a population. This reality necessitates the process of sampling, which allows researchers to generalise larger groups based on smaller, representative subsets.

In the context of this study, the population is defined at two levels: the target population and the accessible population. The target population comprised all senior high school biology teachers in the selected municipalities. This broad group represents the ideal scope of the study's findings.

However, practical considerations led to the identification of a more specific accessible population. This group included all senior high school biology teachers from both public and private schools in the selected municipalities. Specifically, the accessible population consisted of 75 biology teachers from 5 public secondary schools and 26 private secondary schools.

The choice of this accessible population was strategic and practical. The secondary school biology teachers in these municipalities were selected because all the schools in the area were easily accessible.

By clearly defining and distinguishing between the target and accessible populations, the study established a solid foundation for its sampling methodology and subsequent analysis. This approach ensured that the research findings could be meaningfully interpreted within the context of the broader target population

3.5 Sample and Sampling Techniques

For this study, convenience sampling was chosen as the primary sampling method. As defined by Creswell (2014), convenience sampling is a non-probability sampling technique where participants or cases are selected based on their accessibility and availability to the researcher. This method is particularly useful when researchers need to gather data quickly and efficiently from readily available sources.

Convenience sampling is characterised by its ease of implementation. As Boateng (2015) notes, researchers typically choose individuals or cases that are readily available, easily accessible, in close proximity, or available during the research period. These characteristics make convenience sampling an attractive option for studies with time or resource constraints.

The selection of convenience sampling for this study was based on its practicality and efficiency. It allowed for the quick identification and inclusion of participants who met the criteria and were willing to participate. This approach was particularly suitable given the study's focus on biology teachers in specific municipalities, where accessibility was a key consideration.

Using convenience sampling procedures, a total of 73 biology teachers were selected as the study sample. This sample size was determined based on the accessibility of participants and the resources available for the study.

The convenience sampling method facilitated the efficient recruitment of these teachers from both public and private schools in the selected municipalities.

3.6 Research Instruments

The nature of the study, which involved measuring teachers' knowledge bases, was difficult because knowledge is an intangible aspect of teachers' professional development (Lee & Choi, 2003). The complexity of even measuring TPACK in particular is more difficult (Eshun, 2014). However, there have been various researchers who have used divergent means to assess the nature of TPACK teachers possess in teaching particular topics. Inspired by such literature, questionnaires, interviews, and observation guides were the instruments used for data collection.

To assess the consistency of the results derived from each of the instruments utilised, the researcher triangulated the data using questionnaires, semi-structured interviews, and observation guides. When Baser, Kopcha, and Ozden (2015) said, "Triangulation in research is to test for consistency of findings obtained through different instruments," they endorsed this viewpoint. As a result, several tools must be employed to verify the data collected. Each of the instruments is described as follows:

3.7 Questionnaire

The instrument employed in this study was the *Items for TPACK Survey* (ITS), adapted from Sahin (2011) and Archambault and Crippen (2009). The questionnaire was carefully structured into two main parts, Part I and Part II, to gather comprehensive

data relevant to the study's objectives. Part I, referred to as Section A, was designed to collect demographic information from the respondents. This section captured important biographical data such as age, gender, educational qualification, teaching experience, and subject specialization, all of which were considered essential for contextualizing the findings.

Part II of the questionnaire comprised four sections: B, C, D, E, and F. These sections were all composed of closed-ended items aimed at evaluating various domains of knowledge and practices associated with the TPACK framework. Section B included 28 items and used a four-point Likert scale with options such as *Accessible (A)* and *Not Accessible (NA)*. The purpose of this section was to assess the level of access teachers had to various ICT tools, as well as their familiarity and usage patterns regarding these technologies in instructional settings.

Section C adopted a five-point Likert scale consisting of the categories: *Need Improvement (1)*, *Fair (2)*, *Average (3)*, *Good (4)*, and *Very Good (5)*. This section was intended to measure teachers' self-assessed competence in using ICT tools and strategies. It helped to identify areas where teachers perceived themselves as proficient or in need of development, thereby offering insight into their practical readiness for technology integration.

Sections D, E, and F employed a different five-point Likert scale, where responses were rated numerically as follows: *1 = Undecided*, *2 = Strongly Disagree*, *3 = Disagree*, *4 = Agree*, and *5 = Strongly Agree*. These sections were focused on measuring specific dimensions of teachers' professional knowledge. Section D contained six items that evaluated teachers' technical knowledge, their understanding and ability to use technological tools. Section E consisted of five items assessing pedagogical

knowledge, focusing on how well teachers understood and applied instructional strategies. Section F also included five items, which examined technological pedagogical content knowledge (TPACK), the integration of content knowledge, pedagogy, and technology.

For the interpretation of results in Sections D to F, a statistical approach was employed whereby the total weightings of the scale ($1+2+3+4+5 = 15$) were divided by the number of scale points (5), yielding a mean of 3. A computed mean score of 3.10 or above indicated that respondents agreed with the statements in the questionnaire, while a score of 3.00 or below indicated disagreement. This systematic structure ensured that the data collected was analytically robust and suitable for drawing meaningful inferences about biology teachers' TPACK competencies.

3.8 Observation

Sigh (2010) describes observation as the method used for gathering data about environmental phenomena and determining the various processes related to the situation under observation. Liu and Maitlis (2010) also posited that non-participant observation is usually used as a complementary instrument to other data collection methods and can offer a more nuanced and dynamic development of phenomena that cannot be as easily captured through other methods.

Because "observation brings the investigator into contact with the phenomenon being studied," an observation guide was utilised in this study (Kumekpor, 2002, p. 31). In this sense, observation turns into a reliable and efficient technique to report exactly what is true about the topic being studied. By using this method, the researcher was able to observe biology teachers in the study area teaching and studying biology.

To cross-check the questions on biology instructors' technology pedagogical subject understanding, an observation checklist was used (Appendix E).

The observation checklist was adapted from the classroom observational schedule used by the University of Education, Winneba (UEW), to observe internship students. This checklist contains 25 observable items on the schedule that capture most of the necessary PCK elements that could be exhibited in a good lesson that yields effective learning. Again, the observable elements on the schedule were generated from the performance indicators of the UEW professional teaching standards. These performance indicators are rooted in 5 principles that guide teacher development and assessment (Institute for Teacher Education & Continuing Professional Development (ITECPD), 2018).

3.9 Interviews

Interviews are generally viewed as social interaction conducted through conversations between two people on a topic with a shared interest to generate knowledge (Eshun, 2014). From the perspective of Cohen, Manion, and Morrison (2007), interviews differ from ordinary everyday conversations in that it has a specific intent, are question-based, and require responses that are explicit and often as detailed as possible. Bell (2009) adds that “an interview is more than just an interesting conversation (p.161).

Interviews provide direct interaction between interviewer and interviewee, which facilitates the provision of a specific practical suggestion by allowing one (the interviewer) to enter into the other person's (interviewee's) perspective (Cohen et al., 2007).

Qualitative data were gathered from respondents using a semi-structured interview guide that was adapted from Eshun (2014). To allow for flexibility, the study employed a semi-structured interview guide because teachers' comments might need more clarification through questioning. Three sections were used to generate the interview schedule's items. Information on teachers' content knowledge for teaching certain biology topics was gathered in the first segment, and information on teachers' pedagogical knowledge for teaching particular biology topics at the level they teach was gathered in the second segment. The third section generated data on teachers' knowledge of learners. The issues of challenges they face when teaching these topics in biology were stated as items under each section in the interview schedule. In all, the semi-structured interview was guided by 12 items grouped under three sections.

3.9.1 Justification of the Triangulation Method

The researcher cross-checked the authenticity of the responses provided on the questionnaire using both observation and interview guides. The validity of the answers provided by biology teachers in the questionnaire was examined using the observation checklist. To do this, the observation guide was subjected to personal coding to indicate the content understanding and technology pedagogy of biology teachers.

Cohen, Manion, and Morrison (2007) define triangulation as the use of two or more data-gathering techniques in the investigation of a specific aspect of human behaviour. They continued by saying that the triangulation technique seeks to map out or more fully explain the richness and complexity of human behaviour by looking at it from several perspectives and using both quantitative and qualitative data.

In light of this, Oslen (2004) noted that triangulation is beneficial due to the enhanced quality control attained by merging techniques and data sources. The quality of this study was enhanced by the complementary roles played by each of these data collection techniques.

3.9.2 Validity of the instruments

According to Fraenkel, Wallen, and Hyun (2012), validity refers to the defensibility of the inferences that may arise as a result of using an instrument for data collection. As much as possible, these inferences were corrected to permit the instruments to collate valid conclusions about the characteristics under study. For that matter, the face and content validity of the instruments were confirmed.

3.9.3 Face Validity

The determination of face validity was geared towards ensuring that items developed in the observational checklist and questionnaire were devoid of ambiguity, had the correct frame of sentences, and the length of questions and scenarios used was as valid as possible. The instrument was given to the supervisor and other experts in the field of biology to establish the face validity of the instrument.

After scrutiny of the instruments' corrections, suggestions and adjustments were taken into consideration, and the resultant changes were made where necessary to ensure they are valid as much as possible.

3.9.4 Content Validity

Content validity is an essential element in research instrument design, as it ensures that the instrument accurately represents and measures all aspects of the concept or construct being studied. As defined by Cohen et al. (2007), an instrument demonstrates

content validity when it fairly and comprehensively covers the domain or items it intends to measure. Expanding on this concept, Fraenkel et al. (2012) posit that content validity encompasses the appropriateness of the content, its comprehensiveness, its logical approach to the intended variable, and the suitability of the items in representing what is to be assessed. To establish content validity, Fraenkel et al. (2012) suggested involving "someone" capable of making a judgment about the adequacy of the instrument. Following this recommendation, the content validity of the instruments used in this study was determined through a rigorous process. The study's supervisor, acting as the qualified judge, subjected the instruments to critical scrutiny based on the UEW professional teaching standard. This thorough examination ensured that the instruments were comprehensively and appropriately designed to measure the intended variables.

After this meticulous review, the supervisor declared the contents of the instruments valid for the data they sought to collect, thus establishing their content validity for this research.

3.9.5 Reliability of Instruments

Reliability is a crucial aspect of research instrumentation. Fraenkel et al. (2012) noted that due to errors of measurement, researchers expect some variations in test scores when an instrument is administered to respondents more than once, when two different forms of an instrument are used, or even from one part of the instrument to another. To address these potential variations and ensure the reliability of the instruments used in this study, a comprehensive pilot testing process was implemented.

The instruments underwent a pilot test in the Ga South municipality, chosen for its proximity to the study area and similarity to the location and biographical information

of biology teachers in the Accra region. This pilot test was crucial for assessing the validity of the semi-structured interview schedule, the observation schedule, and the TPACK questions. A convenient sample of sixteen biology teachers from four senior high schools in the Ga South Municipality were selected for this purpose. Additionally, two instructors out of the sixteen were purposely chosen to participate in the pilot program for an interview schedule and observation guide. Before the instrument pilot testing, two biology instructors received training on how to assess the respondents' answers to the task-based questionnaires using the generated rubrics and how to observe using the developed observational schedule.

This training was essential to ensure consistency in the evaluation process. Following the completion of pilot testing for the task-based questionnaires and observational schedule, the data from the two raters were categorised and classified to ascertain the inter-rater reliability of the scores.

To evaluate the agreement between the two raters' assessments, Cohen's Kappa (Cohen's K) test was employed. The results showed a significant degree of agreement, $k = .785$ (95% CI, .300 to .886), $p < .000$. Interpreting these results requires understanding the scale of Kappa values. As a rule of thumb, values of Kappa less than 0 are considered poor agreement; 0.0 to 0.20 are regarded as slight agreement; 0.21 to 0.40 are fair; 0.41 to 0.60 are considered moderate; 0.61 to 0.80 substantial, and 0.81 to 1.0 are also considered outstanding (Landis & Koch, 1977). Altman (1999) further suggested that most statisticians prefer Kappa values to be at least 0.60 and most often higher than 0.70 before claiming a good level of agreement. In this context, the Cohen's K value ($k = .785$, $p < .000$) obtained from the analysis was very substantial, indicating a high level of reliability for the observational guide and task-based ratings.

The importance of instrument pilot testing cannot be overstated. As noted by Creswell (2008) and Dillman (2000), it contributes to the production of steady, consistent, and ambiguity-free outcomes that are both legitimate and dependable. In this study, the pilot testing process yielded several valuable insights and improvements. It assisted in reorganising the scenario content for the TPACK into a succinct narrative that emphasises the key components of the lessons being taught. It also facilitated the modification of questions on the tasks and questionnaires that were hard to comprehend, and led to the addition of new questions on the difficulties teachers faced in teaching biology to the original interview guide.

Moreover, following the observational schedule's pilot testing, the importance of audio recording the observational procedure became evident.

Through this comprehensive pilot testing and subsequent refinement process, the reliability and validity of the research instruments were significantly enhanced, ensuring that the data collected would provide a stable and consistent basis for the study's findings and conclusions.

3.9.6 Data Collection Procedure

An introductory letter (Appendix F) was collected from the Department of Biology Education, Winneba, which was used to obtain permission from each municipal Director of Education to conduct the study in senior high schools in each municipality.

The data collection was in three phases, as shown in Table 1 below:

Table 1: Phases for data collection

Phase	Purpose
Phase 1	Distribution of introductory letters and making acquaintances with the headteachers and teachers.
Phase 2	Administration of Questionnaire and Collection
Phase 3	Classroom observation and interview of selected teachers

The data collection process for this study was meticulously planned and executed in three distinct phases, each building upon the previous one to ensure comprehensive and reliable data gathering.

Phase 1 began with the distribution of introduction letters to each of the study's sampled schools. This initial stage served a dual purpose: it facilitated introductions between the researcher, teachers, and head teachers while also clearly outlining the goals and potential benefits of the research. This step was crucial in establishing rapport and ensuring cooperation from all participants.

Following discussions and considerations with headteachers and teachers. Phase 2 was scheduled to commence two weeks after the completion of Phase 1. This second phase focused on the self-administration of questionnaires by each instructor sampled for the study. To ensure clarity and understanding, the researcher took the time to read through and explain the requirements for each task and scenario before the respondents began answering. On average, each respondent was allotted 40 minutes to complete the questionnaires.

An important aspect of this phase was the involvement of research administration assistants in supervising the questionnaire administration process. Before distribution, research assistants were briefed on the importance of monitoring teachers as they responded to prevent any malpractices that could potentially affect the integrity of their answers. This supervision was particularly crucial for items in the TPACK questionnaire pack that assessed teachers' content knowledge, as it prevented teachers from seeking answers from external sources. This phase of data collection spanned from November 7, 2023, to November 24, 2023.

To facilitate the identification of participants for subsequent observation sessions, a coding system was implemented. Each participant who completed the questionnaire was assigned a code name based on an ordinal number (reflecting the order in which they answered the questionnaires) and the initials of their school's municipality.

Importantly, participants' consent was obtained for this coding process, and they were assured that the tracking of their scores would remain confidential, known only to the researcher.

Two weeks after the questionnaire collection, the study progressed to Phase 3. This phase involved classroom observations and interviews with selected respondents following their lessons. Four lessons were observed on different days with two sampled teachers, with each day's performance indicators of the TPACK elements exhibited by the teachers being scored using a specially designed observation schedule. To provide ample opportunities for teachers to demonstrate their TPACK elements in teaching interaction in nature, each teacher taught two different lessons from this unit at their respective teaching levels.

The observation process utilised a scoring system to describe the degree of evidence with which participants demonstrated TPACK elements in teaching biology concepts. The scoring key ranged from 0 (No Evidence) to 4 (Clearer Evidence). To aid in the analysis of these observed lessons, all sessions were audiotaped with the participants' permission.

Following each observation, face-to-face interviews were conducted with the sampled participants. These interview sessions, lasting between 30 to 40 minutes, were also audiotaped after obtaining consent from the respondents. This multi-phase approach, combining questionnaires, observations, and interviews, ensured a comprehensive and in-depth exploration of the teachers' TPACK in biology instruction.

3.9.7 Data Analysis

Lee (2010) indicated that when a researcher organises and summarises data, using descriptive statistics and /or inferential statistics, he or she is doing data analysis. In this study, the explanatory sequential design used in the study requires that quantitative data be analysed first, followed by qualitative data.

3.9.8 Quantitative data

The quantitative phase of the study involved a comprehensive statistical analysis utilising the Statistical Package for the Social Sciences (SPSS) version 24. This analytical process was structured to address multiple research questions and hypotheses, each requiring specific statistical approaches.

The analysis began with the compilation of demographic data, providing a crucial foundation for understanding the study population. This demographic overview set the stage for a more detailed examination of the research questions.

To address research question 1, which focused on pedagogical subject knowledge, the researcher employed a systematic approach. He arranged each respondent's scores in a table, utilising frequency counts and percentages for clear representation. Building on this initial analysis, they further categorised the Pedagogical Content Knowledge (PCK) levels into five distinct categories: need improvement, average, good, very good, and exceptional. Each of these categories was then individually examined using the same statistical methods of frequency counts and simple percentages, providing a nuanced understanding of the distribution of PCK levels among the participants.

The study next turned its attention to research questions 2 and 3, which investigated the availability of contemporary digital resources for biology instruction at the senior high school level as well as the proficiency of biology teachers in integrating new technologies in the classroom. This analysis drew from items in section B of the questionnaire, maintaining consistency in methodology by employing simple percentages and frequency counts. This approach provided a clear picture of the technological landscape in biology education, offering insights into both teacher competencies and resource availability.

Having established a comprehensive view of the pedagogical and technological aspects, the research then delved deeper into a key hypothesis. This hypothesis centred on the potential difference in TPACK based on the professional status of biology teachers. Addressing this question requires a shift in statistical approach, moving from descriptive to inferential statistics. Specifically, the researchers employed a t-test to determine if any observed differences between these two groups were statistically significant.

This multi-faceted analytical approach, combining descriptive statistics for demographic and categorical data with inferential statistics for comparative analysis, allowed the researchers to paint a comprehensive picture of the technological and pedagogical landscape in biology education. By systematically addressing each research question and hypothesis, the study provided valuable insights into the current state of biology teaching, the integration of technology in the classroom, and the potential differences in knowledge and practice between different categories of teachers.

3.9.9 Qualitative data

The study employed a sophisticated mixed-methods approach, strategically combining quantitative and qualitative data to provide a comprehensive analysis of biology teachers' Pedagogical Content Knowledge (PCK). This multifaceted methodology was designed to offer a nuanced understanding of PCK in biology education, leveraging the strengths of both quantitative breadth and qualitative depth.

At the core of the qualitative analysis was the examination of data derived from interview transcriptions and lesson observation schedules. These qualitative elements played a crucial role in supporting and validating the quantitative findings, particularly in addressing the nuances of research question two.

The researchers' approach to analysing the observation schedule data was methodologically rigorous, employing a textual matrix approach as recommended by Check and Schutt (2012). This method involved developing a systematic record of specific features across multiple cases, condensing them into simple categories, and including reflections for further analysis. The classroom observation schedule itself

served as the matrix for this investigation, providing a structured framework for data organisation and interpretation.

To enhance the analytical process, the PCK elements on the observation schedule were strategically categorised into three main components: Content Knowledge (CK), Pedagogical Knowledge (PK), and Knowledge of Learners (KL). This categorisation was not arbitrary but grounded in the performance indicators of the UEW professional teaching standards.

This structured approach allowed for a more systematic examination of both the active and inactive PCK elements demonstrated by participants during their biology concept explanations.

The researcher further enriched their analysis by incorporating a variety of qualitative data sources. He wove in quotations from transcribed post-observation interviews, narratives from audiotaped lessons, and evidence of the teachers' level of PCK exhibition. This multi-faceted approach provided a rich context for understanding the teachers' PCK in action, offering insights that quantitative data alone could not capture. The teacher interviews served a dual purpose in the study's design. Firstly, they corroborated the questionnaire results, providing a cross-validation of the quantitative data. Secondly, they enhanced the analysis of the observed lessons, offering deeper insights into the teachers' thought processes and decision-making during instruction. To ensure accuracy and fidelity to the participants' voices, these interviews were audio-recorded and transcribed verbatim.

In presenting the findings, the researchers adopted a narrative format that skillfully integrated quantitative results with qualitative insights. They used portions of the

transcribed interview recordings to validate and support the PCK demonstrations observed during biology concept presentations. This narrative approach, interspersed with direct quotations, served to corroborate and strengthen the quantitative data, providing a more holistic view of the teachers' PCK.

The study's integrated approach to data collection and analysis exemplifies the power of mixed-methods research in educational studies.

By triangulating data from multiple sources, questionnaires, observations, and interviews, the study achieved a comprehensive view of PCK in biology education.

This methodological triangulation not only enhanced the validity and reliability of the findings but also provided a richer, more nuanced understanding of how biology teachers apply their PCK in real classroom settings.

3.9.9.1 Ethical Consideration

Ethics in research, particularly in educational settings, plays a crucial role in guiding the conduct of researchers and ensuring the integrity of their work. Wellington (2000) provides a foundational definition of ethics as moral principles that guide conduct, often held by a group or profession. This concept is further elaborated by Fieser and Dowden (2004), who equate ethics with moral philosophy, describing it as the systematic approach to defending and recommending concepts of right and wrong behaviour. These definitions set the stage for understanding the ethical framework within which educational research operates.

In the context of education, the ethical considerations take on added significance due to the profound impact of teaching on society. Strike and Soltis (2004) highlight this importance by pointing out that teachers serve as role models, and teaching forms the foundation of human development.

This perspective underscores the critical nature of ethical behaviour not only in teaching but also in conducting educational research. The far-reaching implications of education as a change agent in society further emphasise the vital nature of ethical considerations in educational research, making it imperative for researchers to adhere to high ethical standards.

Recognising these ethical imperatives, this study carefully addressed several key ethical issues throughout its execution. The research process began with seeking permission for data collection, acknowledging the importance of obtaining proper authorisation before proceeding. This initial step sets the tone for a research process grounded in respect for institutional protocols and participant rights.

Protection of privacy and confidentiality was a paramount concern throughout the study. To ensure this, the names of teachers and schools were kept anonymous throughout the research process. This commitment to anonymity extended to the questionnaires, where participants' names were omitted. Furthermore, participants were explicitly informed about the measures taken to ensure subject anonymity and confidentiality, fostering trust and encouraging honest responses.

The ethical framework of the study also emphasised informed consent. Before their participation, all study subjects were required to complete consent forms. This practice ensures that participants are fully informed about the nature of the study and voluntarily agree to take part, aligning with the ethical principle of respect for persons. The design of the questionnaires also took ethical considerations into account, focusing on ease of completion and sensitivity to potentially delicate topics, further demonstrating respect for participants' time and comfort.

Throughout the research process, the researcher maintained a non-intrusive approach, conducting the study without disrupting the natural classroom environment. This approach not only respects the educational process but also helps to ensure the authenticity of the data collected. By minimising interference, the researcher aimed to capture genuine insights into classroom dynamics and teaching practices.

By adhering to these ethical principles and practices, the study aimed to maintain high standards of research integrity while respecting the rights and privacy of all participants. This comprehensive ethical framework served multiple purposes: it protected the subjects of the research, enhanced the credibility and validity of the findings, and contributed to the overall quality and impact of the educational research. The ethical considerations implemented in this study reflect a deep understanding of the moral responsibilities inherent in educational research. By carefully addressing issues of permission, privacy, informed consent, and non-intrusive data collection, the researchers demonstrated a commitment to ethical practice that aligns with the highest standards of educational research. This ethical approach not only safeguards the participants but also enhances the reliability and applicability of the research findings, potentially contributing to meaningful advancements in educational practice and policy.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

The study's data analysis and findings, which examined the technical pedagogical content understanding of biology teachers in particular localities, are presented in this chapter. The study used the t-test, mean, and percentage computation as statistical techniques for data analysis. The Statistical Package for Social Science (SPSS) version 24.0 was used to analyse the data. Every hypothesis was examined at the significance level of 0.05 alpha.

4.1 Demographic Information of Respondents

The demographic characteristics of the respondents are presented in Table 2

Table 2: Summary of The Demographic Characteristics of Biology Teachers in The Selected Municipalities. (n=73)

Demographic factors	Category	Frequency	Percentage (%)
The number of respondents by Municipalities	Ga West	17	23.3
	Ga East	17	23.3
	Adenta Municipal	16	21.9
	La-Nkwantanang	23	31.9
	Total	73	100
Sex	Male	50	68.5
	Female	23	31.5
	Total	73	100
Age	20-30	25	34.2
	31-40	15	20.5
	41 -50	30	41.1
	51 -60	3	4.1
	Total	73	100
Years of Experience in Teaching	Under 5 years	18	24.7
	5-10 years	30	41.1
	10 years above	25	34.2
	Total	73	100

Source: Field Data, (2024)

The respondents were distributed among four municipalities (Table 2). The frequency of respondents ranged between 23 and 16. The respondents are from different municipalities, with the highest number from La-Nkwantanang (31.9%) and the lowest from Adenta Municipal (21.9%). Further details are presented in the table.

Further, there were more male biology teacher (68.5%) than their female colleagues (31.5%).

The age distribution shows a varied demographic, with the highest percentage in the 41-50 age group (41.1%) and the lowest in the 51-60 age group (4.1%).

A significant portion of the respondents were married (60.3%), followed by single individuals (38.4%), and a small percentage were divorced (4.1%). About two-fifths of the respondents (54.8%, 40) at the end of the study had taught for between five and ten years. Respondents with teaching experience below 5 years were the least of the respondents (24.7%, 18).

Most respondents have 1-3 children (61.6%), while 28.8% have 3-5 children, and a small percentage have 5-7 children (9.6%).

4.2 Research Question 1: What is the Content knowledge of biology teachers in teaching the subject in SHS in selected municipalities?

To address research question 1, questionnaires were administered to teachers, and the results are analysed in Table 3.

Table 3: Analysis of Biology Teachers' Proficiency in Biology Instruction

Municipality	Knowledge of Teaching	Frequency	Percentage (%)
Ga – West	Excellent	0	0
	Very Good	13	76.5
	Good	4	23.5
	Average	0	0
	Needs Improvement	0	0
	Total	17	100.0
Ga – East	Excellent	5	33.3
	Very Good	10	66.7
	Good	0	0
	Average	0	0
	Needs Improvement	0	0
	Total	15	100
La-Nkwantanang	Excellent	15	51.7
	Very Good	13	44.8
	Good	1	3.5
	Average	0	0
	Needs Improvement	0	0
	Total	29	100
Adenta	Excellent	0	0
	Very Good	5	41.7
	Good	5	41.7
	Average	2	16.6
	Needs Improvement	0	0
	Total	12	100

Source: Field Survey, (2024).

The responses from each municipality presented in Table 3 provide insight into the perceived knowledge of teaching among educators and reflect variations that can be linked to existing research on teacher quality and educational development. In the Adenta Municipality, the distribution of responses reveals a relatively modest evaluation of teaching knowledge. None of the teachers were rated as “Excellent,” while 41.7% were rated as “Very Good,” another 41.7% as “Good,” and 16.6% as “Average.” This suggests that although a significant proportion of teachers demonstrate a fair level of competence, there remains a gap in achieving the highest standards of teaching excellence. The presence of “Average” ratings, which are absent in the other municipalities, points to underlying challenges that may include limited professional development opportunities, weaker school leadership, or insufficient support systems. This finding is consistent with research by Barber and Mourshed (2007), which argues that school systems can only be as effective as the quality of their teachers and that targeted investment in teacher development is essential for educational improvement. In contrast, La-Nkwantanang Municipality demonstrates a much stronger profile, with 51.7% of teachers rated “Excellent” and 44.8% rated “Very Good,” leaving only 3.5% rated as “Good” and none below that. This municipality shows a significant concentration of highly rated teaching staff, which may reflect more rigorous teacher recruitment, mentoring systems, and ongoing professional learning programs. Research by Darling-Hammond (2000) supports this pattern, emphasising that sustained support for teachers, including access to quality training and a collaborative teaching culture, directly correlates with improved teaching practices and student outcomes. The high ratings in La-Nkwantanang may also indicate strong educational leadership and a culture that prioritises teacher accountability and continuous learning.

Ga East Municipality also performed well, with 33.3% of teachers rated “Excellent” and 66.7% as “Very Good.” While slightly lower than La-Nkwantanang in terms of the proportion of “Excellent” ratings, Ga East similarly recorded no teachers rated below “Very Good,” reflecting a generally strong teaching workforce.

This trend may suggest an effective policy environment that supports teacher growth and monitoring. OECD reports (2019) affirm that municipalities or regions with strong frameworks for teacher evaluation, feedback, and professional development tend to attract and retain high-quality educators, which could explain Ga East’s positive ratings.

Ga West Municipality, while not as highly rated as Ga East or La-Nkwantanang, still showed a commendable distribution with 76.5% of teachers marked “Very Good” and 23.5% as “Good.” The absence of “Excellent” ratings, however, may indicate a ceiling in professional development or a lack of mechanisms to recognise and nurture exceptional teaching. This aligns with findings by Hattie (2009), who noted that effective teacher development must not only raise overall competence but also create pathways for excellence. Without opportunities for advanced training or recognition, teachers may plateau at “Very Good” levels without progressing further.

4.3 The Case of Edwin in Teaching Biology

Edwin was a young teacher between the ages of 25 to 30 years. He was a professionally trained teacher with a Bachelor of Science degree in biology education. He was confident and enthusiastic in teaching biology to his former two senior high school students.

He had taught for the past 3 years at the time of the study. Edwin's first lesson was observed on the 6th of December, 2023, and his second lesson was on the 7th of December 2023.

On those two occasions, the topics he taught were "Zones of the Earth" and "Ecological factors". Both topics were under unit 1 (Interactions in Nature) in section 2 (Interactions in Nature) of the Senior High School biology syllabus. Each lesson lasted for 1 hour and 40 minutes, indicating a double period of 40 minutes each.

Edwin's exhibition of PCK elements in his lesson was rated below level. This implies that he scored between 50 and 59 marks (Appendix E) in both lessons. Among the performance indicators of his lessons, he scored marks that showed some clear evidence (score of 3) of PCK elements, but most of the performance indicators scored did not reflect clear evidence (score of 2, 1, or 0) of PCK elements (Appendix D). His performance in exhibiting PCK elements resulted from his performance in exhibiting the performance indicators that show elements of the various PCK components.

In terms of the performance indicators of the items that measured the elements of CK (Appendix D), Edwin's lessons were rated below average. This was evident in his exhibition of subject matter knowledge.

For instance, he was not all that conversant with some aspects of the topic's content, as he was constantly seen referring to his lesson notes and textbook to write or state some aspects of the subject matter he taught.

Also, when he was asked to state the major issues in the topics he taught, he only dwelt on a few aspects, although he had just finished teaching the topic. For instance, he stated this after his first lesson on zones of the earth: "*This topic talks about the basic*

dwelling place of animals and its relevance to animals” (1st Interview transcript, 19/12/23).

When he was probed if there were any additions to the topic as spelt out in the syllabus, he said: “The topic requires that I teach my students so that they identify the various habitats when they come across them in the physical world” (1st Interview, 19/12/23). He did not include highlights on the importance of the general characteristics of aquatic and terrestrial habitats.

Further, there was no indication of Edwin’s performance that addressed the standard that measured the engagement of students in critical thinking and problem-solving activities during his lessons. When probed about this absence, he retorted, “*I think they should remove the topic from the senior high school syllabus because the topic is not relevant to my students. And since it's irrelevant, I don't bother them with difficult activities*” (2nd Interview transcript, 20/12/23). Although Edwin could not score 3 or 4 to denote clear or clearer evidence, his performance indicators showed some evidence (score of 2) of systematic lesson presentation. This was because his systematic lesson presentation was only seen during the introductory stage of his lessons. He mostly used a question-and-answer method to review students’ RPK, which led to the introduction of the topic. However, his lesson delivery was not consistent with the activities he planned in his lesson notes. He was seen veering off most often, leaving behind core points of concepts, and sometimes revisiting such concepts after referring to the lesson notes.

On the whole, Edwin’s exhibition of content knowledge was rated below the average level. This was because all the evidence of performance indicators for content knowledge was largely scored based on some evidence that was not clear enough, apart

from stating the objectives and procedures for the lesson. As predicted by King (2009), a teacher's exhibition of content knowledge is a predictor of good teaching (PCK). This implies that since Edwin showed poor evidence of the CK elements in his teaching of biology, he may teach the topic poorly as well.

Although Edwin's objectives were SMART (Specific, Measurable, Achievable, Realistic, and Time-bound), the instructional strategies he applied did not align with the objectives. He constantly used the questions and answer method to get his students involved in the lesson rather than engaging them in a group activity or inquiry that provides hands-on manipulations.

To learn this way, they hardly assimilate to extend their knowledge away from the classroom situation. Veal and Makinster (1999) admonished that topic-specific concepts require a specific repertoire of skills and abilities to teach that specific concept. Teaching the concept of ecology requires the use of inquiry-based teaching (Lee, 2011) because it helps learners conceptualise their learning (Ertmer & Newby, 2013).

However, Edwin's exhibition of elements of PK during his lessons made students see the concept of ecology through his eyes instead of ensuring that they learn the concepts through their own eyes, as the literature suggests (Ertmer & Newby, 2013).

Moreover, his style of classroom management was not encouraging. His style of questioning allowed chorus answers. For instance:

Tr: I said the gaseous portion of the Earth is known as what?

Stds: (In chorus) Atmosphere (2nd Classroom observation, 20/12/23).

He also repeated students' responses constantly. When asked why he did that, he responded: "Some of the students at the back may not hear what they say, so I say it louder for those at the back to hear it. Sometimes the way they mention some of the words is not correct, so by repeating it, I correct them" (2nd Interview, 20/12/23). These findings show that Edwin could not manage his classroom routines as expected. Since this is one of the key requirements for effective classroom management, it can be concluded that his classroom management skills were not effective.

Guerriero (2017) indicated that classroom management is one of the requirements that facilitate an effective instructional process. Therefore, Edwin's shortfalls in managing classroom routines may affect his score on performance indicators that measure elements of PK and, ultimately, his exhibition of elements of PCK required to ensure learning of biology concepts.

Nonetheless, Edwin used charts, board illustrations, non-verbal, oral/sign, and written communication to explain his concepts. However, in most cases, they were not appropriate to create the needed understanding of the concept they are used for.

The absence of technological knowledge (TK) in Edwin's lessons showed a lack of one essential element of Technological Pedagogical Content Knowledge (TPACK) despite his existing pedagogical and content knowledge. The implementation of effective TK strategies uses digital tools and technological resources as enhancers for educational processes between teachers and students. The explanation of "Zones of the Earth" and "Ecological Factors" concepts through technology-based methods remained absent from Edwin's teaching approach. The lesson about habitats and ecological factors would have benefited from virtual simulations that displayed aquatic and terrestrial zones together with videos featuring ecological zone diversity. The combination of

technological solutions brings active learning opportunities and better comprehension of challenging concepts by students. The lack of technology as an educational tool indicates a weakness in Edwin's TPACK framework because it hinders his ability to involve students and develop enhanced knowledge acquisition. Research findings show that adding Technology Knowledge to teaching materials produces chances for students to conduct inquiries together (Mishra & Koehler, 2006). The combination of traditional teaching approaches and the non-use of technology for stimulating experiential learning might have reduced the impact and depth of the educational content delivered by Edwin.

For instance, instead of drawing or taking them to visit the aquatic and terrestrial habitats to explain, he uses verbal explanations instead.

Most of Edwin's exhibition of PK elements was not as clear as expected, except for how he projects his voices and how he engaged his students in his lesson closure. Consequently, Edwin's PK components display can be regarded as below-average for the teaching of biology concepts at the senior high school level based on the performance metrics of the exhibition.

This confirms Kind's (2009) results, which indicated that a teacher's exhibition of content knowledge is a predictor of good teaching. Edwin's exhibition of subject matter knowledge in biology concepts, which was below average, resulted in an exhibition of elements of PK, which was also below average, in teaching concepts (PK).

The below-average performances in the exhibition of CK and PK largely contributed to the description of Edwin's exhibition of PCK elements as below the average level.

However, Edwin's enthusiastic nature kept his class lively. He also maintained a positive rapport with his students and called each of them by name. This is indicative that he knew and related to each student in his class as an "individual".

He also used motivational markers that encouraged students' active participation. Moreover, as evidence of his respect for the diversity in his class, Edwin used planned repetitions to provide immediate and constructive feedback to his students. Choral answers and the use of mother tongue were also allowed to create an atmosphere that encourages participation because some of his students would not contribute in class in a formal setting due to their inability to speak English well.

Again, he extensively used questioning as an instructional technique to probe and refocus pupils' understanding and attention toward the contents they should be conversant with and to engage them in their learning. For example:

Student (Std): Sir, please, what is the meaning of habitat?

Teacher (Tr): Do you know where fish live?

Student: Yes, Sir

Teacher: Why do fish live in water?

Std: Because that's where they get food from.

Tr: Great! That is what we call "habitat", the natural dwelling place of animals or people. Are you with me?

Stds: (In unison) Yes, Sir (2nd Classroom observation, 20/12/23).

Therefore, Edwin's below-average exhibition of TPACK elements can be attributed primarily to his underperformance in demonstrating strong content knowledge (CK) and pedagogical knowledge (PK), as well as the complete absence of technological knowledge (TK) in his teaching. His inability to integrate technology into his lessons

limited opportunities for interactive and engaging learning experiences, which are crucial for fostering a deeper understanding of biology concepts. These deficiencies collectively impacted the overall quality of his instructional delivery.

4.5 Research Question 2: What is the technological knowledge (TK) of Biology teachers in teaching the subject in SHS in the selected municipalities?

To address research question 2, questionnaires were administered to teachers, and the results are analysed in Table 4.

Table 4: Technological Knowledge of Biology Teachers

Technology Knowledge	M	SD
Technology is the process by which people alter the natural world to suit their needs and desires, improving and easing their lives.	4.33	0.55
I have a favourable outlook on using technology	4.35	0.63
I am familiar with common technologies like smartboards, interactive whiteboards, and digital display boards.	4.20	0.88
I am knowledgeable about contemporary and cutting-edge technology like computers, digital video, interactive whiteboards, the Internet, and overhead projectors.	4.25	0.90
I can use computer software in an educational setting.	4.22	0.80
I have the technological know-how to take advantage of cutting-edge resources.	4.12	0.85

Source: Field Survey (2024). M= Means SD= Standard Deviation

The means of means= 4.25 The means of Standard Deviation = 0.77

The findings displayed in Table 4 reveal a mean score of (M = 4.33; SD = 0.55), suggesting that Biology teachers concurred with the notion that technology involves the human-driven transformation of nature to fulfil needs and enhance quality of life. This interpretation resonates with definitions proposed by Ayas (2006) and Karve

(2009), who describe technology as both a tool and a process used to reshape nature for practical benefit. Similarly, Hooper and Rieber (1995) assert that technology entails applying existing knowledge for beneficial purposes and adapting systems through the integration of emerging knowledge.

In addition, the results show a mean score of ($M = 4.35$; $SD = 0.63$), indicating that the biology teachers exhibited a favourable disposition toward utilising technology. This supports Woodrow's (1992) assertion that for any significant change in educational practices to occur, educators must first cultivate a positive orientation toward new technological tools. Likewise, Watson (1998) emphasises that fostering positive attitudes in teachers is essential to promote the integration of ICT and to mitigate resistance to technological adoption. Gulbahar and Guven (2008) also argue that teachers' perceptions and attitudes play a critical role in predicting the adoption of new technologies in teaching environments, as these attitudes influence both the educators' and their students' experiences. Zhao (2007) echoes this perspective, explaining that the impact and extent of technology use in education are largely dependent on users' attitudes. This underscores the importance of teachers' approval and dedication for the successful integration of technology into academic curricula. Comparable conclusions were reached by Isman, Abanmy, Hussein, and Al Saadany (2012), whose study on secondary Social Studies educators revealed generally positive attitudes towards interactive whiteboards, with a minority of respondents reporting effective classroom usage.

Moreover, Biology teachers reported agreement on their familiarity with both traditional tools (Smartboards, Interactive boards, Digital Whiteboard) and more modern technologies (computers, the internet, digital video, interactive whiteboards,

overhead projectors), as indicated by the mean scores of ($M = 4.20$; $SD = 0.88$) and ($M = 4.25$; $SD = 0.90$), respectively. Archambault and Barnett (2010) affirm these responses by explaining that technological knowledge manifests in teachers' ability to use various tools to facilitate instruction, encompassing everything from basic teaching aids to advanced digital systems. Cox (2008) further supports this, pointing out that educators' technological knowledge spans a wide range, from everyday tools such as books and overhead projectors to sophisticated resources like computers and internet-based platforms. Additionally, Koehler and Mishra (2006) maintain that a teacher's understanding of technology should encompass both low- and high-tech tools, including digital media and software programs. According to Mishra and Koehler (2006), while traditional tools require minimal training, modern digital technologies often demand more advanced competencies and are not always intuitive without prior training.

A further mean score of ($M = 4.22$; $SD = 0.80$) suggests that the teachers believed they could competently operate both hardware and software in educational settings. This perception aligns with the view that technological knowledge is not a fixed endpoint but an evolving skill set that develops through continual, meaningful engagement with various technological resources.

Supporting this idea, Niess (2005) argues that technological competence encompasses the ability to use software applications, presentation tools, hardware, and other classroom-relevant technologies.

Additionally, a mean score of ($M = 4.12$; $SD = 0.85$) signifies that the teachers felt they possessed the necessary technological competencies to employ innovative tools effectively. This concurs with the assertion by Education Technology Research

Development (2007), which highlights the need for teachers to master three primary competencies to integrate technology effectively: technical skills, pedagogical techniques supported by technology, and classroom management strategies related to technology use. Anderson and Speck (2001) reinforce this by redefining technological knowledge within the TPACK framework as the capability to utilise digital tools and communication networks to access, manage, integrate, assess, create, and communicate information, while also considering ethical and legal considerations in the digital age.

Table 5: An examination of how biology teachers were trained to use contemporary digital technologies (ICT) in the classroom

Types of Instruction	N	(%)
Formal Training	35	47.9
Informal Training	17	23.3
Self-Training	21	28.8
Total	73	100.0

Source: Field data, (2024)

The types of training biology instructors have received in using contemporary digital technologies (ICT) for instruction are shown in Table 4a.

The table presents a breakdown of the responses based on three categories of training: formal training, informal training, and self-training, along with their respective frequencies and percentages.

From the data, it is evident that the most common form of training reported was formal training, with 35 respondents representing 47.9% of the total sample. This indicates that nearly half of the biology teachers have received structured and organised instructional training on the use of ICT. This relatively high level of formal

engagement reflects positively on the provision of professional development programs, suggesting that some schools or educational authorities are offering deliberate ICT training opportunities for teachers. This finding contrasts with earlier studies, such as Lawless & Pellegrino (2007), which argued that inadequate professional development programs often hinder the effective integration of ICT in teaching. In this context, the result suggests some progress in addressing that gap within the studied population.

Self-training followed closely, accounting for 21 participants, or 28.8% of the total. This indicates a notable inclination towards self-directed learning, where teachers take the initiative to acquire ICT skills independently. This finding aligns with Mishra & Koehler (2006), who emphasised that teachers often resort to self-learning methods to develop their Technological Pedagogical Content Knowledge (TPACK) due to the inconsistency or unavailability of structured programs. The high percentage of teachers who trained themselves reflects their motivation and autonomy in enhancing their teaching with digital tools, especially in environments where access to formal training is limited or unavailable.

Informal training was reported by 17 respondents, representing 23.3% of the sample. This form of learning typically involves on-the-job experiences, peer collaborations, and mentorship. It highlights the value of social and collaborative learning processes, which are increasingly recognised in teacher development literature. As Putnam & Borko (2000) asserted, much of teachers' professional learning occurs through interactions within communities of practice and collaborative environments, and this appears to be reflected in the experiences of the respondents.

The data suggest that while formal training holds the highest representation, a combined 52.1% of respondents still rely on informal and self-directed learning approaches. This may indicate a gap in consistent and comprehensive ICT training programs available to Biology teachers. It is plausible that in some cases, where digital tools are introduced into schools, there may be an assumption that teachers will adapt on their own or learn from peers rather than being engaged in structured training programs.

Such assumptions may result in uncoordinated or purpose-lacking self-training, which could weaken the effective integration of ICT into classroom instruction.

Additionally, it may reflect a systemic issue where teachers either do not receive ICT training during their pre-service education or where professional development opportunities are sporadic and not prioritised by school administrators or government agencies. Nonetheless, the presence of self-initiated efforts by a considerable number of teachers also suggests a level of personal responsibility and interest in improving their digital literacy for educational purposes.

Table 6: Examining the Use of Contemporary Digital Tools (MDTs) in Biology Education

Accessibility	N	(%)
Accessible	27	37.0
Not-Accessible	46	63.0
Total	73	100.0

Source: Field data, Ebo (2024)

Table 7: Analysis of Accessibility of Modern Digital Technologies (ICT) in the Teaching of Biology Concepts

Modern Digital Technologies	YES	NO
SOFTWARE		
MS Word	Yes	
PowerPoint	Yes	
MS Excel	Yes	
Paint Editor	Yes	
Corel Draw	Yes	
Animation in biology		No
Computer-Based Test		No
HARDWARE		
Computer in the classroom	Yes	
CD ROM	Yes	
Media Player	Yes	
DVD	Yes	
Printer	Yes	
Projector		No
Interactive whiteboard		No
Digital Camera		No
Wireless Classroom Microphone		No
Podcast		No
Mobile device	Yes	

Source: Field data, (2024)

Table 6 presents information on the availability of a certain resource, categorised into "Accessible" and "Not Accessible," with corresponding frequencies and percentages. Out of a total of 73 responses, 37% indicated that modern digital technologies are available.

The majority of respondents, representing 63%, report that the resource in question is not available. This suggests a potential limitation or scarcity of the resource, which could impact various aspects such as work processes, project execution, or access to essential tools.

Since the proportion of respondents who access digital technologies is lower than the accessibility percentage, it signifies that a notable portion of the surveyed population has no access to the resource.

It was suggested that most biology professors were unable to integrate cutting-edge digital technology into their teaching methods because of their restricted access to it. This finding is consistent with Koehler and Mishra's (2009) viewpoint, which highlighted that just implementing new technologies does not always result in better outcomes. In a similar vein, the research by Graham, Burgoyne, Cantrell, Smith, Clair, and Harris (2009) showed that teachers have realised that simply knowing how to use technology is not enough; they also need to be able to use it effectively to improve students' learning experiences. Consequently, scholarly attention has increasingly turned to exploring strategies for embedding technology meaningfully within pedagogical frameworks. The effectiveness of any efforts to integrate information and communication technology (ICT) into classroom settings heavily relies on educators' technological proficiency and the extent to which this proficiency influences their instructional use of such tools (Gilakjani, Leong, & Ismail, 2013).

4.4 The Case of Joy in Teaching Interaction in Nature

Joy was a science teacher aged 30-35 years. At the time of the study, he had taught Biology at a Senior High School for 3 years. He graduated from the University of Education, Winneba, Mampong campus with a Bachelor of Science (Agricultural

Education). Joy came across as a confident science teacher. My first observation in Joy's class was on 8th December 2023, and the second was on the 10th of December 2023. On those two occasions, the topics he taught were “the use of rain gauge” and ‘temperature’

Each lesson lasted for 70 minutes, indicating double periods with 35 minutes each. Concepts such as interaction in nature and the uses of rain gauges were part of section 2 (Ecology I) of the SHS 3 syllabus. Joy's exhibition of the elements of TPACK in both lessons was rated as an average performance (Appendix E).

The scores he attained as the performance indicators that show evidence of the elements of TPACK were dominated by scores of some evidence (score of 2) and clear evidence (score of 3). The subsequent paragraphs reflect Joy's performances in showing evidence of performance indicators that reflect elements of the TPACK components observed in his teaching of interaction in nature.

Per the performance indicators that measured elements of CK (Appendix E), Joy's performance in exhibiting the elements of CK expected can be rated as an average performance. In that, he exhibited clear evidence of knowledge of the subject matter in both lessons. For instance, Joy mostly taught his lessons without referring to any material. He was seen reading for confirmation of some of the contents he writes on the board intermittently.

This made him communicate with confidence and enthusiasm. Again, when he was asked to state highlights of the topics he taught in his second lesson, he stated concisely what the topic entails. In his own words, he said:

The contents of the topic are such that it deals with how to use a rain gauge to measure the amount of rainfall. The unit requires that we

teach students the rain gauge and how to use it in general. Also, it covers areas like safety precautions to observe when using the instrument” (2nd interview transcript, 4/12/19).

However, in his first lesson, he misinformed the students by telling them that the rain gauge is also called the Measuring gauge and its components are fixed. In the post-observation interview, his attention was drawn to it, and he admitted to misinforming his pupils. He also promised to correct it during his subsequent lesson.

He continued that:

“I was not trained as a typical Biology teacher. I was trained to teach Agricultural science, and in my degree courses, I wasn’t exposed to some of these concepts, so I still have a lot to learn (1st interview transcript, 8th December, 2023).

Based on Joy’s statement can be ascribed to his wrong conception of the facts in the interaction in the nature unit, which was carried on to the classroom situation. This situation affirms Krauss et. al.'s (2008) findings that the wrong conceptions and misconceptions teachers have of a concept are usually carried into actual teaching. Again, critically assessing Joy’s response to why he misinformed the students suggests a gap between the knowledge he acquired through training and the content he is teaching.

Anderman, Sinatra, and Gray (2012) indicate a seeming gap between the knowledge teachers acquire during teacher preparation programs for biology teachers and the content they teach in the classroom. In Joy’s case, he was trained in agricultural science, yet he was expected to teach biology concepts. This evidence shows a mismatch between his prior learning and the content knowledge required to teach nature interaction at the senior high school level.

Joy said that in addition to the required textbooks, he reads from the internet and other sources to make up for this gap. Joy's claim about the sources of his knowledge supports the findings of McConnell et al. (2013), Ijeh (2012), and Jang, Guan, and Hsieh (2009), who discovered that after graduation, teachers continue to expand their content knowledge in particular fields by interacting with textbooks, curriculum documents, the internet, revision books, and other teachers and students.

Joy's exhibition of elements of CK was also seen in how he explained his subject matter to his students. He blended the local language to bring the explanation of concepts to the level of his students' understanding.

He also presented his lessons systematically by ensuring the contents of the topics he taught were in order and aligned with his objectives.

He also stated the purpose, objectives, and procedures for the lesson. Evidence of the systematic lesson presentation implied how much planning he had to put into the lesson. Therefore, when he was asked about how important the lessons he taught were to him, he gave two reasons. First, it was to prepare students for exams, and second, to give them the foundation of ecology for advanced learning or career development related to ecology.

However, there was no evidence to indicate that Joy engaged his students in critical thinking and problem-solving activities. During his post-observation interview, his attention was drawn to the absence of this indicator, and he explained that some of the content of the topics is too technical even for him to understand; therefore, he is reserved when it comes to giving his students tasks that will engage them in critical thinking. He also added that such activities may require investigations, and his school did not have the necessary TLMs to help him achieve that.

In summary, Joy's exhibition of the performance indicators that measure the elements of CK can be rated as average because among the five elements he was expected to exhibit, he was rated to show clear evidence of three of them.

For Joy's exhibition of elements of PK in his lessons, he performed below average. On the two occasions of Joy's lessons observed, his choice of techniques was also not effective in modifying and extending students' learning because students' participation in the lessons was minimal. Joy's performance indicators, which measured elements of PK in his lessons, showed clear evidence of confidence and enthusiasm in his communications.

He used appropriate and accurate non-verbal and written communication, and his objectives were SMART. But, on the low side, his choice of instructional strategies was not suitable for the lessons he taught. The only time his students were involved in their learning was during the lessons' introduction when he reviewed their RPK through questions and answers. During the lesson delivery, students were generally involved in reiterating information or mentioning a taught idea.

This created boredom, thereby reducing the students' interest and active participation in the lesson. Ideally, the teaching of interaction in nature should be a practical activity that involves investigations (Kazeni, Baloyi, & Gaigher, 2018).

Joy's teaching demonstrated pedagogical content knowledge (PCK) skills, but lacked technical knowledge (TK), a crucial component of the technological pedagogical content knowledge (TPACK) framework. Joy failed to include technology in his lessons, thus missing an opportunity to improve students' teaching and learning of "interaction in nature" and "use of a rain gauge." The waiting period for appropriate

technological instruments between simulations and videos, and interactive digital mediums excluded students from effectively visualising scientific content. Utilising technology would have assisted Joy in bridging his subject matter knowledge gap with student comprehension and would have promoted critical thinking in their scientific learning processes. McConnell et al. (2013), together with Shamsudin et al. (2013), state that teaching complex topics such as ecology becomes more successful when technology integrates interactive learning experiences based on inquiry. The absence of technological tools rendered Joy's teaching incompatible with the TPACK framework since TPACK demands the integration of technology elements.

When probed as to why he taught his lesson that way, he asserted that;

“Yes, my lesson was teacher-centred, and it didn't involve all the students... it is a common thing I do when I'm teaching interaction in nature. I know it is not the right way, but you see it is the only way to explain things to my students who usually don't have the basic understanding of ecology” (1st interview transcript, 8/12/23).

Nonetheless, Joy's use of techniques like demonstrations and illustrations modified and extended students' learning. For instance, he demonstrated to pupils how to calculate the amount of rainfall after using a rain gauge. During the discussions, he extended students' learning on how a change of subject is done. He also showed clear evidence of performance that indicated that his evaluation exercises and homework were also based on the lesson's objectives.

Moreover, in Joy's lessons, his performance in exhibiting the indicators that measured elements of KL in the teaching of interaction in nature can be described as an average performance. This was because among the 6 elements of KL he was expected to exhibit (Appendix E), his performance in both lessons was invariably dominated by the show of some evidence (score of 2), with little clear evidence (score of 3).

Joy's performance also indicated clear evidence of his respect for the diversity among his students. An instance of such elements was seen in his use of planned repetition to reinforce taught concepts. In other instances, he clearly explained the procedures to the level of students' understanding using the L1 (Mother tongue) intermittently.

Again, due to his respect for his learners' diversity, he used analogies that related to students' life experiences to drive home some concepts he taught. An instance was seen in the excerpt below:

Teacher (Tr): An increase in heat in the atmosphere increases the temperature. This relationship is called direct proportionality. Do you understand? (*Few responses came up, so he rephrased his sentence.*)

What I mean by saying the relationship between heat and temperature is proportional because the temperature will only increase when the heat also increases.

For example, anytime the government increases petrol prices, what happens to lorry fares?

Students (Stds): (In chorus) The lorry fares also increase.

Teacher (Tr): Good! Shine for yourselves! So, anytime an increase in one variable, for example, petrol prices, causes an increase in lorry fares, we say they are proportional. So, an increase in temperature is because heat is also increased. Are you with me?

Stds: Yes, Sir! (Classroom observation, 8/12/23).

It was difficult to identify pupils' misconceptions or misunderstandings since they were not actively engaged in their learning, and also, in both lessons, students' contributions were largely planned repetitions. From Joy's exhibition of elements that showed his

performance in the exhibition of elements of the component of PCK, it can be concluded that his performance largely influenced his average performance rate in the exhibition of PCK elements in the exhibition of elements of CK and KL.

The contribution of his exhibition of the element of PK to the average performance rate of Joy's exhibition of the element of PCK was the least among the PCK components. Park, Jang, Chen, and Jung (2010) suggest that students' ability to excel and develop better attitudes and values in scientific concepts (Interaction in nature) largely depends on the teachers' in-depth understanding of science concepts and positive attitudes towards science in the context to ensure learning. However, Van Driel et al. (1998) suggest that this phenomenon cannot be seen in most science classrooms because many teachers lack confidence, interest, and the requisite pedagogical and subject content knowledge for teaching science.

A cursory look at the elements of PCK exhibited by the two teachers against the expected performance indicators of the elements of PCK shows that both teachers demonstrated evidence of PCK needed to teach basic concepts in ecology. However, the level of evidence expected to translate subject matter knowledge to good teaching (PCK) was not encouraging. Both Edwin and Joy exhibited an average performance in their exhibition of elements of PK. This adversely affected their exhibition of TPACK elements in teaching basic concepts in ecology. This is in line with Juttner and Neuhaus's (2012) position that senior high school science teachers with limited Technological Pedagogical Content Knowledge adversely affect their science teaching (TPACK). Furthermore, Edwin's overall performance in the exhibition of TPACK elements was better than Joy's.

4.5 Research Question 3: What is the Pedagogical Knowledge (PK) of Biology teachers in teaching the subject in SHS in the selected municipalities?

Shulman (1986) emphasised that pedagogical knowledge encompasses the various beliefs and theories teachers hold regarding instructional practices and learning processes, which in turn shape their approach to teaching. Biology holds a recognised and specialised position within the educational curriculum across all levels in Ghana. However, the subject faces a number of obstacles due to its relatively recent introduction into the school system, a shortage of well-trained Biology educators, and the pressing need for teachers to demonstrate a high level of instructional competence in the subject.

According to Abdu-Raheem (2011), the aims of Biology education remain largely unfulfilled, primarily because of ineffective teaching practices and the insufficient or inappropriate use of teaching resources and strategies that can engage and inspire learners. Rodger (2003) contends that selecting the right teaching method to match specific teaching and learning contexts is critical for maintaining a teacher's professional vitality and ensuring effective instructional delivery.

The data obtained is presented in Table 8.

Table 8: Pedagogical Knowledge of Biology Teachers

Pedagogical Knowledge	M	SD
I can modify my teaching methods for various students.	4.55	0.56
I know how to organise and maintain classroom management.	4.42	0.60
I employ student-centred strategies to accomplish my lesson's particular goal.	4.39	0.68
During the teaching period, I usually employ problem-solving and discovery learning.	4.33	0.62
I know how to assess student performance in a classroom.	4.61	0.49

Source: Field Survey, Philip (2024). M= Means SD= Standard Deviation

The Means of Means= 4.46 The Means of Standard Deviation = 0.59

The findings presented in Table 8 reveal that Biology teachers showed a strong consensus regarding their ability to tailor their instructional methods to accommodate the diverse needs of learners, as reflected in a high mean score (M = 4.55; SD = 0.56). This outcome highlights their flexibility in instructional delivery, aligning with the perspective of Sumber, Ndofirepi, and Gwirayi (2012), who emphasised the importance of aligning teaching methods with students' learning styles. They advocated for a learner-centred approach in which students actively participate in their educational journey, while teachers serve as guides or facilitators.

In addition, the data show a mean score of (M = 4.42; SD = 0.60), indicating that Biology teachers affirmed their proficiency in organising and maintaining effective classroom management. According to Hudson (2007), pedagogical practice encompasses a variety of skills, including lesson planning, material preparation, time and classroom management, the application of teaching strategies, questioning

techniques, and student assessment. He argued that the pedagogical approach adopted by a teacher directly impacts how they manage their classroom, engage learners, and assess learning outcomes. Supporting this notion, Rodger (2003) emphasised that a teacher's instructional method can significantly minimise disruptive behaviours in class, thereby contributing to a more structured and effective learning environment.

Another prominent finding is the mean score of ($M = 4.39$; $SD = 0.68$), which indicates that Biology teachers affirmed the frequent use of student-centred instructional approaches aimed at achieving lesson objectives. Teaching methods in Biology, much like in other hands-on disciplines, can be broadly categorised into approaches that either prioritise the teacher or the learner (Tamakloe, Amedahe, & Atta, 2005). Given the human-centric nature of Biology, which aims at cultivating relevant knowledge and skills for societal functionality, Abdu-Raheem (2011) argued for the necessity of student-centred approaches to meet the subject's objectives. Similarly, Cresswell (2004) noted that teachers who present content with clarity and enthusiasm, remain open and relaxed, and focus on goal-oriented tasks tend to foster more effective learning.

These teachers also encourage student participation through elaboration and probing, further deepening understanding.

Moreover, the findings show a mean score of ($M = 4.33$; $SD = 0.62$), suggesting that Biology teachers regularly incorporate problem-solving and discovery-oriented learning strategies in their lessons. Abdu-Raheem (2010) supported this observation, stating that methods such as inquiry, discovery, role-play, and discussion are instrumental in enhancing students' learning experiences.

He later reiterated in 2011 that problem-solving approaches are particularly effective due to the active student engagement they foster. Complementing this view, Richards (2005) and Ogunkunle (2008) highlighted that self-directed learning methods enhance meaningful learning, boost problem-solving capabilities, and cater to a wide range of learner needs.

Regarding teachers' ability to assess students' academic performance, the results show a mean score of ($M = 4.61$; $SD = 0.49$), which confirms strong agreement among teachers on their competence in this area. Hudson (2007) and Shulman (1986) emphasised that assessment forms an integral part of pedagogical knowledge, alongside classroom management, instructional planning, and questioning strategies. Hudson (2007) further maintained that the type of pedagogical methods employed significantly influences classroom organisation, student engagement, and assessment practices.

The overall mean score for the research question focusing on Biology teachers' pedagogical knowledge stood at ($M = 4.46$; $SD = 0.59$), suggesting that respondents acknowledged possessing the essential pedagogical skills necessary for effective instruction at the Senior High School level. The accompanying standard deviation indicates that responses were tightly grouped around the mean, reflecting a high level of agreement and reliability in the responses regarding teachers' pedagogical competence.

To reinforce the survey data and verify the self-reported claims, a classroom observation was conducted involving twelve Biology teachers purposefully selected from three different municipalities, three from each. The observational protocol used a detailed checklist targeting five core pedagogical dimensions: adaptability of

teaching to learner needs, classroom management, student-centred instruction, implementation of problem-solving and discovery methods, and assessment practices.

Analysis of the classroom observation data revealed consistently high performance across all pedagogical dimensions. Teachers demonstrated adaptability to diverse learner profiles, scoring an average of $M = 4.56$ ($SD = 0.39$), indicating their capability to adjust instructional strategies based on students' individual needs. Effective classroom organisation was also evident, with a mean score of $M = 4.43$ ($SD = 0.45$), reflecting their ability to create orderly, supportive, and engaging environments conducive to learning.

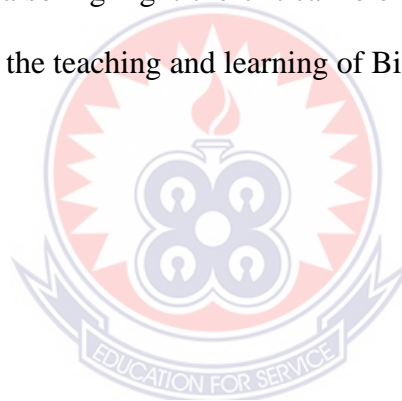
Teachers' adoption of student-centred practices was also strongly observed, with a mean of $M = 4.47$ ($SD = 0.41$). They frequently employed group tasks, interactive activities, and question-based discussions to facilitate active student participation. The domain assessing the use of inquiry and discovery strategies yielded a mean of $M = 4.38$ ($SD = 0.50$), suggesting regular engagement of learners in critical thinking and experiential learning processes.

Additionally, the assessment of learning outcomes was robustly practised, scoring a mean of $M = 4.55$ ($SD = 0.36$), highlighting the teachers' capacity to evaluate, monitor, and provide feedback on student progress effectively.

Overall, the average score across all observed dimensions was $M = 4.48$ ($SD = 0.42$), pointing to a high level of pedagogical proficiency among the observed teachers. These findings strongly correspond with the survey results and confirm that what teachers reported aligns with their actual classroom behaviour. The instructional

strategies witnessed during observation mirror the best practices emphasised by Hudson (2007) and Shulman (1986), who stressed the integration of management, design, inquiry-based strategies, and continuous evaluation in effective teaching.

Additionally, these findings reinforce Abdu-Raheem's (2011) argument for the use of student-centred and problem-solving instructional approaches to boost learner engagement and academic achievement. In alignment with Cresswell's (2004) observations, teachers who deliver content enthusiastically, encourage active inquiry, and maintain dynamic student interactions are better positioned to facilitate deep and meaningful learning. Thus, the observational insights not only substantiate the questionnaire data but also highlight the critical role of varied and learner-focused strategies in improving the teaching and learning of Biology.



4.6 Research Question 4: What is the technological pedagogical content knowledge (TPACK) of Biology teachers in teaching the subject in the selected municipalities?

In order to examine how technology, pedagogy, and academic content interact in dynamic and fruitful environments, the concept of technological pedagogical content knowledge was developed. The results gathered are displayed in Table 6.

Table 9: Technological Pedagogical Content Knowledge of Biology Teachers

Technological Pedagogical Content Knowledge	M	SD
I can represent or create "Biology" concepts using technology that is understandable to students.	4.32	0.69
I can "improve" the teaching and learning of biology using technology.	4.10	0.85
I possess the technological know-how to successfully integrate technology and biology curriculum information.	4.23	0.78
I can expand classroom discussions beyond the school's walls by utilising technology resources.	4.18	0.74
At my school and/or district, I may take the lead in assisting others in coordinating the use of technology, instructional strategies, and materials during PLCs.	4.28	0.72

Source: Field Survey (2024). M= Means SD= Standard Deviation

The Means of Mean = 4.22 The Means of Standard Deviation = 0.76

The data presented in Table 9 reflects that Biology teachers attained mean scores of (M = 4.32; SD = 0.69) and (M = 4.28; SD = 0.72), which indicates a strong consensus among them regarding their ability to articulate and design Biology content in a technologically enriched manner that facilitates learner comprehension. It also suggests

that they see themselves as capable of guiding in coordinating content delivery, instructional methods, and technological tools at both school and district levels. Education Technology Research and Development (2007) underscores the necessity for teachers to possess proficiency in three key areas to achieve successful technology integration: technical expertise, pedagogical skills that are supported by technology, and classroom management strategies tailored to technology use. For teachers to fully leverage the benefits of classroom technology, they must harmonise it effectively with the subject content.

This aligns with Cuban's (1986, 2001) perspective that technology should be adapted to fit the curriculum rather than altering the curriculum to accommodate technology.

Basilicato (2005) notes that technological devices such as interactive whiteboards require committed educators who can instil a genuine interest in the subject among learners. Fullan (2000) contends that although technology is widely accessible, the real challenge lies in its proper utilisation and management. He asserts that as digital tools become increasingly sophisticated, the presence of effective teachers becomes even more critical. Fullan also points to insights from cognitive science, which stress the importance of enabling students to actively construct knowledge; thus, teachers must skillfully deploy and manage technology to enrich the learning experience.

Lee (2008) adds that Biology teachers should immerse themselves in content that is intrinsically linked to technology and seek to enhance that content through technological innovations, which necessitates deliberate pedagogical strategies. He outlines various instructional techniques that educators can use to successfully integrate content knowledge, pedagogy, and technology. Painter (2001) further highlights that meaningful integration requires teachers to be adaptable and proficient, possessing

deep knowledge of the curriculum, an understanding of student capabilities, and digital literacy.

Additional data points, with mean scores of ($M = 4.10$; $SD = 0.85$), ($M = 4.23$; $SD = 0.78$), and ($M = 4.18$; $SD = 0.74$), reveal that Biology teachers believe they can meaningfully engage with content that is technologically oriented, possess the technical expertise to blend curriculum content with digital tools, and can utilize technological resources to broaden classroom discussions beyond the traditional school setting.

Lee (2008) reinforces that working with technology-rich content involves modifying it through technological means, which demands thoughtful instructional action.

In line with these findings, Buabeng-Andoh (2012) explored how Biology teachers perceive the role of technology in teaching and discovered that most viewed it as a valuable asset for enhancing course delivery and learning experiences. Moulton (2009) distinguishes between the mere use of technology and its application in ways that tangibly improve student learning outcomes. This distinction underscores the need for teachers to be adept with a variety of technological tools to create rich, engaging learning environments.

Research by Harkverdi, Gucum, and Korkmaz (2007) indicates that genuine integration occurs when technology use aligns with educational goals and encourages active student participation, collaboration, meaningful interaction, and connections to real-life contexts. Similarly, Ryan and Cooper (2006), along with Honey (2001), emphasise the transformative potential of instructional technology in education. Sheingold (1990) points out that the essence of technology integration is not in teaching students how to operate devices, but rather in using these tools to facilitate learning.

Echoing earlier points, the Education Technology Research and Development (2007) reiterates the importance of developing teachers' abilities in three essential domains: technical skills, technology-based pedagogical strategies, and classroom management related to technology use.

Observational data from a purposive sample of 20 Biology teachers, five from each of the four municipalities, show a mean rating of ($M = 4.32$; $SD = 0.69$), illustrating a high level of proficiency in crafting and delivering Biology content through the integration of technology in ways that aid student comprehension.

This indicates that the observed educators are adept at using digital tools to improve students' grasp of biological concepts. Moreover, a mean score of ($M = 4.10$; $SD = 0.85$) highlights that these teachers are skilled in engaging with content that is naturally aligned with technology, thereby enhancing subject matter delivery through suitable technological interventions.

Additionally, the ($M = 4.23$; $SD = 0.78$) mean score shows that these educators effectively merge technological tools with Biology curriculum content to support engaging instruction. This reflects their capability in employing technology to conduct dynamic, student-centred lessons. Another result ($M = 4.18$; $SD = 0.74$) further demonstrates that Biology teachers are extending the boundaries of classroom interaction using technology, offering students learning opportunities that go beyond physical classroom spaces.

Finally, a mean score of ($M = 4.28$; $SD = 0.72$) signifies that these teachers exhibit strong leadership qualities by aiding peers in synchronising teaching content, methods, and technological use within their educational institutions.

This underscores their role as facilitators and mentors in promoting effective and meaningful technology integration in teaching.

4.7 Testing of Hypothesis

H₀: There is no statistically significant difference between the technological pedagogical content knowledge (TPACK) of professional and non-professional biology teachers in the selected municipalities

H₁: There is a statistically significant difference between the technological pedagogical content knowledge (TPACK) of professional and non-professional biology teachers in the selected municipalities.

The independent sample t-test results for the difference in technological pedagogical content knowledge (TPACK) between biology teachers who are professionals and those who are not are summarised in Table 7.

Table 10: Table of T-tests to Display the Analysis of the Average Score of Biology Teachers' Technological Pedagogical Content Knowledge by Professional Status

Variables	Groups	N	M	STD	Df	T	P
TPACK	Professional Teachers	35	19.50	3.20	71	-1.20	0.24
	Non-Professional Teachers	38	20.10	3.00			

Source: Field Survey (2024).

The researcher began by assessing the equality of variances using Levene's test. In this context, a significance value (Sig) greater than 0.05 suggests that the variances are considered equal, whereas a value below 0.05 indicates unequal variances. The analysis

produced a Sig value of 0.341 from the independent sample t-test, signifying that the assumption of equal variances holds.

Table 7 shows that none of the qualified (professional) and uncertified (non-professional) teachers in the chosen municipalities had a statistically significant difference in technological pedagogical content knowledge (TPACK) ($t = -1.20$; $df = 71$; $p > 0.05$). As a result, failed to reject the null hypothesis (H_0).

Further scrutiny of the group mean scores showed that certified teachers had a mean of 19.50 with a standard deviation of 3.20, while uncertified teachers had a slightly higher mean of 20.10 with a standard deviation of 3.00. Despite this slight variation in averages, the difference was not statistically meaningful. The findings suggest that teacher qualification does not significantly influence the ability to integrate technology into the teaching and learning process of Biology in the municipalities studied.



CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.0 Overview

This chapter presents summaries of the study and reports major findings. It highlights the conclusion of the study and its implications for practice. The implications were based on the major findings identified in the preceding chapter. It further outlines some recommendations and suggestions for future research.

5.1 Summary of the Study

The abysmal performance of senior high school biology students in Ghana has been a major concern to Ghanaian teachers (Appiah, 2014; Dorwu, 2015; Sakpaku, 2016). However, studies have shown that some teachers' inability to integrate technology into the teaching and learning process could be a reason why students are performing poorly in the exams (Dorwu, 2015; Sakpaku, 2016). Baumert et al. (2010) assert that teachers with high TPACK create a better lesson.

Therefore, this study sought to explore the TPACK level of senior high school biology teachers. The knowledge bases that were considered components of TPACK were content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical knowledge (TPK). Four research questions and one hypothesis were formulated to guide the study. They were;

1. What is the Content knowledge of biology teachers in teaching the subject in SHS in selected municipalities?
2. What is the technological knowledge (TK) of Biology teachers in teaching the subject in SHS in the selected municipalities?

3. What is the Pedagogical Knowledge (PK) of Biology teachers in teaching the subject in SHS in the selected municipalities?
4. What is the technological pedagogical content knowledge (TPACK) of Biology teachers in teaching the subject in the selected municipalities?

An explanatory sequential approach was adopted to gather and analyse quantitative and qualitative data. The sample for this study was sampled through a convenience sampling technique. For the quantitative phase, convenience sampling was used to select 31 senior high schools, comprising 5 public schools and 26 private schools. From the sampled schools, a sample of 73 senior high school biology teachers was purposively sampled for the study. For the qualitative phase of the study, a sub-sample of 2 groups of teachers was purposively selected from the study's sample (professional and non-professional teachers). The hypothesis was also tested using the t-test with a significance level of 0.05.

5.3 Major Findings

- I. The biology educators within the identified municipalities demonstrated a strong grasp of subject-specific content in Biology.
- II. Findings from the research indicated that teachers acknowledged having the requisite technological proficiency essential for facilitating Biology instruction, with the average score for teachers' technological expertise being ($M = 4.245$; $SD = 0.77$).
- III. The study also highlighted teachers' affirmation of possessing effective teaching strategies necessary for delivering Biology lessons at the Senior High School level in the targeted municipalities. With a mean score of ($M = 4.46$; $SD = 0.59$).

- IV. Further analysis of the teachers' understanding of Technological Pedagogical Content Knowledge (TPACK) produced a composite mean score of ($M = 4.22$; $SD = 0.76$). This reflects the teachers' consensus that they have the expertise, abilities, and confidence to effectively blend technological tools, pedagogical approaches, and content knowledge in ways that promote meaningful Biology instruction.
- V. The independent samples t-test results showed that the TPACK of qualified and uncertified senior high school biology teachers in the study area did not differ statistically significantly. This implies that a teacher's capacity to successfully combine technology, pedagogy, and biology subjects in these municipalities is not greatly impacted by their level of schooling.

5.4 Conclusion

Based on the findings of this study, the following are the conclusions

Despite the seemingly limitless expanse of the field of Biology (Jutner & Neuhaus, 2003), Biology educators at the Senior High School level within the designated municipalities demonstrated adequate mastery of the subject matter necessary to guide students toward becoming productive and responsible members of society.

Although technological advancements continue to progress rapidly, Biology instructors in the Senior High Schools across the identified municipalities exhibited sufficient technological expertise required to integrate technology and related tools effectively in their instruction of Biology. Insights gathered from the observation checklist revealed that their familiarity and implementation of technological tools were largely confined to commonly accepted or conventional technological applications.

Contrary to Abdu-Raheem's (2011) assertion that the goals of Biology education remain unmet due to substandard instructional delivery and insufficient or unavailable teaching materials, Biology educators within the selected municipalities at the SHS level exhibited the pedagogical proficiency and teaching strategies essential for promoting meaningful Biology instruction and student learning.

Finally, Senior High School Biology teachers in the targeted municipalities showed evidence of possessing the needed capabilities in technology, the ability to incorporate technological tools into pedagogy, and the classroom management skills aligned with technology use. These competencies allowed them to appropriately align technology with curricular goals rather than altering the curriculum to suit the technology, as emphasised by Ahktar (2001).

5.5 Recommendation

The study's findings have led to the following policy and practice recommendations. It is anticipated that if these suggestions are implemented, the senior high schools in the chosen communities will be able to integrate technology into biology instruction more effectively and efficiently.

- I. To maintain and elevate the technological proficiency of Biology teachers, it is advisable to strengthen their knowledge in this area through structured technology-oriented training initiatives. This can be effectively achieved by regularly organising professional learning avenues such as workshops, seminars, and in-service training sessions that focus on the practical application of digital tools and resources in Biology instruction.
- II. Considering the expansive and ever-evolving scope of Biology as a subject, it becomes crucial for the Municipal Directorates of Education, in collaboration

with Biology curriculum experts from the Ministry of Education, to arrange periodic refresher programs and professional development courses. These initiatives are essential to enhance both the academic and instructional capabilities of Biology teachers, ultimately promoting the adoption of current technological innovations in the teaching and learning processes of Biology.

- III. It is further suggested that the Ministry of Education, together with the government, take deliberate steps to equip Biology teachers with advanced technological tools. These resources may include computers, digital projectors, interactive whiteboards, as well as stable internet access or modems. The availability of such tools would empower teachers to create a more technology-rich and interactive classroom environment for Biology education.
- IV. Additionally, school administrators and educational supervisors should adopt motivational strategies that encourage Biology teachers to engage in self-directed technological learning. Teachers can take the initiative to stay informed by accessing and subscribing to relevant technology-focused journals, educational blogs, newsletters, digital magazines, and video tutorials. Such independent learning efforts will contribute significantly to building their competence in integrating technology into pedagogy.
- V. Furthermore, it is advised that ICT teachers within senior high schools be officially appointed as coordinators for facilitating technology integration efforts within their institutions. They should be entrusted with the responsibility, along with appropriate incentives, to offer consistent technological support and guidance to Biology teachers. To fulfil this role effectively, ICT teachers themselves must undergo specialised training tailored to equipping them with skills specific to technology integration in teaching.

5.6 Suggestion of Further Research

The following recommendations were put forth in light of the study's findings:

- I. To assess the degree of Technological Pedagogical Content Knowledge (TPACK) among biology teachers in Ghanaian senior high schools, future studies could be expanded to different parts of the nation.
- II. It is further recommended that inquiries be made into how the integration of technology impacts both teacher performance and student academic outcomes.
- III. While this research concentrated on Biology teachers in assessing their TPACK, subsequent studies could explore the same construct among educators of other subjects taught at the secondary school level.
- IV. Additional investigations may also explore student academic achievement by comparing learners taught by educators with strong Technological Pedagogical Content Knowledge to those instructed by teachers with less developed TPACK.
- V. This study only covered three of the six dimensions of Technological Pedagogical Content Knowledge namely, Content Knowledge, Pedagogical Knowledge, and Technological Knowledge; future studies might broaden the scope to include other dimensions such as teachers' understanding of the educational environment, their grasp of the broader aims of education, and their knowledge of the curriculum.

REFERENCES

- Abbitt, J.T. (2011). An investigation of the relationship between self-efficacy beliefs about technology integration and technological pedagogical content knowledge (TPACK) among preservice teachers. *Journal of Digital Learning in Teacher Education*, 27(4), 134–143.
- Abdu-Raheem, S. (2010). Effective methods of teaching biology: Inquiry, problem-solving, discussion, discovery, and role-playing. *Journal of Educational Research*, 10(3), 112-118.
- Abdu-Raheem, S. (2011). The role of student-centred teaching in the achievement of educational objectives in biology. *International Journal of Education*, 15(2), 45-52.
- Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea?. *International journal of science education*, 30(10), 1405-1416.
- Abell, S. K., & Lederman, N. G. (2007). *Research on science education*.
- Abimbola, I. O. (2013). *Philosophy of science degree students*. Ilorin: Bamitex Printing and Publishing Enterprise.
- Addy, N. A., & Ofori-Boateng, P. (2015). ICT and education: An analysis into Ghana's universities. *International Journal of ICT and Management*, 3(2), 23-28.
- Adebayo, A. S., & Dorcas, A. T. (2015). Comparative Analysis Of Students In Social Studies And Integrated Science At Junior Secondary School Certificate Examination In Edu Local Government Area Of Kwara State, Nigeria. *European scientific journal*, 11(1).
- Agyei, D. D. (2013). *Analysis of technology integration in teacher education in Ghana*.
- Akhtar, J. (2016). *Research Design*. Research in Social Science Interdisciplinary Perspectives, 3 (3), 68-84.
- Akkoç, H. (2010). Investigating the Development of Prospective Mathematics Teachers' Technological Pedagogical Content Knowledge about Student Difficulties: The Case of Radian Concept. *Informal Proceedings of the British Society for Research into Learning Mathematics (BSRLM) Day Conference, 13 November 2010* (Vol. 30, No.3, pp. 1-6). Newcastle University, England. <http://www.bsrlm.org.uk/IPs/ip30-3/BSRLM-IP-30-3-Full.pdf> (Retrieved from 09.02.2024)
- Alazam, A. O., Bakar, A. R., Hamzah, R., & Asmiran, S. (2013). Teachers' ICT skills and ICT integration in the classroom: The case of vocational and technical teachers in Malaysia. *Creative Education*, 3(08), 70.

- Albion, P., Jamieson-Proctor, R., & Finger, G. (2010). *Auditing the TPACK confidence of Australian pre-service teachers: The TPACK confidence survey (TSC)*. In D. Gibson & B. Dodge (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2010* (pp.3772-3779). Chesapeake, VA: AACE
- Alice. M. A. & Teddlie, C. (2010). A continuation of the paradigm wars? Prevalence rates of methodological approaches across the social behavioural Scientists *Journal of 4(2), Mixed Methods Research*, 103-126, Inter/Adon.org: 10.1080
- Altman, E. (1999). *Constrained Markov decision processes (Vol 7)*. Prague: CRC Press.
- American Association for the Advancement of Science (2013). *The handbook of technological pedagogical content knowledge (TPACK) for teachers*. Marwah, NJ: Lawrence Erlbaum Associates.
- American Association of Colleges for Teacher Education (AACTE) Committee on Innovation and Technology. (2008). *Handbook of technological pedagogical content knowledge (TPCK) for teachers*, New York: Routledge.
- Anderman, E. M., Sinatra, G. M., & Gray, D. L. (2012). The challenges of teaching and learning about science in the twenty-first century: Exploring the abilities and constraints of adolescent learners. *Studies in Science Education*, 48(1), 89-117.
- Anderson, R. E., & Speck, B. W. (2001). *Using technology in K–8 literacy classrooms*. Prentice Hall.
- 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.
- Angeli, C., & Valanides, N. (2015). Pre-service elementary teachers as information and communication technology designers: An instructional systems design model based on an expanded view of pedagogical content knowledge. *Journal of Computer Assisted Learning*, 21(4), 292–302.
- Appleton, K. (2008). Developing science pedagogical content knowledge through mentoring elementary teachers. *Journal of Science Teacher Education*, 19(6), 523-545.
- Archambault LM, & Barnett JH, (2010) Revisiting technological pedagogical content knowledge exploring the TPACK framework. *Computer Education* 55(4):1656– 1662
- Archambault, L. (2016). Exploring the use of qualitative methods to examine TPACK. In M. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge for teachers* (2nd ed., pp. 65-

86). New York, NY: Routledge

- Archambault, L., & Barnett, J. H. (2010). Revisiting technological pedagogical content knowledge: Exploring the TPACK framework. *Computers & Education*, 55(4), 1656–1662. <https://doi.org/10.1016/j.compedu.2010.07.009>
- Archambault, L., & Crippen, K. (2009). Examining TPACK of k-12 online distance education in the United States. *Contemporary Issues in Technological and Teacher Education*, 13(1), 71-88.
- Arzi, H. J., & White, R. T. (2008). Change in teachers' knowledge of subject matter: A 17-year longitudinal study. *Science Education*, 92(2), 221-251.
- Asempa, D. (2020). *Investigating factors influencing the integration of technological and pedagogical content knowledge of social studies teachers in the South Dayi District in the Volta Region of Ghana* (Doctoral dissertation, University of Education Winneba).
- Ayas, C. (2006). An examination of the relationship between the integration of technology into social studies and constructivist pedagogies. *The Turkish Online Journal of Educational Technology*, 5(1), 64-72.
- Ayoub, K. (2015). *TPACK development in teacher design teams: assessing the teachers' perceived and observed knowledge in R. McBride, & M. Searson (Eds.)* Proceedings of Society for Information Technology and Teacher Education International Conference 2013 (pp. 4698-4703) Chesapeake, VA: AACE.
- Barnett, J., & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science education*, 85(4), 426-453
- Baser, D., Kopcha, T. & Ozden, M. (2015). *Developing a technological pedagogical content knowledge (TPACK) assessment for preservice teachers learning to teach English as a foreign language*, Computer Assisted Language Learning.
- Basilicato, M. (2005). *The interactive whiteboard: A tool for enhancing learning*. *Journal of Educational Technology*, 12(3), 23-35.
- Bauer, W. (2010). Technological Pedagogical and Content Knowledge for Music Teachers. In D. Gibson & B. Dodge (Eds.). *Proceedings of Society for Information Technology & Teacher Education International Conference 2010*(pp. 3977-3980). Chesapeake, VA: AACE.
- Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., ... & Tsai, Y. M. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American educational research journal*, 47(1), 133-180.
- Becker, H.J.; Ravitz, J.L, & Wong, Y (1999). *Teacher and teacher-directed student*

use of computers and software. Center for Research on Information Technology and Organizations, University of California, Irvin, and University of Minnesota.

- Bello, R. A. & Abimbola, I. O. (2016). Model of the elements of pedagogical content knowledge. *Unpublished M.Ed. Thesis Department of Science Education, Faculty of Education, University of Ilorin, Nigeria*.
- Ben-Peretz, M., Kleeman, S., Reichenberg, R., & Shimoni, S. (2010). Educators of educators: their goals, perceptions and practices. *Professional development in education*, 36(1-2), 111-129.
- Biesta, G. (2010). *Pragmatism and the philosophical foundations of mixed methods research*. In A. Tashakkori & C Teddlie (Eds.), *Sage handbook of mixed methods in social & behavioural research* (2nd ed.) (pp. 95-118). Thousand Oaks, CA. Sage.
- Blömeke, S., & Delaney, S. (2012). *Assessment of teacher knowledge across countries: A review of the state of research*. *ZDM*, 44(3), 223-247.
- Boateng, R. (2015). *Examining basic school teachers' pedagogical content knowledge of the English language and their classroom teaching practices in the case of Azrin South District*. Dissertation, University of Education, Winneba
- Borowski, A., Neuhaus, B. J., Tepner, O., Wirth, J., Fischer, H. E., Leutner, D., ... & Sumfleth, E. (2010). Professionswissen von Lehrkräften in den Naturwissenschaften (ProwiN)-Kurzdarstellung des BMBF-Projekts. *Zeitschrift für Didaktik der Naturwissenschaften: ZfDN*, 16, 341-349.
- Brickhouse, N. W. (1990) Teacher beliefs about the nature of science and their relationship to classroom practices. *Journal of Teacher Education*, 41(3), 53-62.
- Bromme, R. (2005). Thinking and knowing about knowledge: A plea for and critical remarks on psychological research programs on epistemological beliefs. *Activity and sign: Grounding mathematics education*, 191-201.
- Brush, T., & Saye, J. W. (2009). Strategies for preparing preservice social studies teachers to integrate technology effectively: Models and practices. *Contemporary Issues in Technology & Teacher Education*, 9(1), 46-59.
- Buabeng-Andoh, C. (2012). *Factors influencing teachers' adoption and integration of information and communication technology into teaching: A review of the literature*. *International Journal of Education and Development using Information and Communication Technology*, 8(1), 136-155.
- Canbazoğlu Bilici, S. (2012). *Fen Bilgisi Öğretmen Adaylarının Teknolojik Pedagojik Alan Bilgisi ve Özyeterlikleri*. Unpublished Doctoral Thesis. Ankara: Gazi University Institute of Educational Sciences.

- Carpenter, J. P., Krutka, D. G., & Kimmons, R. (2020). # RemoteTeaching & # RemoteLearning: Educator tweeting during the COVID-19 pandemic. *Journal of technology and teacher education*, 28(2), 151-159.
- Cavanagh, R. & Koehler, M. J. (2013). A turn towards specifying validity criteria in the measurement of technological Pedagogical content knowledge (TPACK). *Journal of Research in Technology Education*, 11(3), 85-92.
- Cavin, R.M. (2007). Developing Technological Pedagogical Content Knowledge in Preservice Teachers through Micro-teaching Lesson Study. (*Unpublished doctoral dissertation*). The Florida State University, the United States of America.
- Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2016). A review of the quantitative measures of technological pedagogical content knowledge (TPACK). In M. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge for teachers* (2nd ed., pp. 87-106). New York, NY: Routledge.
- Chai, C. S., Koh, J. H. L., Tsai, C.C., & Tan, W. L. (2011). Modeling primary school preservice teachers' Technological Pedagogical Content Knowledge (TPACK) for meaningful learning with information and communication technology (ICT). *Computers & Education*, 57, 1184-1193.
- Check, J., & Schutt, K. R. (2012). *Research Methods in Education*. Thousand Oaks: Sage Publications, Inc. Pp. 360-362
- Cheng, S. L., & Xie, K. (2018). The relations among teacher value beliefs, personal characteristics, and TPACK in intervention and non-intervention settings. *Teaching and Teacher Education*, 74, 98-113.
- Clandinin, D. J., & Connelly, F. M. (2004). *Narrative inquiry: Experience and story in qualitative research*. John Wiley & Sons.
- Clare, K., Dharamshi, P., & Menna, L. (2019). From Tinkering Around the Edges to Reconceptualizing Courses: Literacy/English Teacher Educator's Views and Use of Technology. *International Research, Policy and Practice in Teacher Education*. (63-73).
- Clotfelter, C. T., Ladd, H. F., & Vigdor, J. L. (2006). Teacher-student matching and the assessment of teacher effectiveness. *Journal of human Resources*, 41(4), 778-820.
- Cohen, L., Manion, L., & Morrison, K. (2007) *Research methods in education* (6th ed.). London: Routledge.
- Coll, R. K., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: implications from research. *International Journal of Science Education*, 27(2), 183-198.

- Conklin, H. G. (2015). Preparing novice teacher educators in the pedagogy of teacher education. *Action in teacher education*, 37(4), 317-333.
- Cox, S. (2008). A conceptual analysis of technological pedagogical content knowledge. *Doctoral dissertation, Brigham Young University*. <https://scholarsarchive.byu.edu/etd/1480>
- Cox, S., & Graham, C. R. (2009). Diagramming TPACK in practice: Using an elaborated model of the TPACK framework to analyse and depict teacher knowledge. *Tech-Trends*, 53(5), 60–69.
- Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, 37(9), 916-937.
- Creswell, J. W. (2014). *Research design: Qualitative, Quantitative and Mixed Methods approaches* (4th Ed.) Thousand Oaks, California: SAGE Publications, Inc
- Creswell, J. W. (2012). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Thousand Oaks, California: SAGE Publications Inc
- Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920*. Teachers College Press.
- Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Harvard University Press.
- Darling-Hammond, L., & Richardson, N. (2009). *Teacher learning: What matters?* Educational Leadership, 66(5), 46-53.
- Dasare, A., Chowdhury, A. R., Menon, A. S., Anand, K., Deepak, K. T., & Prasanna, S. R. M. (2023, November). Bridging the Gap: Towards Linguistic Resource Development for the Low-Resource Lambani Language. In *International Conference on Speech and Computer* (pp. 127-139). Cham: Springer Nature Switzerland.
- Dhanapal, S., Kanapathy, R., & Shan, E. W. Z. (2014). A Comparison of the Effectiveness between Free and Structured Play in Enhancing Students' Problem Solving Skills in Mathematics. *Asian Journal of Education and e-Learning*, 2(4)
- Dillman, D. (2000). *Mail and Internet Survey the Tailored Design Method*. New York, NY: John Wiley and Sons
- Dilworth, J. R., & Hueting, R. (2012). Metal complexes of thiosemicarbazones for imaging and therapy. *Inorganica Chimica Acta*, 389, 3-15.
- Education Technology Research and Development. (2007). Professional development for technology integration: Relevance for educational leaders. *Educational*

Technology Research and Development, 55(5), 493–512.
<https://doi.org/10.1007/s11423-006-9017-9>

- Education Technology Research and Development. (2007). *The integration of technology in schools: A review of current research*. Educational Technology Research and Development, 55(4), 405-425.
- Ertmer, P. A., & Newby. T. J. (2013). *Behaviourism, cognitivism, constructivism: comparing critical features from an instructional design perspective*. Performance Improvement Quarterly, 26(2), 43-71. Retrieved August 21, 2024, from <https://doi.org/10.1002/piq>, 21 -43.
- Eshun, E. S. (2014). *A study of teachers' use of language on junior high school Students' conceptual understanding of some mathematics Concepts*.
- Ferdig, R. E. (2006). Assessing technologies for teaching and learning: understanding the importance of technological pedagogical content knowledge. *British journal of educational technology*, 37(5), 749-760.
- Fieser, J. and Dowden B. (2004). The internet encyclopaedia of philosophy. Accessed 3rd December 2018, from lamp/www.am.edu/research/inc/ethics.html
- Fraenkel. I. R. Wallen, N., E and Hyun. H., H (2012). *How to design and evaluate research in Education (8th Ed.)*. New York: McGraw-Hill.
- Fraenkel. K. R. Wallen, N., E and Hyun. H., H (2012). *How to design and evaluate research in Education (8th Ed.)*. New York: McGraw-Hill.
- Fraser, N. (2016). *Capitalism's crisis of care*. *Dissent*, 63(4), 30-37.
- Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, 46(4), 357-383.
- Fullan, M. (2000). *The new meaning of educational change* (3rd ed.). Teachers College Press.
- Gess-Newsome, J. (2002). *Pedagogical content knowledge: an introduction and orientation*. In J. Gess Newsome & N. Lederman (Eds), PCK and science education (pp. 3–17). New York, NY:
- Ghavifekr, S., & Rosdy, W. Wan Athirah. (2015). *Teaching and Learning with Technology: Effectiveness of ICT Integration in Schools*. *International Journal of Research in Education and Science*, 1(2).
- Gilakjani, Abbas Pourhosein, Leong, Lai-Mei, & Ismail, Hairul Nizam. (2013). Teachers' Use of Technology and Constructivism. I. J. *Modern Education and Computer Science*, 4, 49-63. Doi: 10. 5815/ijmecs. 2013. 04. 07.

- Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical knowledge (TPACK). *Computers & Education*, 57, 3, 1953–1960.
- Graham, C. R., Borup, J., & Smith, N. B. (2012). Using TPACK as a framework to understand teacher candidates' technology integration decisions. *Journal of Computer Assisted Learning*, 28 (6), 530–546. doi: 10.1111/j.1365-2729.2011.00472.x
- Graham, C. R., Burgoyne, N., Cantrell, P., Smith, L., Clair, L. S. & Harris, R. (2009). TPACK development in science teaching: Measuring the TPACK confidence of in-service science teachers. *Tech-Trends*, 53, 5,70–79.
- Graham, C., Cox, S., & Velasquez, A. (2009). Teaching and Measuring TPACK Development in Two Preservice Teacher Preparation Programs. In I. Gibson et al. (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2009*(pp 4081-4086). Chesapeake, VA: AACE.
- Gronseth, S., Brush, T., Ottenbreit-Leftwich, A., Strycker, J., Abaci, S., Easterling, W., & Leusen, P. V. (2010). Equipping the next generation of teachers: Technology preparation and practice. *Journal of Digital Learning in Teacher Education*, 27(1), 30-36.
- Guerriero, S (2017). *Pedagogical knowledge and the changing nature of the teaching profession*. Paris: OECD Publishing.
- Gulbahar, Y., & Guven, I. (2008). A survey on ICT usage and the perceptions of social studies teachers in Turkey. *Educational Technology & Society*, 11(3), 37–51.
- Guzey, S. S., & Roehrig, G. H. (2009). Teaching science with technology: case studies of science teachers' development of technological pedagogical content knowledge (TPCK). *Contemporary Issues in Technology and Teacher Education*, 9(1), 25-45.
- Han, I., Eom, M., & Shin, W. S. (2013). Multimedia case-based learning to enhance pre-service teachers' knowledge integration for teaching With technologies. *Teaching and Teacher Education*, 34(2), 122–129.
- Hansen, N. (2016). The CMA evolution strategy: A tutorial. *arXiv preprint arXiv:1604.00772*.
- Harkverdi, A., Gucum, M., & Korkmaz, H. (2007). *Effective technology integration in the classroom: A study of Turkish teachers' perspectives*. *Educational Technology & Society*, 10(3), 107-120.
- Harris, J. B., & Hofer, M. J. (2011). Technological pedagogical content knowledge (TPACK) in action: A descriptive study of secondary teachers' curriculum-

- based, technology-related instructional planning. *Journal of Research on Technology in Education*, 43(3), 211-229.
- Harris, J. B., & Hofer, M. J. (2011). Technological pedagogical content knowledge in action: A descriptive study of secondary teachers' curriculum-based, technology-related instructional planning. *Journal of Research on Technology in Education*, 43(4), 211.
- Harris, J. B., Grandgenett, N., & Hofer, M. (2010) *Testing a TPACK-Based Technology Integration Assessment Rubric*. In D. Gibson & B. Dodge (eds.), International Conference 2010, Chesapeake, VA: Association for the Advancement of Computing in Education (AACE), pp.3833-384. Retrieved from <http://publish.wm.edu/bookchapters/6>
- Harris, J. B., Mishra, P., & Koehler, M.J. (2007). *Teachers' technological pedagogical content knowledge: Curriculum-based technology integration reframed*. Paper presented at the 2007 Annual Meeting of the American Educational Research Association, Chicago, IL.
- Harris, J., Mishra, P. & M. J. Koehler. (2009). Teachers' Technological Pedagogical Content Knowledge and Learning Activity Types: Curriculum-based Technology Integration Reframed. *Journal of Research on Technology in Education*. 41(4), 393-416.
- Hendriks, A. J., Kuyper, H., Lubbers, M. J., & Van der Werf, M. P. (2011). Personality as a moderator of context effects on academic achievement. *Journal of school psychology*, 49(2), 217-248.
- Hew, K. F. & Brush, T. (2007). Integrating technology into K-12 teaching and learning: current knowledge gaps and recommendations for future research. *Education Tech Research Development*, 55, 3, 223–252.
- Hicks, T. (2006). Expanding the conversation: A commentary toward revision of Swenson, Rozema, Young, McGrail, and Whitin. *Contemporary Issues in Technology and Teacher Education*, 6(1), 46-55.
- Hill, H. C. (2011). The nature and effects of middle school mathematics teacher learning experiences. *Teachers College Record*, 113(1), 205-234.
- Honey, M. (2001). *Transforming the quality of education: The promise of technology*. Educational Leadership, 59(5), 60-63.
- Horzum, M. B. (2013). An investigation of the technological pedagogical content knowledge of pre-service teachers. *Technology, Pedagogy and Education*, 22(3), 303-317. doi: 10.1080/1475939X.2013.795079 <http://www.britannical.com/science/biology>.
- Hudson, P. (2007). The pedagogical process in teaching science: Classroom management, problem-solving, and assessment. *Journal of Science Education*, 45(1), 56-67.

- Information and Communication Technology. (2017). *How information and communication technology can achieve sustainable development goals*. Key research insights.
- Isman, A., Abanmy, F. A., Hussein, H. B., & Al Saadany, M. A. (2012). Teachers' perceptions of the interactive whiteboard for teaching and learning in Saudi Arabia. *TOJET: The Turkish Online Journal of Educational Technology*, 11(3), 286–296.
- ISTE (2002). *National Educational Technology Standards and Performance Indicators for All Teachers*. Retrieved March 10, 2010, from <http://cnets.iste.org/teachers/tstands.html>.
- Jepsen, C., & Rivkin, S. G. (2002). *Class size reduction, teacher quality, and academic achievement in California public elementary schools*. Public Policy Institute of CA.
- Jimoyiannis, A. (2010). *Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers' professional development*. *Computers & Education*, 55(3), 1259-1269. doi: 10.1016/j.compedu.2010.05.022
- Jung, A. R., Kim, D., & Park, E. A. (2021). Cognitive intervention using information and communication technology for older adults with mild cognitive impairment: a systematic review and meta-analysis. *International journal of environmental research and public health*, 18(21), 11535.
- Junnaina, H. C., & Hazri, J. (2014). The Effect of Field Specialization Variation on Technological Pedagogical Content Knowledge (TPACK) Among Malaysian TVET Instructors. *The Malaysian Online Journal of Educational Technology*, 2(1), 36–44.
- Jüttner, M., & Neuhaus, B. J. (2012). Development of items for a pedagogical content knowledge test based on empirical analysis of pupils' errors. *International Journal of Science Education*, 34(7), 1125-1143.
- Käpylä, M., Heikkinen, J. P., & Asunta, T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education*, 31(10), 1395-1415.
- Karasavvidis, I., & Kollias, V. (2014). *Technology integration in the most favorable conditions: findings from a professional development training Program*. In C. Karagiannidis (Ed.), *Research on e-learning and ICT in Education* (pp. 197–224). New York: Springer.
- Karve, V. (2009). *The meaning of technology*. Retrieved from <http://karvediat.blogspot.com/2009/07/meaning-of-technology.html>.
- Kathryn MacCallum, Lynn Jeffrey, & Kinshuk. (2014). Factors impacting teachers' adoption of mobile learning. *Journal of Information Technology Education*,

13.

- Kazua, I. & Demirkol, M. (2014). Effect of blended learning environment model on high school students' academic achievement. *The Turkish Online Journal of Educational Technology* 13(1).
- Khaddage, & Knezek, (2013). *Introducing a Mobile Learning Attitude Scale for Higher Education*. Paper presented at the X World Conference on Computers in Education, Toruń, Poland.
- Kilic, B. (2009). Current trends in traditional Turkish meat products and cuisine. *LWT-Food Science and Technology*, 42(10), 1581-1589.
- Kind, V. (2009). A conflict in your head is an exploration of trainee science teachers' subject matter knowledge development and its impact on teacher self-confidence. *International Journal of Science Education*. 31(11), 1529-1562.
- Kind, V., & Chan, K. K. (2019). Resolving the amalgam: connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education*, 41(7), 964-978.
- Kinnersley, T. (2019). *Application of repertory grid technique to explore perceptions of expertise held by those working within the profession of conductive education*.
- Kivunja C., & Kuyini A., B. (2017) Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, 6 (5), 26-41. Kluwer Academic Publishers.
- Koehler, M. J. & Mishra, R. (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research*, 32, 2, 131–152.
- Koehler, M. J. & Mishra, R. (2008). *Introducing TPACK*. In *AACTE committee on innovation and technology (Ed.)*, Handbook of technological content knowledge (TPCK) (pp. 3–30). New York: Routledge.
- Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education (CITE Journal)*, 9(1), 60-70.
- 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.
- Koehler, M. J., Shin, T. S., & Mishra, P. (2012). *How Do We Measure TPACK? Let Me Count the Ways*. In R. N. Ronau, & Rakes.
- Koh, J. L., Chai, C. S., & Tsai, C. C. (2015). Examining the technological pedagogical content knowledge of Singapore preservice teachers with a large-

scale survey. *Journal of Computer Assisted Learning*, 26(6), 563- 573.
doi:10.1111/j.1365- 2729.2010.00372.x

- Kramarski, B., & Michalsky, T. (2010). Preparing preservice teachers for self-regulated learning in the context of technological pedagogical content knowledge. *Learning and Instruction*, 20(5), 434-447.
- Krepf, M., Plöger, W., Scholl, D., & Seifert, A. (2018). Pedagogical content knowledge of experts and novices. What knowledge do they activate when analyzing science lessons?. *Journal of Research in Science Teaching*, 55(1), 44-67.
- Kumekpor, T. K. (2002). Research Methods and Techniques of Social Research, Accra. *Son Life Press and Services. Manchester School of Economic and Social Studies*, 24, 203-244.
- Landis, J. R., & Koch, G. G. (1977). *The measurement of observer agreement for categorical data. Biometrics*, 159-174.
- Lee J. (2010). Design of blended training for transfer into the workplace. *British Journal of Educational Technology*, 41(2), 181-198.
- Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education*, 30(10), 1343-1363.
- Lee, M. H., & Tsai, C. C. (2010). Exploring teachers' perceived self-efficacy and technological pedagogical content knowledge concerning educational use of the World Wide Web. *Instructional Science*, 38,1-21.
- Lee, Y. S. (2011). *The effects of a content knowledge workshop on teachers' pedagogical content knowledge and student learning in a soccer unit in middle school physical education*. Doctoral dissertation, The Ohio State University.
- Lei, J., & Zhao, D. (2006). Global P-wave tomography: On the effect of various mantle and core phases. *Physics of the Earth and Planetary Interiors*, 154(1), 44-69.
- Levine A, Sober E, and Wright E., O. (1987). Marxism and methodological individualism. *New Left Review*, 162.
- Liu, F., & Maitlis, S. (2010). *Non-participant Observation*. In Albert J. Mills, G. Durepos, & E. Wiebe (Eds.), *Encyclopedia of Case Study Research*. (pp. 610-612). Thousand Oaks, CA: SAGE Publications. Retrieved 24 August 2023, from hupe/orno.sagepub.com/viewimcys-of-sass-study-research/n229.xml.
- LiveScience (2017). *The Science and Study of Living Organisms*. Retrieved from <https://www.livescience.com>.

- Loughram, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practices. *Journal of Research in Science Teaching*, 41(4), 370-391.
- Luera, G. R., Otto, C. A., & Zitzewitz, P. W. (2005). A conceptual change approach to teaching energy & thermodynamics to pre-service elementary teachers. *Journal of Physics Teacher Education Online*, 2(4), 3-8.
- Lux, N. J. (2010). *Assessing Technological Pedagogical Content Knowledge*. Unpublished 3430401, Boston University, United States - Massachusetts.
- Magnusson, M. K., Arvola, A., Hursti, U. K. K., Åberg, L., & Sjöden, P. O. (2001). Attitudes towards organic foods among Swedish consumers. *British food journal*, 103(3), 209-227.
- Magnusson, S., Krajcik, J. & Borko, H. (1999). *Nature, sources, and development of pedagogical content knowledge for science teaching*. In J. Gess-Newsome & N. Lederman (Eds), *PCK and science education* (pp. 3–17). New York, NY: Kluwer Academic Publishers.
- Mahdum. (2015). Technological pedagogical and content knowledge (TPACK) of English teachers in Pekanbaru, Riau, Indonesia. *Mediterranean Journal of Social Science*, 6(5), 168-176.
- Manfra, M., & Hammond, T. C. (2008). Teachers' instructional choices with student-created digital documentaries: Case studies. *Journal of Research on Technology in Education*, 41(2), 223-245.
- Maor, D. & Roberts, P. (2011). *Does the TPACK framework help to design a more engaging learning environment?* In T. Bastiaens & M. Ebner (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2011* (pp. 3498-3504). Chesapeake, VA: AACE.
- Margerum-Leys, J., & Marx, R. W. (2002). Teacher knowledge of educational technology: A case study of student/mentor teacher pairs. *Journal of Educational Computing Research*, 26(4), 427-462.
- Markauskaite, L., Bachfischer, A., Goodyear, P., & Kali, Y. (2011). *Beyond technology, pedagogy and content: Insights into the knowledge bases for collaborative learning design*. Paper presented at the American Educational Research Association Annual Meeting, New Orleans, Louisiana.
- Marschall, M. J., & McKee, R. J. (2002). From campaign promises to presidential policy: Education reform in the 2000 election. *Educational Policy*, 16(1), 96-117.
- Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1997). Enacting project-based science. *The elementary school journal*, 97(4), 341-358.

- Mehan, H. (1989). Microcomputers in classrooms: educational technology or social practice? *Anthropology & Education Quarterly*, 20(1), 4-22. Merriam-Webster (2014). Definition of Biology. Retrieved from <https://www.merriam-webster.com/biology>.
- Mishra, P. & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6) 1017–1054.
- Mishra, P. & Koehler, M. J. (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research*. 32(2), 131-152.
- Mishra, P. (2012). *Is TPACK Fundamentally Flawed? A Quick Response*, Retrieved June 1st, 2023 from <http://punya.educ.msu.edu/2012/01/24/is-pack>
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054. <https://doi.org/10.1111/j.1467-9620.2006.00684.x>
- Mishra, P., Koehler, M. J., Zellner, A., & Kereluik, K. (2012). *Thematic Considerations in Integrating TPACK in a Graduate Program*. In D. Polly, C. Mims & K. A. Persichitte (Eds.). *Developing Technology-Rich Teacher Education Programs: Key Issues* (pp. 1-12). Hershey, PA: IGI Global.
- Moallem, M. (1998). An expert teacher's thinking and teaching and instructional design models, and principles: An ethnographic study. *Educational technology research and development*, 46(2), 37-64.
- Mohamad, F. S. (2021). Technological pedagogical content knowledge (TPACK) and the teaching of science: Determinants for professional development. *Studies of Applied Economics*, 39(1).
- Mohamad, M. (2010). The ascendance of bureaucratic Islam and the secularisation of the Sharia in Malaysia. *Pacific Affairs*, 83(3), 505-524.
- Morrison, J. A., & Lederman, N. G. (2003). Science teachers' diagnosis and understanding of students' preconceptions. *Science education*, 87(6), 849-867.
- Moulton, K. (2009). *Using technology in the classroom to improve student outcomes: A comparison of traditional and technology-enhanced instruction*. *International Journal of Educational Research*, 50(4), 235-248.
- Murphy, R., Penuel, W., Means, B., Korbak, C., Whaley, A. (2001). *E-DESK: A review of recent evidence on the effectiveness of discrete Educational Software*. Menlo Park, CA: SRI International.
- National Council of Teachers of Mathematics (2000). *The Technology Principle*. Retrieved from <http://standards.nctm.org/document/chapter2/techn.htm>

- National Research Council. (2000) *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
- 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://doi.org/10.1016/j.tate.2005.03.006>
- 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.
- Niess, M. L. (2013). *TACK in the classroom: Developing Technological Pedagogical and Content Knowledge*. Retrieved September 30th 2023 from <http://www.igi-global.com/newsroom/archive/tack-classroom- developing-technologies/1547/>
- Olsen, W. (2004). Triangulation in social research: Qualitative and quantitative methods can be mixed. *Developments in sociology*, 20, 103-118.
- Orlando, J. (2013). ICT-mediated practice and constructivist practices: Is this still the best plan for teachers’ uses of ICT?. *Technology, Pedagogy and Education*, 22(2), 231-246
- Özden, M. (2008). Environmental awareness and attitudes of student teachers: An empirical research. *International research in geographical and environmental education*, 17(1), 40-55.
- Özgün-Koca, S. A., Meagher, M. & Edwards, M.T. (2010). *Preservice Teachers’ Emerging TPACK in a Technology-Rich Methods Class*. *The Mathematics Educator*, Vol. 19, No. 2, 10–20
- Painter, L. (2001). *Pedagogical readiness: Integrating technology into teaching and learning*. *Journal of Teacher Education*, 52(5), 123-135.
- Pamuk, S. (2012). Understanding preservice teachers' technology use through the TPACK framework. *Journal of computer-assisted learning*, 28(5), 425-439.
- Pamuk, S., & Marino, M. T. (2013). *Understanding pre-service teachers’ technology use through the TPACK framework*. *J. Computer-assisted learning*. 28:425-439.
- Papanikolaou, A. (2014). *Ship design: methodologies of preliminary design*. Springer.
- Papanikolaou, K., Gouli, E., & Makri, K. (2014). Designing pre-service teachers' training based on a combination of Educational Sciences (WCES-2013). *Procedia-Social and Behavioural Science*. 116, 3437- 3442.
- Parker, J., Osei-Himah, V., Asare, I., & Ackah, J. K. (2018). Challenges faced by teachers in teaching integrated science in Junior High Schools in Aowin Municipality-Ghana. *Journal of education and practice*, 9(12), 65-68.

- Penso, S. (2002). Pedagogical content knowledge: how do student teachers identify and describe the causes of their pupils' learning difficulties?. *Asia-Pacific Journal of Teacher Education*, 30(1), 25-37.
- Peruski, L., & Mishra, P. (2004). Webs of activity in online course design and teaching. *Research in Learning Technology*, 12(1), 37-49.
- Petra, F., Joke V., Johan, V.B., & Jo, T. (2015). *The SAGE Encyclopedia of Technology: Measuring and Assessing Technological Pedagogical Content Knowledge*. 490-493. Thousand Oaks
- Pierson M. E. (2001). Technology integration practice as a function of pedagogical expertise. *Journal of Research on Computing in Education* 33, 413–430.
- Pitjeng-Mosabala, P., & Rollnick, M. (2018). Exploring the development of novice unqualified graduate teachers' topic-specific PCK in teaching the particulate nature of matter in South Africa's classrooms. *International Journal of Science Education*, 40(7), 742-770.
- Polly, D., McGee, J. R., & Martin, C. S. (2010). Employing technology-rich mathematical tasks in professional development to develop teachers' technological, pedagogical, and content knowledge (TPCK). *Journal of Computers in Mathematics and Science Teaching*, 29, 455-472.
- Prensky, M. (2013). Listen to the natives. *Educational Leadership*, 63(4), 8- 13.
- Rahi, S. (2017). Research design and methods: a systematic review of research paradigms, sampling issues, and instrument development. *International Journal of Economics & Management Science*, 6(2), 1-5.
- Retelsdorf, J., Schwartz, K., & Asbrock, F. (2015). "Michael can't read!" Teachers' gender stereotypes and boys' reading self-concept. *Journal of Educational Psychology*, 107(1), 186.
- Richards, J. C. (2005). Self-directed learning in the language classroom: Making learning more meaningful. *Modern Language Journal*, 89(4), 537-547.
- Ringstaff, C., & Kelley, L. (2002). *The learning return on our educational technology investment*. WestEd.
- Roćko, A. (2004). For Peace and Freedom. *ACADEMIA. The magazine of the Polish Academy of Sciences*, 30-31.
- Rodger, D. (2003). The impact of teaching methods on classroom management. *Educational Leadership*, 60(5), 72-77.
- Ryan, K., & Cooper, J. M. (2006). *Those who can, teach* (12th ed.). Houghton Mifflin.

- Sahin, I. (2011). Development of a survey of technological, pedagogical and content knowledge (TPACK). *TOJET. The Turkish Online Journal of Educational Technology*, 10, 1, 97–105.
- Schmidt, D. A., Baran, E. A. (2009). *Technological Pedagogical Content Knowledge (TPACK)*. The Development and Validation of an Assessment Instrument for Preservice Teachers, 123-149.
- Shafer, G., & Vovk, V. (2008). A tutorial on conformal prediction. *Journal of Machine Learning Research*, 9(3).
- Shaharom, N., & Faridah, S. (2010). *Tahap Pencapaian Pengetahuan Pedagogi Dan Kandungan Dalam Kalangan Bakal Guru Fizik*. Repositori Universiti Teknologi Malaysia.
- Sheingold, K. (1990). *Instructional technology: An assessment of the field*. *Educational Leadership*, 47(5), 14-18.
- Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, 57, 1, 1–22.
- Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Research*, 15(2): 4-14.
- So, H. J. & Kim, B. (2009). Learning about problem-based learning: Student teachers integrating technology, pedagogy, and content knowledge. *Australasian Journal of Educational Technology*, 25(1), 101-116.
- Strike K., A. and Soltis, J. F (2004). *The ethics of teaching*. New York: Columbia University.
- Subbey, M. (2017). *Research Methods*. Cape Coast: Edsam Printing and Publishing Ltd.
- Sumber, H., Ndofirepi, T., & Gwirayi, P. (2012). Aligning teaching styles with learners' learning styles: A key to improving learning. *Journal of Educational Psychology*, 98(3), 235-248.
- Syh-Jong, J., & Kuan-Chung, C. (2010). From PCK to TPACK: Developing a transformative model for pre-service science teachers. *Journal of Science Educational Technology*, 19, 553–564.
- Tagoe, M., Addae, D., & Amuzu, D. (2022). Lifelong education trajectories and futures in Ghana: issues of policy, ideology and practice. *International Journal of Lifelong Education*, 41(3), 327-342.
- Tamakloe, E. K., Amedahe, F. K., & Atta, G. (2005). Effective methods of teaching practical subjects: A case study of biology. *African Journal of Education*, 18(1), 36-42.

- Teddle, C. (2010). A continuation of the paradigm wars? Prevalence rates of methodological approaches across the social behavioural. *Journal of Science Education*, 4(2), 103-126.
- Tepner, O., Borowski, A., Dollny, S., Fischer, H. E., Jüttner, M., Kirschner, S., ... & Wirth, J. (2012). Modell zur Entwicklung von Testitems zur Erfassung des Professionswissens von Lehrkräften in den Naturwissenschaften. *Zeitschrift für Didaktik der Naturwissenschaften: ZfDN*, 18, 7-28.
- Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education*, 3, 297-328.
- Tseng, J. J. (2014). Developing an instrument for assessing technological pedagogical content knowledge as perceived by EFL students. *Computer Language Learning: 29*(2), 302-315.
- UNESCO (2002). *Information and communication technology in education: A curriculum for schools and a program of teacher development*. Paris: UNESCO.
- Veal, W. R., & MaKinster, J. G. (1999). *Pedagogical content knowledge taxonomies*. Electronic Journal of Science Education, 3, Retrieved August 22, 2023, from <http://unr.edu/homepage/crowther/ejse/vealmak.html>.
- Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge (TPACK). *A review of the literature. Journal of Computer Assisted Learning*, 29, 109–121.
- Wang, W., Schmidt-Crawford, D., & Jin, J. (2018). Preservice Teachers' TPACK Development: A Review of Literature. *Journal of Digital Learning in Teacher Education* 34 (4), 234-258.
- Watson, D. M. (1998). Blame the technocentric artifact! What research tells us about teachers' use of ICT in the classroom. In G. Marshall & M. Ruohonen (Eds.), *Capacity Building for IT in Education in Developing Countries* (pp. 185–192). Springer. https://doi.org/10.1007/978-0-387-35195-7_21
- Wellington, J. (2000). *Educational Research: Contemporary issues and practical approaches*. London: Continuum.
- Wetzel, K., Buss, R., Foulger, T. S., & Lindsey, L. (2014). Infusing educational technology in teaching methods courses: Successes and dilemmas. *Journal of Digital Learning in Teacher Education*, 30(3), 89-103
- Woodrow, J. E. (1992). The influence of programming training on the computer literacy and attitudes of pre-service teachers. *Journal of Research on Computing in Education*, 25(2), 200–219. <https://doi.org/10.1080/08886504.1992.10782043>

- Wu, Y., & Wang A. Y. (2015). Technological pedagogical content knowledge in teaching English as a foreign language: *Representation of primary school teachers of English in Taiwan Asia-Pac. Educ. Res.*24(3): 525-533.
- Yager, R.E. (2000). The constructivist learning model. *The Science Teacher*, 67(1): 44-45.
- Yapici, İ., Umit, & Hevedanli, M. (2012). Pre-Service Biology Teachers' Attitudes Towards ICT Use in Biology Teaching. *Procedia - Social and Behavioral Sciences* 64 633 – 638. doi: 10. 1016/j. sbspro.2012. 11. 074
- Zhang, Y. (2005). *Development and validation of an Internet use attitude scale. Computers and Education*. Available at: <http://www.sciencedirect.com/science> {Accessed 10 February 2023}.
- Zhao, Y. (2003). *What teachers should know about technology: Framing the question*. In Y. Zhao (Ed.), *What should teachers know about technology: Perspectives and practices*. Greenwich, T: Information Age Publishing.
- Zhao, Y. (2007). Social studies teachers' perspectives of technology integration. *Journal of Research on Technology in Education*, 39(3), 281–307. <https://doi.org/10.1080/15391523.2007.10782487>.



APPENDIX A

UNIVERSITY OF EDUCATION, WINNEBA
SCHOOL OF GRADUATE STUDIES
FACULTY OF SCIENCE EDUCATION
DEPARTMENT OF BIOLOGY EDUCATION
QUESTIONNAIRE ON TECHNOLOGICAL PEDAGOGICAL
CONTENT KNOWLEDGE OF BIOLOGY TEACHERS IN SENIOR HIGH
SCHOOLS IN SELECTED MUNICIPALITIES.

Dear Sir/Madam,

This tool's objective is to collect pertinent data regarding the technical pedagogical subject knowledge of senior high school biology teachers. The term "technological pedagogical and content knowledge" describes the intricate interactions between a teacher's use of technology, teaching strategies, and subject-matter knowledge.

Kindly respond to all items by ticking (✓) where appropriate. Your responses will be treated with the utmost confidentiality.

Thank you in anticipation of your cooperation.

SECTION A

PERSONAL INFORMATION

Please tick [✓] where appropriate.

1. **Name of School:**

2. **Sex:**

❖ Male []

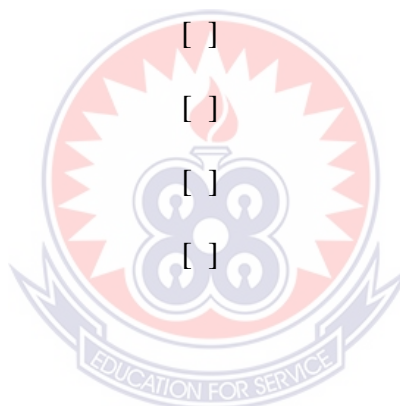
❖ Female []

3. Age:

- ❖ 20-30 []
- ❖ 31-40 []
- ❖ 41 -50 []
- ❖ 51 -60 []

4. Qualifications:

- ❖ PhD []
- ❖ M.Ed. []
- ❖ M.Sc []
- ❖ MPhil []
- ❖ B.Sc (Ed) []
- ❖ B.Sc []
- ❖ HND []



APPENDIX B**SECTION B**

Please indicate appropriately the availability and accessibility of ICT Gadgets with Available (AV), Not Available (NV), Accessible (AS), and Not Accessible (NA). However, kindly rate your level of expertise in the following ICT gadgets. (1) Needs Improvement (2)-Fair (3)-Average (4)-Good (5)-Very Good (6)-Excellent as well as Type of Training acquired. Formal Training (FT), Informal Training (IT), Self-Training (ST)

ICT Gadgets	Availability		Accessibility		Confidence Level						Type of Training		
	AV	NV	AS	NA	1	2	3	4	5	6	FT	IT	ST
SOFTWARE													
MS -Word													
PowerPoint													
MS Excel													
Corel Draw													
Animations in Biology													
HARDWARE													
Computer in the classroom													
CD ROM													

Media Player																			
DVD																			
Printer																			
Projector																			
Scanner																			
Digital Camera																			
Interactive whiteboard																			
Mobile device																			
Podcast																			
Wireless classroom microphone																			
SOCIAL MEDIA																			
Email																			
Facebook																			
WhatsApp																			

SECTION C:

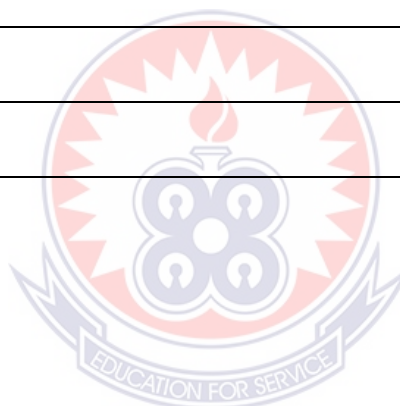
Please rate your level of expertise in teaching biology by ticking [√] where appropriate.

Rating scale: (1) Needs Improvement (2) Fair (3) Average (4) Good (5) Very Good

(6) Excellent

CONCEPT OF LIVING	1	2	3	4	5	6
The character of Living Things						
Cell Structure/ Cell Theory						
REPRODUCTION						
Male Reproductive System						
Female Reproductive System						
ECOLOGICAL SYSTEM						
Ecological Succession						
Trophic Level						
Pollution						
Conservation						
PLANT AND ANIMAL NUTRITION						
Nutrition/Macronutrient						
Photosynthesis						
Osmosis						
RESPIRATION						
Kreb Cycle						
Glycolysis						

CONSERVATION OF MATTER & ENERGY						
Conservation						
Thermodynamics						
EVOLUTION						
Theory of Evolution						
Natural Selection						
Darwin's Theory						
GENETICS						
Mendel's Law						
Monohybrid Inheritance						
Dihybrid Inheritance						
Mutation						



SECTION D

Technology Knowledge	SD	D	N	SA	A
Technology is the process by which people alter the natural world to suit their needs and desires, improving and easing their lives.					
I have a favourable outlook on using technology					
I am familiar with common technologies like smartboards, interactive whiteboards, and digital display boards.					
I am knowledgeable about contemporary and cutting-edge technology like computers, digital video, interactive whiteboards, the Internet, and overhead projectors.					
I can use computer software in an educational setting.					
I have the technological know-how to take advantage of cutting-edge resources.					

SECTION E**Table 8: Pedagogical Knowledge of Biology Teachers**

Pedagogical Knowledge	SD	D	N	SA	A
I can modify my teaching methods for various students.					
I know how to organise and maintain classroom management.					
I employ student-centred strategies to accomplish my lesson's particular goal.					
During the teaching period, I usually employ problem-solving and discovery learning.					
I know how to assess student performance in a classroom.					

SECTION F**Table 9: *Technological Pedagogical Content Knowledge of Biology Teachers***

Technological Pedagogical Content Knowledge	SD	D	N	SA	A
I can represent or create "Biology" concepts using technology that is understandable to students.					
I can "improve" the teaching and learning of biology using technology.					
I possess the technological know-how to successfully integrate technology and biology curriculum information.					
I can expand classroom discussions beyond the school's walls by utilising technology resources.					
At my school and/or district, I may take the lead in assisting others in coordinating the use of technology, instructional strategies, and materials during PLCs.					

APPENDIX C

A SAMPLE OF INTRODUCTORY LETTER

