UNIVERSITY OF EDUCATION, WINNEBA

QUALITY AND STATUS OF PEDAGOGICAL CONTENT KNOWLEDGE OF WELL-PERFORMING PHYSICS TEACHERS: A CASE STUDY OF SIX TEACHERS IN SENIOR HIGH SCHOOLS IN VOLTA REGION

GEOFFREY YAO KLUTSE

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GEOFFREY YAO KLUTSE

(200004163)

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DECLARATION

STUDENT'S DECLARATION

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

Signature ………………………………….

Date …………………………………………..

SUPERVISORS' DECLARATION

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

…………………………………………………………………….. (Principal Supervisor)

Signature ………………………………….

Date ………………………………………….

…………………………………………………………………….. (Co-Supervisor)

Signature ………………………………….

Date ………………………………………….

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ABSTRACT

The study explored the pedagogical content knowledge (PCK) among well-performing senior high school (SHS) physics teachers in the Volta Region of Ghana. This research investigated the link between teacher knowledge and learner achievement, with a specific focus on topic-specific PCK. A case study design and qualitative method were employed to examine the PCK of six physics teachers and their development in teaching thermal physics. The selection of participating teachers was based on their schools' consistent performance in WASSCE physics over a five-year period. Data were collected through lesson plan analysis, pre-lesson interviews, lesson observations, post-lesson interviews, and document analysis. The analysis assessed individual teachers' content knowledge in thermal physics, their understanding of instructional strategies, their knowledge of learners' preconceptions and learning difficulties and factors contributing to the development of teachers' PCK. The findings revealed that the six physics teachers generally possessed the necessary content knowledge of thermal physics and employed topic-specific instructional strategies. However, they demonstrated limited knowledge of learners' preconceptions and learning difficulties related to thermal physics. Even though these well-performing teachers demonstrated limited knowledge of learners' preconceptions and learning difficulties related to thermal physics, they exhibited adequate knowledge of content and instructional strategy, and this apparently, is the reason their learners perform well. The teachers' development of PCK in teaching thermal physics was primarily attributed to formal university education programmes, extensive classroom teaching experience, peer support, and participation in in-service workshops. The implications include enhancing the quality of physics instruction in senior high schools by encouraging both well-performing and non-performing teachers to adopt effective instructional strategies, improve their PCK while they identify and address common student misconceptions. This integrated approach can lead to improved student understanding and learning outcomes in physics, particularly in challenging topics such as thermal physics. The study emphasised the need for teachers to address learners' learning difficulties to enhance instructional effectiveness. Additionally, it underscores the significance of continuous professional development programmes to further enhance teachers' PCK and improve physics education outcomes in the region.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter begins with background to the study which provides the insight and rationale for embarking on this study. The statement of the problem indicates lack of adequate literature on PCK and its effect on physics teaching and learning. The Objective of the study is to find out how much PCK well-performing physics teachers have and what contributed to the development of their PCK. The study then presents research questions which boarder on the amount of PCK the well-performing physics teachers have and the mode of acquisition. Finally, discussions point to the fact that the study cannot be generalised since it is limited to only Volta Region but will be significant in similar context and settings as it provides a knowledge base to the academia. Under the organisation of the study, it is indicated that the study is presented in six chapters.

1.1 Background to the Study

Physics education at the senior high school (SHS) level is of paramount importance as it plays a critical role in shaping students' scientific understanding and future academic pursuits. Effective physics education shapes students' understanding of the physical world and their broader cognitive and analytical abilities. Physics is often described as the fundamental science which provides the basis for comprehending the fundamental principles that govern the universe. Proficient physics teaching does not only equip students with essential scientific knowledge but also cultivates critical thinking, problem-solving skills, and a curiosity-driven approach to learning.

Teacher knowledge base, specifically topic-specific Pedagogical Content Knowledge (PCK), is an essential factor linked with student understanding and achievement in science. PCK refers to the knowledge of how to teach a particular subject matter and how to effectively convey that knowledge to students. Pedagogical content knowledge refers to the specialised knowledge and skills that teachers possess to effectively teach a specific subject, in this case, thermal physics. This knowledge goes beyond simply knowing the content itself but also includes an understanding of how to teach that content in a way that is engaging and accessible for students (Wibowo, Masunah, Karyono, & Milyartini, 2022). Hodges, Tippins, and Oliver (2013) stated that effective science instruction ultimately results in satisfactory student performance in science. The three types of teacher knowledge, namely subject matter knowledge, pedagogical knowledge, and knowledge of learners' preconceptions, relate to what Shulman (Shulman,1986, as cited in Ijeh, 2013) and others (e.g. Loughran, Berry & Mulhall, 2012; Magnusson, Krajcik & Borko, 2001) have collectively referred to as pedagogical content knowledge. It is not enough for a teacher to possess content knowledge and pedagogical knowledge. Science teachers should have a thorough understanding of how students learn (Clark, 2012). When teachers lack this depth, they might not probe students' understanding or misunderstanding, which could result in superficial learning (Alshehry, 2014; Clark, 2012). Pedagogical content knowledge has been simply described as that teacher knowledge that allows teachers to assist learners to access specific content knowledge in a meaningful way (Miller, 2007). So pedagogical content knowledge is an important teacher knowledge base needed for effective teaching to take place.

Quality of education depends largely on the effectiveness of teachers in imparting knowledge to students. Within the educational landscape, science education, particularly physics, plays a crucial role in nurturing analytical thinking, problem-solving abilities, and critical inquiry skills among students. The role of teachers in facilitating effective science education cannot be overstated, as they are the primary agents responsible for translating complex scientific concepts into comprehensible and engaging learning experiences. However, a growing concern has emerged over the declining performance of students in physics, particularly in challenging topics such as thermal physics (WAEC, 2019). This downward trend in performance has raised questions about the factors influencing effective physics education and pedagogical practices. In response to these challenges, this study embarks on an in-depth exploration of the pedagogical content knowledge possessed by well-performing physics teachers within the Volta Region of Ghana as one most important factors that has been linked with student understanding and achievement in science is teacher PCK.

Some studies (Brown, Friedrichsen & Abell, 2013; De Jong, Veal & Van Driel, 2002; Kind, 2009) have underscored the pivotal role of teacher knowledge in influencing students' comprehension and achievement in science education. Specifically, a teacher's possession of topic-specific PCK has been highlighted as a crucial determinant of effective teaching. PCK has to do with a teacher's ability to seamlessly integrate subject matter knowledge, instructional strategies, and an understanding of students' preconceptions and learning challenges. By possessing a robust PCK, teachers can adeptly navigate complex topics, adapt their instructional methods, and create meaningful learning experiences for their students (Loughran, Berry, & Mulhall, 2012; Schmelsing, Van Driel, Juttner, Brandenbusch, Sandmann, & Neuhaus 2013).

Recent educational assessments, as indicated by the West African Senior School Certificate Examination (WASSCE) results analysis from the Regional Education Directorate of the Ghana Education Service (GES), reveal a divergence in the performance of schools offering elective physics. While certain schools have consistently exhibited commendable performance in elective physics, others have struggled to achieve satisfactory outcomes. This divergence in outcomes is particularly evident in the context of challenging physics topics (WAEC, 2019), with thermal physics standing out as an area where students frequently encounter difficulties, leading to sub-optimal performance in examinations.

The quality of teachers' PCK has been seen as one of the important factors in determining the success of science education. It has been indicated that teachers with a deep and well-developed PCK tend to foster better understanding and higher levels of engagement among their students (Kratz & Schaal, 2015). This assertion has been emphasised by Wilson, Stuhlsatz, Hvidsten, and Gardner, (2018) as they indicated that teachers with a strong understanding of how to elicit and respond to student thinking, engage students in scientific practices, and develop effective learning experiences have been able to increase student achievement compared to more traditional approaches. The relationship of the PCK of science teachers to the classroom behaviour of students, and their learning, indicated that the PCK of science teachers directly influences the active participation of students in the class (Rajput, 2018). Conversely, inadequate PCK can lead to misconceptions, disinterest, and reduced learning outcomes. Hence, understanding the PCK of physics teachers, particularly those who are considered well-performing, is crucial for enhancing science education at the secondary school level.

Pedagogical content knowledge refers to the unique blend of subject matter knowledge and pedagogical expertise that teachers possess. It involves understanding not only the content but also the most effective ways to teach that content to diverse groups of students. PCK is especially important in science education, where the interplay of content understanding and teaching methods significantly influences students' comprehension and interest in the subject. A teacher's ability to bridge the gap between abstract scientific concepts and concrete classroom experiences is a fundamental aspect of effective science teaching. Shulman introduced the concept of pedagogical content knowledge in 1986 and since then a number of researchers have worked on this concept. The PCK for science teaching consists of various components: knowledge of the subject matter, knowledge of instructional strategies, knowledge of students' understanding of science, preconception, and learning difficulties (Rajput, 2018).

This study focuses on investigating the PCK of well-performing physics teachers in senior high schools within the Volta Region. By well-performing, the study is referring to teachers who have consistently demonstrated the ability to produce students with commendable academic outcomes in physics. Exploring the PCK of these teachers can shed light on the strategies, practices, and instructional methods that contribute to their success. The Volta Region, with its unique cultural, socioeconomic, and educational landscape, presents an intriguing context for this study. Understanding the factors that underpin effective teaching in physics within this region can provide valuable insights for enhancing the quality of physics education across Ghana and potentially beyond. This region is home to a diverse range of senior high schools that serve as educational institutions nurturing the future of Ghana. The quality of education in this region, as in any other, relies heavily on the capabilities and competencies of its educators. Well-performing physics teachers are key agents in shaping students' understanding of complex scientific principles and cultivating an interest in the subject. Senior high schools in this region have demonstrated varying levels of academic achievement, with some consistently producing commendable results in physics. The study therefore explores the PCK of six physics teachers whose students have consistently performed well in WASSCE physics over a period of five consecutive years.

In brief, physics education, like other science disciplines, requires teachers to possess a unique blend of subject content knowledge and effective teaching methods. The ability to transform abstract scientific concepts into engaging and comprehensible lessons requires a deep understanding of the subject matter as well as the ability to tailor teaching strategies to meet the diverse needs of students. As such, the quality of PCK among physics teachers significantly influences the overall educational experience and academic achievement of students. This study, therefore, enables the systematic exploration of the participating teachers' content knowledge in thermal physics, their adeptness with topic-specific instructional strategies, as well as their understanding of students' preconceptions and learning challenges in this domain.

1.2 Statement of the Problem

Teachers' pedagogical content knowledge (PCK) is very important for the quality of teaching and learning in a subject. Analysis of the WASSCE physics results obtained from the planning unit of GES, Volta Regional Education Directorate, and further analysis by the researcher indicated a decline in learners' performance in physics at the senior high school level. However, while some schools are underperforming, others are identified as well-performing schools in elective physics. Notably, three top-performing schools - XYZ Senior High School, ABC Senior High School, and DEF Senior High School - achieved remarkable percentage performances between 2017 and 2021, as presented below:

Table 1. Performance Trends (2017 - 2021)

Year	XYZ Senior High School	ABC Senior High School	DEF Senior High School
2017	74%	75%	71%
2018	76%	79%	78%
2019	81%	84%	76%
2020	88%	84%	80%
2021	95%	90%	83%

Despite the declining performance in many schools, these high-performing schools have consistently achieved impressive results. However, many students in other schools still find physics topics, especially thermal physics, difficult to understand and perform poorly in these examinations (WAEC, 2019). This contrast raises an important question, that is: what do these physics teachers have and do differently to enable their students produce these ‘good’ results?

An important factor linked with learner understanding and achievement in science is the teacher's knowledge base, particularly topic-specific pedagogical content knowledge (Shulman, 1986a, as cited in Ijeh, 2013; Mapulanga, 2019; Gess-Newsome, & Ledeman, 2001). PCK is essential for topic-specific teaching (Abell, 2008; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). However, there is scanty and limited documented literature on the PCK of Ghanaian science teachers at the senior high school level. Very little is known about the teacher knowledge base required to make seemingly difficult physics topics, such as thermal physics, more understandable and accessible to learners.

At present, the status and quality of the PCK demonstrated by science teachers at the senior high school level in Ghana are not well documented. Studies from elsewhere (Kind, 2009; Schneider & Plasman, 2011) confirm that little is known about what PCK science teachers demonstrate in class, suggesting the need for more studies in this area. This study, therefore, attempts to identify the PCK that physics teachers in well-performing schools, such as XYZ Senior High, ABC Senior High School, and DEF Senior High School, possess in the context of teaching thermal physics.

1.3 Purpose of the Study

The purpose of this study is to investigate and understand the pedagogical content knowledge of well-performing senior high school physics teachers, specifically in the context of teaching thermal physics. The study aims to identify and analyse the instructional strategies, content knowledge, and understanding of student misconceptions and learning difficulties that contribute to effective teaching practices. Additionally, it seeks to identify factors and analyse the professional development experiences and opportunities that have contributed to the development of these teachers' pedagogical content knowledge in thermal physics. The implication is providing insights that can inform teacher training and professional development programmes, thereby enhancing the overall quality of physics teaching and learning.

1.4 Objectives of the Study

The following objectives guided the study.

To determine:

1. the extent to which the six well-performing physics teachers master subject matter knowledge of thermal physics.
2. the instructional strategies that the six well-performing physics teachers use in teaching thermal physics.
3. the physics teachers' knowledge of their students' misconceptions and learning difficulties relating to thermal physics.
4. the factors and practices that contribute to the development of pedagogical content knowledge among well-performing physics teachers in teaching thermal physics.

1.5 Research Questions

The study sought to find answers to the following research questions:

1. What content knowledge of thermal physics do the well-performing physics teachers have and demonstrate during classroom practice?
2. What instructional strategies do the six well-performing physics teachers use in teaching the concept of thermal physics?
3. What knowledge of learners' misconceptions and learning difficulties relating to thermal physics do the physics teachers have and demonstrate during classroom practice?
4. What factors and practices contribute to the development of pedagogical content knowledge among well-performing physics teachers in teaching thermal physics?

1.6 Significance of the Study

This study is significant as it provides insights into the development and application PCK among physics teachers in the participating senior high schools. By focusing on these specific schools and their teachers, the study intends to closely examine how PCK is cultivated and used in the teaching of thermal physics, with the goal of enhancing students' academic performance in these institutions.

The findings will be essential in assessing the current status and quality of PCK among the selected teachers. By analysing their teaching activities, the study will reveal how these well-performing physics teachers effectively combine content knowledge with pedagogical strategies tailored to their unique classroom environments. This localised approach will offer a clear understanding of the specific methods that lead to good student performances with regards to teaching of thermal physics.

The study will also explore the professional journeys of these physics teachers, examining the factors within their schools that have influenced their PCK development. This includes an investigation into the role of school-based professional development programmes, collaborative teaching practices, and the specific challenges and opportunities presented by their teaching contexts. By identifying these factors, related recommendations will be given to school leaders and administrators in the participating schools to further support and enhance their teachers' PCK.

What is more, by analysing student performance data in thermal physics, the study will demonstrate the impact that PCK has on learners in these schools. This will provide evidence-based insights into how PCK can be applied to improve teaching and learning outcomes in the specific context of the participating schools.

1.7 Delimitations of the Study

The study concentrates on the teaching of thermal physics within the broader subject of physics. It does not extend to other areas of physics, such as mechanics, electricity, or light. The study is limited to how physics teachers introduce, explain, and reinforce concepts related to thermal energy.

The focus is on specialist physics teachers. These are teachers who have specialised training, qualifications, expertise and experience in teaching physics at the senior high school level. The investigation excludes other science teachers such as chemistry, biology and integrated science teachers. or those who may teach physics without specialised training. The study intends to capture the unique teaching strategies and content knowledge of teachers who are experts in the field of physics.

Geographically, the study is delimited to senior high schools in the Volta Region of Ghana, specifically those offering elective physics under the Ghana Education Service (GES). The study does not include schools from other regions or those without elective physics, as the context and focus of science teaching might differ.

The study focuses on the pass rate of students achieving a minimum grade of C6 in the West African Senior School Certificate Examination (WASSCE) physics exam. This grade represents a threshold for passing and the minimum entry grade into Ghanaian tertiary institutions.

The study is delimited to physics teachers who voluntarily decide to participate. This ensures that the data collected is from individual teachers who are genuinely interested in contributing to the study. Teachers who may not be interested are not included, this helps to maintain the integrity and ethical standards of the research.

1.8 Limitations of the Study

The limitations of this study need to be taken into consideration when interpreting the findings as the researcher was aware of them from the onset and care was taken to accommodate them in the best possible way. Some of these limitations of the study include:

1. Influence of Personal Teaching Philosophy and External Factors: Teachers' individual teaching philosophies and personal beliefs about education and factors such as teacher motivation, school resources and administrative support may influence the development of pedagogical content knowledge but are not directly addressed in the study.

2. Subjectivity of Self-Reported Data: The data gathered from interviews and self-reports may be influenced by teachers' perceptions and biases, which is

likely to affect the accuracy of the information on their development of pedagogical content knowledge.

3. Context-Specific Findings: The study focuses exclusively on well-performing physics teachers in the Volta Region. As a result, the findings may not be applicable to all physics teachers in other regions or educational contexts.

4. Teacher Professional Development Differences: Variations in the availability and quality of professional development opportunities across schools could affect the development of pedagogical content knowledge, and these differences may not be fully captured in the study.

1.9 Organisation of the Study

The study is presented in six chapters. Chapter 1 which is the introduction presents background to the study, and the way in which the background relates to the problem under investigation. The context in which the study took place is described. The chapter then presents the guiding research questions based on the purpose and objectives of the study. The scope of the study in the form of delimitations and limitations are highlighted and discussed. The chapter concludes with a brief discussion of the structure of the thesis after presenting significance of the study. Chapter 2 focuses on the literature review, which captures the empirical and theoretical aspects related to the process of PCK development, and how it is used in classroom practice to teach science.

Chapter 3 discusses the methodology of the study. It is argued that a rich description of data comes from using several strategies of investigation, data collection, and data analysis. The chapter describes the methodological plans for the study, the pilot study, the participants, the research activities, and the various instruments used in the collection of data. The validity of the instruments is also discussed in this chapter.

Chapter 4 has to do with the results of the study. The demographic profile of the participating teachers is presented. This is followed by data presentation and analysis according to data sources. Pre-observation interview, lesson observation and post-lesson interview data are presented and analysed. The chapter concludes with document analysis.

Chapter 5 discusses the PCK profile of each of the six teachers, and how it was assumed to have been developed, Chapter six contains the summary of teacher PCK profile and how it was developed. This chapter ends with the study conclusions, contribution to knowledge and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter reviews various categories of relevant literature. PCK is an appropriate theoretical framework for the study as it addresses the key issues. It starts with subject matter content knowledge which describes what it is and how connected it is to PCK. It continues with pedagogical knowledge as it explains it and presents its relevance in science teaching. The chapter discusses different models of pedagogical content knowledge, their components, similarities and differences. The effects teachers' knowledge of learners' learning difficulties have on teaching and learning is discussed. The chapter discusses teaching the concepts of thermal physics with respect PCK. Methods of teaching thermal physics, factors and challenges associated with teaching of thermal physics were discussed. The conceptual framework of the study is grounded in Shulman's model of PCK and it is diagrammatically presented. The chapter concludes by giving a summary as it attempts bridging the gap in PCK development in science teaching.

2.1 Content Knowledge

Within the last three decades, research in the area of teacher knowledge has seen tremendous growth. Clearly, teachers must know and understand the subjects that they teach, including knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organise and connect ideas; and knowledge of the rules of evidence and proof (Shulman, 1986 as cited in Ijeh, 2013). Content knowledge is knowledge about the actual subject matter that is to be learnt or taught. The content to be covered in high school social studies or algebra is very different from the content to be covered in science. Knowledge and the nature of inquiry differ greatly among content areas, and it is critically important that teachers understand the disciplinary “habits of mind” appropriate to the subject matter that they teach. As Shulman noted, content includes knowledge of concepts, theories, ideas, organisational frameworks, methods of evidence and proof, as well as established practices and approaches toward developing such knowledge in a particular discipline. The cost of teachers having an inadequate content-related knowledge base can be quite prohibitive; students can develop and retain epistemologically incorrect conceptions about and within the content area (Pfundt, & Duit, 2000).

The strategies and methods for studying content knowledge for science teachers have developed (Kieran, 2014). Studies indicated that teacher knowledge is one of the most important components of effective teaching (Shulman, 1986, as cited in Ijeh, 2013). The development of body of research in teacher knowledge does not only lend itself to the idea that, in order to be effective, teachers must possess a profound understanding of content knowledge, but also has it that adequate teacher knowledge is very important in the enforcement of students' learning (Capraro, Capraro, Parker, Kulm, & Ralerson, 2005).

Teachers learn unfamiliar content alongside the students, as well as learning how to teach it and their weaknesses in content knowledge impact on their classroom practice. Childs and McNicholl (2007) investigated this by analysing the discourse used by a single science teacher teaching within and outside specialism. In some cases, they reported similar findings that when the teacher had adequate content knowledge, the science concept could be more accurately explained resorting less often to simplistic dialogue based on interaction-response-feedback. Childs and McNicholl (2007) continued by stating that when the teacher was teaching topics in which less confidence was expressed, students were forced to learn by factual recall and information from experiments as the teacher could not explain the concept clearly and dialogue was focused on mainly procedural matters.

Ball (2000) and Deng (2007) perceived that content knowledge and PCK are not completely distinct categories of knowledge, and the line between the two categories of knowledge is thin. Ball began by indicating that subject matter and pedagogy have been peculiarly and persistently divided in the conceptualisation and curriculum of teacher education and learning to teach. Ball added that teachers are expected to meet the challenge of integrating content knowledge and PCK themselves.

Ball (2000) again argued that the content knowledge required for teaching must be identified, taking what teachers do and the role played by content knowledge in their work into account. Ball continued by stating that content knowledge must be viewed from the learners' perspective: what they know; their difficulties; and what textbooks are appropriate. Ball continued to challenge the assumption that someone who knows content for himself or herself is able to use that knowledge in teaching. Ball stated that providing more opportunities to study mathematics, science or history will not make better teachers, but indicating what sort of content knowledge is needed and how to make use of this may help and opportunities for helping teachers learn how to make use of the content knowledge necessary must be created.

Deng (2007) suggested that helping teachers learn the content knowledge required by a school science instead of the academic discipline behind it lies at the heart of teachers' specialised content knowledge. Deng challenged studies that stated that science teachers transform knowledge of their academic discipline, asking why academic disciplines are being used as a basis for theorising teachers' specialised subject-matter knowledge. Deng presented data that illustrated differences between the key ideas in academic and school physics by observing two experienced physics teachers at work. Deng was of the view that school and academic physics differ in logical, social, psychological and epistemological aspects. Deng concluded that school content knowledge needs to be presented as an essential framework and that secondary science teaching relies more on a teacher understanding a subject from a school-based than an academic perspective. This argument by Deng thus challenged the assumption, raised by Kind and Wallace (2008) that possession of a high quality degree in a science subject is essential for teaching.

2.2 Pedagogical Knowledge

Pedagogical knowledge is the knowledge about teaching which is usually acquired through practice. As Hegarty (2000) put it, this is craft knowledge which encompasses expository skills, classroom management, questioning and differentiation. Since teaching strategies and approaches have to be explored from the practice of teachers, this craft knowledge is better understood in a context-specific situation. Pedagogical knowledge is deep knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims. This is a generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation, and student evaluation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge, acquire skills, and develop habits of mind and positive dispositions toward learning. As such, pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in their classroom.

Shulman originally defined and confined pedagogical knowledge to classroom management and its organisation (Shulman, 1987 as cited in Ijeh, 2013), and it has since been broadened to include a clear understanding and a wider use of the teaching and learning process.

Guerriero (2017) generally defined pedagogical knowledge as the specialised knowledge of teachers which is employed in creating and facilitating effective instruction in the classroom, irrespective of in-depth subject matter knowledge. Pedagogical knowledge which is a task-oriented knowledge places so much premium on typical teacher tasks such as classroom management and again concerns itself with academic disciplines underlying general classroom instructional strategy (Konig, 2014).

Similarly, Ball and Bass (2000) argued that the subject matter knowledge needed by teachers is found not only in the topics of to be learned but also in the practice of teaching itself. In other words, knowing the content of a subject is not enough to qualify a teacher to teach; what makes a teacher capable of teaching is how well he or she facilitates learning (Ijeh, 2013).

According to these authors, little is known about the way in which 'knowing' a specific topic in a list of topics affects a teacher's capabilities, and if one expects to identify the subject matter content knowledge needed for teaching from the curriculum without focusing on practice as well, not much will be gained (Ball & Bass, 2000; Plotz, 2007).

To meet the changing and increasing demands of education, schools are continually challenged to provide appropriate and timely professional development measures that will enhance beginning teachers' skills, knowledge, and attitudes (Choy, Wong, Lim

& Chong, 2013). Studies confirmed repeatedly that a significant factor in raising students' academic gains is through the improvement of instructional capacity (Marzano & Marzano, 2003). The challenge for school leaders and policymakers is to determine how best to provide high-quality professional development opportunities for their teachers.

One of first things a teacher must do to design an effective classroom is to create a conducive learning environment that supports students' engaged learning and meaningful instruction. These elements of lesson planning serve as a guide for beginning teachers to use good pedagogy in the classroom. Lesson planning makes teaching more conscious and purposeful (Choy, Wong, Lim & Chong, 2013).

2.3 Pedagogical Content Knowledge

Shulman's pioneering work some few decades ago, introduced the concept of PCK, highlighting its role in making topics understandable to learners during instruction. Subsequently, different researchers proposed various models of PCK, categorised as transformative and integrative models. The transformative models view PCK as a new type of knowledge formed through the amalgamation of content and pedagogical knowledge, while integrative models consider it as knowledge resulting from the combination of these two domains. Pre-service and in-service teacher education programmes are considered crucial in improving teachers' competence (Aydın & Boz, 2012). Various frameworks have been used in teacher education studies, with PCK being the most common and influential one. Researchers like Abell (2008) and Kind (2009) have acknowledged PCK's strength in guiding teacher educators and researchers to understand the types of knowledge teachers possess.

Pedagogical content knowledge (PCK) originated as one of seven categories of teacher knowledge‖ proposed by Shulman (Shulman,1986a as cited in Ijeh, 2013). Shulman highlighted the transition from the 1870s, when teacher training was based largely on factual knowledge, to the middle of 1980s. This suggested that there was a missing paradigm in teacher education. Without this, (Shulman, 1986a as cited in Ijeh, 2013) understanding how subject matter was transformed into instruction, and how lesson content relate to students' knowledge and ideas would be impossible. These issues border directly on teaching, yet were absent from analysis of teachers' competences. In contrast comparatively, medicine and law were defined by skills, cases and procedures that characterised practice and on which analysis of doctors' and lawyers' competences could be based. To address this gap, Shulman (Shulman, 1986b as cited in Ijeh, 2013) first proposed three categories of content knowledge for teachers: subject-matter content knowledge; subject-matter pedagogical knowledge; curricular knowledge.

By subject-matter content knowledge, Shulman (Shulman, 1986b as cited in Ijeh, 2013) meant the amount and organisation of knowledge in the mind of the teacher. Shulman defined subject-matter pedagogical knowledge as the ways of representing and formulating the subject that make it comprehensible to others, that is, the analogies, illustrations, examples, explanations and ideas that a teacher uses in lessons. The third category, curricular knowledge according to Shulman, equates to a doctor‘s knowledge of current techniques and treatments to relieve an illness: in teaching terms, current materials include textbooks, software, laboratory demonstrations and other ephemera available to use in the classroom. Shulman went on to argue that an understanding of both content and process are needed by teaching professionals, within the content we must include knowledge of the structures of one‘s subject, pedagogical knowledge of the general and specific topics of the domain and specialised curricular knowledge (Shulman, 1986b as cited in Ijeh, 2013) .

Shulman (Shulman, 1987 as cited in Ijeh, 2013) refined the initial three categories into a more comprehensive list of seven:

- content knowledge;
- general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organisation that appear to transcend subject matter;
- curriculum knowledge, with particular grasp of the materials and programmes that serve as tools of the trade for teachers;
- pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
- knowledge of learners and their characteristics;
- knowledge of educational contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
- knowledge of educational ends, purposes, and values, and their philosophical and historical grounds (p. 8).

PCK is distinctive of teachers' practice, worthy of special attention as a unique feature of their work (Shulman, 1987 as cited in Ijeh, 2013). Other professions, such as law and medicine, have their own curricular knowledge. Shulman stated that (Shulman, 1987 as cited in Ijeh, 2013) in law, PCK comprises knowledge about cases, statutes and procedures; in medicine, knowledge of anatomy, physiology, biochemistry as well as pharmacology, medical and surgical procedures. Shulman indicated that law and medicine also have their equivalent of learners, thus clients needing advice, or patients requiring attention. Shulman argued that although the other knowledge types have their equivalents in different fields, PCK remains unique to teachers. In PCK, content and pedagogy are blended and the teacher combines his or her understanding about a topic with instructional strategies and additional that are pedagogically power-ful and yet adaptive to the variations in ability and knowledge to promote student learning. Shulman again described PCK as, the capacity of a teacher to transform the content knowledge he or she possesses into forms background presented by the stu-dents (Shulman, 1987 as cited in Ijeh, 2013). Teachers received Shulman's proposals enthusiastically. Subsequently, researches have attempted to establish these categories of teacher knowledge as an all-embracing paradigm for teacher education. Although aspects of Shulman's general views have been widely accepted, many models of PCK have been proposed, as researchers have interpreted Shulman's ideas differently.

Banks, Leach and Moon (2005) pointed to school knowledge as an essential PCK component that bridges the gap between subject knowledge and pedagogic knowledge. The personal subject construct these authors suggested underpins all teachers' PCK which includes elements based on past learning experiences, beliefs and knowledge about their subject.

2.3.1 The Concept of Pedagogical Content Knowledge

Pedagogical content knowledge is an essential component of effective science teach-ing. According to Lim (2003), pedagogical content knowledge is the specialised knowledge and skills that teachers possess in order to effectively teach a specific subject, in this case, physics. This knowledge goes beyond simply knowing the content itself, but also includes an understanding of how to teach that content in a way that is engaging and accessible for students (Wibowo, Masunah, Karyono, & Milyartini, 2022). Pedagogical content knowledge is a unique domain of teacher knowledge that involves the transformation of subject matter knowledge into knowledge for teaching. It is composed of several components, including orientations toward science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific topics, knowledge and beliefs about assessment for teaching science, and knowledge and beliefs about instructional strategies for teaching science (Lim 2003).

Banks, Leach and Moon (2005) presented a model of teachers' professional knowledge in which school knowledge, subject knowledge and pedagogic knowledge were linked by a teacher's personal subject construct. In proposing their model, Banks, Leach and Moon (2005) split PCK into school knowledge, an entirely new category, and pedagogic knowledge. School knowledge describes how subject knowledge is adapted for school use for example, what can be termed school science, the representation of the subject delivered in science lessons, differs from science as practised by scientists. Their study suggested teachers need to understand the historical and ideological origins underpinning how their subjects are organised for teaching purposes. This category subsumes Shulman's curricular knowledge. Pedagogic knowledge comprises the practices and beliefs that inform teaching and learning, such as knowledge of analogies, illustrations, and explanations needed to teach a topic, as well as an understanding of the relationship between school and subject knowledge. Thus, school knowledge can be seen as a bridge or intermediary between subject knowledge and pedagogic knowledge, facilitating choice of resources for teaching and understanding of the curriculum and how these influence pedagogic practices. In this structure, subject knowledge equates with Shulman‘s content knowledge, while pedagogic knowledge includes an understanding of the crucial relationship between subject knowledge and school knowledge. A teacher‘s personal subject construct comprises knowledge gained from the teacher’s learning experiences, opinions about good teaching and beliefs about the purposes for the subject. The authors claimed Shulman‘s theory presents a teacher‘s knowledge as a static body of content lodged in the mind of the teacher. They also criticised Shulman for adopting a teacher-centred model of cognition focusing on a teacher‘s skills and knowledge rather than the process of learning. Instead, their model draws on theories of learning suggested by Gardner (Gardner, 1983, 1991, as cited in Ijeh, 2013), and the French concept of didactic transposition. Gardner‘s multiple intelligences theory stimulates consideration of learners’ different understandings, while didactic transposition acknowledges variation and progression in the way a teacher develops his or her practice. The authors argued that these principles offer a contrast to Shulman‘s emphasis on transformation, which implies teachers learn in a way to teach a concept in a specific setting.

2.3.2 Development of Pedagogical Content Knowledge

Sperandeo-Mineo, Fazio and Tarantino (2006) found that PCK developed over time, with trainees reporting classroom experience as the most important influential factor. These authors suggested that PCK development is complex, it occurs in phases and relates to trainees’ abilities to integrate knowledge from a variety of sources. Possession of content knowledge is identified as essential to PCK development.

Justi and van Driel (2005) analysed changes in five teachers‘ PCK relating to using models and modelling prompted by participation in a specially devised course and completion of a research project on the topic. They found a variety of responses from one teacher who used material garnered from the intervention to allow students to express their ideas, to another who blamed lack of success on developing students’ thinking on the students themselves. The authors made a number of comments about how their work might influence teacher education, including that analysis of new experiences and reflection on personal development which are critical to the success of an intervention. Studies based on interventions located in training and school settings were also found.

Kind and Wallace (2008) analysed the impact of experienced teacher-led sessions specifically designed to help develop trainees’ PCK for teaching a range of science topics to learners between the ages of 11-14years. The intended emphasis on PCK was not identified by a majority of the 80 trainees, most of whom used the sessions as opportunities to learn content knowledge, not PCK. Among a sub-group of six who were observed teaching, only one explained a difficult science idea correctly, while the other five tended to avoid explaining concepts by opting for a basic level description, instead thinking pupils were learning because they behaved well and completed their allotted tasks.

Burn, Childs and McNicholl (2007) observed interactions between teachers in a school science department, noting how expertise was shared through collaborative discussions in informal settings. The study indicated that trainee and newly-qualified teachers benefited from an environment in which ideas could be shared and concepts explained freely. This enabled them to access expert teachers’ PCK in an atmosphere of trust, care and mutual respect, without feeling a sense of failure.

The role of collaboration in developing PCK featured by Daehler and Shinohara (2001), who used series of science teaching cases pointed to a study with primary teachers. The cases focused on electricity and magnetism concepts and data were collected through using these to stimulate teachers' group discussions. Thus, teachers worked collaboratively to make sense of the concepts and to consider how best to teach them. The study found that teachers' content knowledge was an important factor. Teachers often began discussing how to teach the concepts while not clearly understanding the concepts themselves. Where discussions were highly interwoven between content and how to teach, these seemed to be most fruitful in terms of PCK. These and other studies offer confirmation that PCK exists, that novices are not born with PCK, and acquire a bank of skills and new knowledge in becoming professional science teachers as the process of transition to expert is lengthy and success is not guaranteed.

2.3.3 PCK and its Significance in Effective Teaching

Shulman argued that pedagogical content knowledge is essential for effective teaching, as it recognises the unique challenges and nuances of teaching different subjects (Wibowo, Masunah, Karyono, & Milyartini, 2022). For science teachers, pedagogical content knowledge involves having a deep understanding of both the content knowledge of science and the most effective strategies for teaching that content to students. This includes knowledge about the appropriate instructional methods, learning strategies, and assessment techniques that support student understanding and skill development in science. Moreover, pedagogical content knowledge also encompasses an understanding of the specific goals and objectives of science instruction, as well as how to effectively assess student learning and provide feedback. In the opinions of Wibowo, Masunah, Karyono and Milyartini (2022) pedagogical content knowledge is important in science teaching because it helps teachers bridge the gap between subject matter expertise and effective instructional practices. This type of knowledge allows teachers to make informed decisions about what to teach, how to teach it, and how to assess student understanding. Additionally, pedagogical content knowledge in science teaching recognises the dynamic nature of scientific knowledge and its impact on instructional practices. Teachers with strong pedagogical content knowledge are better able to adapt their teaching strategies to reflect the most current scientific understanding, ensuring that students receive accurate and up-to-date information. Furthermore, pedagogical content knowledge plays a crucial role in fostering students' understanding and engagement in science. Teachers with strong pedagogical content knowledge are able to effectively communicate complex scientific concepts in a way that is accessible and meaningful to their students. By drawing on various pedagogical strategies and approaches, they can create a learning environment that promotes inquiry, critical thinking, and active engagement in scientific practices. This type of pedagogical content knowledge also helps teachers anticipate and address students' misconceptions, facilitating their conceptual development in science (Dolenc, Sorgo, & Virtic, 2021). Pedagogical content knowledge is a key component of effective science teaching. It allows teachers to integrate their subject matter expertise with effective instructional strategies, promoting student understanding and engagement in science.

According to Rumala, Hidary, Ewool, Emdin and Scovell (2011), pedagogical content knowledge is crucial for effective science teaching as it encompasses the understanding of both subject matter expertise and instructional practices. These authors are of the view that teachers with strong pedagogical content knowledge possess a deep understanding of the aims of science instruction, assessment methods, and how students learn science. They are able to break down complex scientific concepts into understandable chunks, scaffold students' learning experiences, and provide appropriate support and guidance. In addition, teachers with strong pedagogical content knowledge are able to make connections between scientific concepts and real-world applications, helping students see the relevance and importance of science in their everyday lives.

Since the introduction of PCK as the differentiating factor between teachers, researchers have been working to comprehend, define, assess, and enhance this construct in both pre-service and in-service teachers. Neumann, Kind and Harms, (2018) presented empirical findings that facilitate further discussion, allowing a post-hoc examination of a recently described "consensus" model of PCK, highlighting its strengths and potential concerns. Their study particularly revealed the central relationship between content knowledge, pedagogical knowledge, and pedagogical content knowledge, probing the hypothesis of pedagogical content knowledge as an amalgamation of content and pedagogical knowledge.

Lee and Luft (2008) did a study and the focus was on the professional learning continuum for science teachers, with an emphasis on pedagogical content knowledge (PCK) from the perspective of experienced secondary science teachers who serve as mentors to beginning teachers. The study aimed to gain insights into teacher learning over time, particularly in relation to PCK. The findings highlighted essential components that experienced science teachers could benefit from in professional development programmes and illustrate how these components can interact with teaching practice. According to Lee and Luft (2008), understanding these components and their interactions can be valuable for those involved in planning and implementing professional development programmes for science teachers.

Abell (2008) highlighted the contributions that PCK has made to the teachers' understanding of effective science teaching and learning, and emphasised its ongoing relevance for guiding research and practice in science education. Abell's study revealed significant issues and ideas that have shaped teachers' understanding of PCK and the nature of PCK research and it suggested potential directions such as exploring the development of PCK over time, investigating the impact of PCK on student learning outcomes, and examining the influence of contextual factors on PCK for further investigation and exploration to advance the understanding of PCK in the context of science education.

Henze, van Driel, and Verloop (2008) explored the development of pedagogical content knowledge (PCK) among nine experienced science teachers during their initial years of teaching a new science syllabus in the Dutch secondary education system. The study aimed to identify the content and structure of PCK specifically for the topic of 'Models of the Solar System and the Universe.' The focus was on describing the development of PCK in terms of four interconnected aspects: knowledge of instructional strategies, understanding of students' perspectives, assessment of student learning, and alignment with curriculum goals and objectives. By examining the PCK development among experienced science teachers, the study revealed contributes to a deeper understanding of how teachers' knowledge evolves over time. The findings also revealed that these two types of PCK evolved in unique and distinct ways.

A study was conducted in the evolution of pedagogical content knowledge (PCK) in prospective secondary school physics teachers. The study adopted craft knowledge as an epistemological perspective and followed the development of two prospective physics teachers through their science curriculum class and student teaching field experience in a teacher preparation programme. The findings of this study revealed that in development of PCK there is the need for teachers to emphasise the importance of classroom experience in their development process, adopt a student-centred teaching approach and engage in reflection and philosophical contemplation about their beliefs regarding science teaching and learning (Veal, Tippins & Bell, 1999). They found the development of PCK to be complex and non-linear. Content knowledge and knowledge of students are identified as the most significant forms of knowledge in shaping PCK development. These two types of knowledge serve as the foundation for prospective teachers to develop domain-specific PCK.

2.3.4 Dimensions of PCK specific and Physics Teaching

A number of researchers are of the opinion that many physics teachers have limited pedagogical content knowledge (PCK). Halim and Meerah (2002) found that Malaysian science trainee teachers had limited PCK for promoting conceptual understanding in physics, which affected their ability to employ appropriate teaching strategies. Fariyani and Kusuma (2021) found that pre-service physics teachers had poor content knowledge capabilities and needed remediation to improve their PCK. Wangchuk (2022) found that physics teachers in Central Bhutan displayed adequate use of PCK in terms of content knowledge and knowledge of teaching strategies, but had limited knowledge of learners' misconceptions and alternative teaching strategies. Seung (2012) found that physics graduate teaching assistants developed PCK in three components: knowledge of curriculum goals, instructional strategies, and students' learning, but also highlighted the complexity of adopting curriculum reforms and the necessity to support knowledge development when a novel science curriculum is adopted. Overall, these studies suggest that there is a need for more training and support for physics teachers to develop their PCK.

While PCK is widely recognised as crucial for effective teaching, empirical evidence linking PCK to teaching practice and student learning outcomes has yielded mixed results according to Alonzo and Kim (2016). In their study on pedagogical content knowledge (PCK) and the need for further attention to the measurement of its dynamic aspects and to address this gap, the authors argue for the measurement of spontaneous and flexible elements of PCK. They propose two video-based interview methods for eliciting teachers' PCK and describe a study conducted with high-school physics teachers on the topic of force and motion. According to Alonzo and Kim (2016) while the teachers consistently demonstrated the main components of declarative PCK in both interviews, there was the characterisation of a more dynamic form of PCK that underlies teachers' in-the-moment instructional reasoning. Teachers with strong dynamic PCK relied heavily on their declarative PCK as they reasoned about new examples of student thinking and corresponding instructional responses. The display of dynamic PCK also included elements that support further PCK development, such as critical thinking about student thinking, physics content, and instructional representations. Although meaningful differences were detected between teachers' declarative and dynamic PCK, the diversity and contextualisation of strong PCK responses raise questions about differentiation for measurement purposes and the potential for moving beyond elicitation towards the measurement of dynamic PCK.

Wangchuk and Pem (2022) investigated the use of Pedagogical Content Knowledge (PCK) by physics teachers in teaching grade 10 students. The study examined the teachers' use of content knowledge and teaching strategies in teaching two topics related to force and motion, namely gravitational force and gravitational field. The findings revealed that the teachers demonstrated a satisfactory application of PCK through their content knowledge and use of teaching strategies. However, the study also highlights certain limitations observed in the teachers' PCK. Firstly, the teachers exhibit limited knowledge of learners' misconceptions regarding the topics being taught. Additionally, they demonstrate a lack of familiarity with alternative teaching strategies that could be employed to support students facing difficulties in understanding the subject matter.

2.3.5 Factors that Contribute to the Development of Teachers' PCK

The development of pedagogical content knowledge is promoted by the constant use of subject matter knowledge in teaching situations (Lim, 2003). Inquiry-based instruction can enhance science teachers' pedagogical content knowledge (Nuangchalerm, 2012). It is believed that exemplary science teachers use four kinds of knowledge, including pedagogical content knowledge, in designing and implementing science lessons (Barnett. 2001).

Wangchuk and Pem (2022) identified several approaches adopted by the teachers to enhance their PCK in the field of Physics. These include the use of social networks, engaging in lesson observations, and conducting lesson reviews.

Factors that contribute to the development of teachers' PCK, include; formal university education, the school context, journal reflection, and participation in professional development programmes (Mthethwa-Kunene, Onwu & de Villiers, 2015).

Melo, Canada-Canada, Gonzalez-Gómez, and Jeong (2020) explored the significant contributions of pedagogical content knowledge (PCK) in teaching physics. Their study presented multiple studies that provided evidence of the development of various components of PCK, positioning it as a crucial element in physics teacher training models. The programme centred on reflections about teaching, particularly focusing on the electric field in physics education. The findings indicated that certain categories of PCK, such as knowledge about the curriculum and teaching strategies, demonstrated growth following the intervention programme. However, knowledge related to evaluation and students exhibited less progression. This suggested that encouraging teachers to reflect on their instructional designs can lead to a teaching and learning process that is more innovative and focused.

A study done explored the pedagogical content knowledge exhibited by science tutors in colleges of education and its impact on the advancement of PCK among teacher trainees. The findings indicated that the demonstration of pedagogical content knowledge by the science tutors was influenced by their years of teaching experience and qualifications (Bayuo, Abukari, Alagbela & Bornaa, 2022). Notably, two tutors exhibit the highest level of pedagogical content knowledge, having accumulated 10-12 years of teaching experience. The analysis indicated a strong positive influence of the science tutors' pedagogical content knowledge on the development of PCK among their teacher trainees.

Wangchuk and Pem (2022) investigated the use of Pedagogical Content Knowledge (PCK) by physics teachers in teaching grade 10 students. The study examined the teachers' use of content knowledge and teaching strategies in teaching two topics related to force and motion, namely gravitational force and gravitational field. The findings revealed that the teachers demonstrated a satisfactory application of PCK through their content knowledge and use of teaching strategies.

A study was conducted to examine the pedagogical content knowledge (PCK) and its development among four experienced biology teachers who taught genetics in schools, The findings indicated that the teachers' PCK profiles primarily consisted of declarative and procedural knowledge related to teaching fundamental genetics concepts (Mthethwa-Kunene, Onwu & de Villiers, 2015). Some teachers also demonstrated conditional knowledge, which involves the integration of declarative and procedural knowledge. According to Mthethwa-Kunene, Onwu and de Villiers (2015), the teachers employed specific instructional strategies, such as context-based teaching, illustrations, peer teaching, and analogies, to facilitate learning, but overlook the use of physical models and individual or group experimental activities to support students' internalisation of the concepts. Notably, all six teachers lacked knowledge of students' preconceptions related to genetics (Mthethwa-Kunene, Onwu & de Villiers, 2015).

2.4 Teaching the Concepts of Thermal Physics

Thermal physics constitutes an essential component of any undergraduate physics curriculum. Its scope comprises the foundational principles of classical thermodynamics, which originated primarily in the nineteenth century and were driven by the desire to comprehend the conversion of heat into work through engines, as well as statistical mechanics which pertains to the statistical behaviour of the system's underlying microstates. These topics pose a significant challenge to students, who frequently encounter difficulties due to a lack of familiarity with fundamental mathematical concepts, particularly those pertaining to probability and statistics (Blundell & Blundell, 2009). Additionally, the conventional emphasis of thermodynamics on steam engines appears distant and largely inapplicable to a twenty-first-century student. Regrettably, this is a missed opportunity, as an understanding of thermal physics is critical to virtually all contemporary physics and the critical technological obstacles that confront us in this era (Blundell & Blundell, 2009).

Teaching the concepts of thermal physics can be challenging for students due to the abstract nature of the subject and the presence of alternative conceptions. However, there are effective strategies that can be employed to enhance conceptual understanding. The thinking frames approach, based on educational research, has been shown to be highly effective in addressing naive conceptions about heat and leading to significant gains in understanding (Blundell & Blundell, 2009). Additionally, incorporating modern examples from various fields such as astrophysics, atmospheric physics, and condensed matter physics can make the subject more relevant and engaging for students (McLure, Won & Treagust, 2020). It is also important to clarify the objectives of thermodynamics courses and emphasise the operational and mathematical aspects, as well as the philosophical interpretations, to provide a comprehensive understanding of the subject (Wasserman, 2011). As a result, thermal physics has been considerably enriched in concepts, technique and purpose, and now has a dominant role in the developments of physics. By challenging misconceptions through experiments and discussions, students can quickly acquire the necessary concepts to develop their understanding of thermal physics.

Taber (2000) argued that, whilst simplification is necessary, a point will be reached where the logical structure of the subject is compromised and it is suggested that recent recommendations in Physics Education about teaching heat and temperature may have reached such a point.

Doige and Day (2012) explored the conceptions of heat as presented in textbooks from across the science disciplines and found that there was a significant variation in the definitions of heat within a discipline and between the disciplines Specifically, the physics and chemistry textbooks used energy in transit or transfer of energy definitions, whereas textbooks from other disciplines typically used definitions which related heat to molecular kinetic energy.

2.4.1 Instructional Strategies Used in Teaching the Concepts of Physics

According to Wasserman (2011), objectives of all thermal physics concepts at all levels should be clarified as there is a need to treat introductory thermodynamics as physics in relation to other branches of physics, and not just to heat. This should be taught (1) from an operational point of view with respect to the world of physical phenomena, (2) with emphasis upon the use of mathematics with respect to the world of physical concepts, and (3) with a concern for philosophical interpretations with respect to the world of physical theory.

Baser. (2006) investigated the effectiveness of cognitive conflict based physics instruction over traditionally designed physics instruction on preservice primary school teachers at grade 2, and found that there was no statistically significant difference between experimental and control groups at the beginning of the instruction in terms of understanding of heat and temperature concepts.

Students taught by means of conceptual change oriented instruction outperformed students who received traditionally designed instruction and logical thinking ability accounted for a significant variation in heat and temperature concepts achievement (Baser, 2006).

Model-eliciting activities (MEAs) are developed to help repair misconceptions in dynamics and the thermal sciences and it is hypothesised that rich discussion and model re-formulation will help students recognise and repair misconceptions, and that the real world context will help them remember these critical concepts (Self, Miller, Kean, Moore, Ogletree & Schreiber, 2008).

Nottis, Prince, and Vigeant (2017) conducted a pilot study to examine whether researcher-developed and inquiry-based activities could increase conceptual understanding of heat transfer and alter common misconceptions, and found that participants significantly improved their overall scores from pre-test to post test.

Tanahoung, Chitaree, Soankwan, Sharma, and Johnston (2009) investigated the effectiveness of interactive lecture demonstrations over traditional instruction on university students' understanding of heat and temperature concepts and found that students who were taught using Interactive Lecture Demonstrations had a better understanding of concepts than students taught using traditional instruction.

Bilgin, Nas and Coruhlu (2017) investigated the effects of guiding materials developed based on the REACT teaching model on students' conceptual understanding of 'heat-temperature' concepts. The study involved 5th grade students selected from an elementary school, with a total of 56 participants divided into an experiment group (27 students) and a control group (29 students). The study found no significant difference between the pre-test scores of the control group and experiment group students. However, a significant difference was observed in favour of the experiment group in the post-test. The materials prepared in accordance with 'The fire context' applied to the experiment group had a positive effect on students' conceptual understanding.

Turgut and Gurbuz (2012) did a study on eighth-grade students' misconceptions related to heat and temperature. The study aimed to investigate eighth-grade students' misconceptions related to heat and temperature, compare the effectiveness of the 5E model and traditional instruction on students' understanding of heat and temperature concepts and their attitudes towards science and technology, and determine the extent to which conceptual change is retained. The study included two different classes in a primary school in Erzurum, taught by the same teacher during the 2009-2010 academic year. One class was randomly assigned as the experimental group, receiving instruction through activities prepared according to the 5E model, while the other class served as the control group, receiving instruction through traditional methods (teacher-cantered, based on straight narrative and question-answer method). The results of the Heat and Temperature Concept Success Test indicated that the 5E model was more successful in remedying misconceptions and promoting lasting conceptual change compared to traditionally designed instructions. However, there was no statistically significant difference between the experimental and control groups in terms of students' attitudes towards science and technology.

Science students, particularly in senior high school, encounter difficulties in understanding subjects related to heat, temperature, enthalpy, and energy in chemical reactions. It is important to assess their conceptual understanding in these areas to guide teachers in building upon their existing knowledge to introduce new concepts in thermodynamics. To ascertain this, Saricayir, Ay, Ccmek, Cansiz and Uce (2016) investigated the conceptual understanding levels of high school students in common thermodynamics subjects, including heat, temperature, enthalpy, and energy changes in chemical reactions. The study revealed that students exhibited a very low level of conceptual understanding in thermodynamics concepts. Specifically, their understanding was particularly weak in areas related to: (1) the relationship between energy, enthalpy, and bonds in chemical reactions, (2) energy and catalysts in chemical reactions, (3) changes in heat, temperature, and enthalpy during changes of state, and (4) the relationship between heat, temperature, mass, and specific heat. Despite studying these topics since primary school, the majority of students did not demonstrate a comprehensive understanding of common thermodynamics concepts.

Tanahoung, Chitaree, Soankwan, Sharma and Johnston (2009) conducted a study aimed to investigate the effectiveness of Interactive Lecture Demonstrations compared to traditional instruction in enhancing university students' understanding of heat and temperature. The participants included 327 first-year undergraduate students from two science classes in two academic years at the same university in Thailand. One class served as the experimental group, receiving instruction through Interactive Lecture Demonstrations, while the other class served as the control group, receiving traditional instructional methods. The Heat and Temperature Conceptual Evaluation test was administered to both the experimental and control groups before and after the instruction to assess student understanding. The results revealed that the average normalised gain in the experimental group was higher than that in the control group. These findings suggest that students taught using Interactive Lecture Demonstrations exhibited a greater improvement in their understanding of heat and temperature concepts compared to students taught using traditional instruction.

A study was conducted by Schonborn, Haglund and Xie (2014) to explore the potential of combining the sense of touch with infrared (IR) thermal imaging to enhance pupils' understanding of heat and temperature. The participants were eight 7th-grade pupils (12-13 years old) who worked in pairs and engaged in three laboratory exercises: real-time IR imaging, static IR images, or using thermometers. During the experiments, an anomaly was introduced where there was a discrepancy between the perceived "coldness" of objects and their measured temperature. However, the pupils were unable to resolve this cognitive conflict. Although they observed the objects getting warmer and increasing in temperature, they did not explain the experiments as involving a heat flow from their bodies to the objects. The study suggests that successful explanation of heat and temperature concepts might require a combination of thermal imaging and the explicit introduction of a simple heat-flow model. It highlights the importance of multisensory experiences, such as combining touch and IR thermal imaging, in enhancing students' understanding of thermodynamics concepts.

Jones, Carter and Rua (2000) did a study which focused on fifth-grade students and aimed to investigate the relationships and development of communities of concepts related to heat and convection. The participants included five classes of fifth-grade students who engaged in a series of heat and convection laboratory investigations with a partner. The study described the patterns and connections among students' conceptual ecologies related to heat and convection and examined the types of schemas accessed by students before and after instruction. The findings highlight the influence of familial and cultural experiences, such as airplanes, weather patterns, and religious beliefs, on the development of conceptual understanding. The study also explores the impact of competing phenomena, such as evaporation and dissolving, on the formation of new conceptual understandings. The study was effective in uncovering the processes and prior knowledge that students used as they interpreted new observations in light of their pre-existing experiences.

A cross-sectional study aimed to investigate the progression and consistency of students' understanding of thermal concepts in everyday contexts across different grade levels conducted by Adadan and Yavuzkaya (2018) involved a total of 656 Turkish students from Grade 8, Grade 10, and the first year of the college. The findings revealed a significant progression in students' scientific understanding of thermal concepts as they advanced through the grade levels. Again the study found that the frequency of students' alternative conceptions about thermal concepts generally decreased across grade levels. However, certain alternative conceptions were consistently observed across all grade levels to a similar extent. The number of students who consistently used scientific ideas increased as they progressed in the grade levels, while the number of students consistently using non-scientific ideas decreased. However, the study also identified that the number of students who used scientific and non-scientific ideas inconsistently generally increased as they advanced in the science curriculum. These findings therefore suggested that the progression and consistency of students' understanding of thermal concepts are influenced by both the gradual enrichment processes and the presence of alternative conceptions, leading to either fragmentation or integration of scientific concepts into their conceptual frameworks (Adadan & Yavuzkaya, 2018).

In a study conducted by Başer and Geban (2007) to investigate the differential effects of two modes of instructional programmes (conceptual change oriented and traditionally designed) and gender differences on students' understanding of heat and temperature concepts and their attitudes toward science as a school subject, 72 seventh-grade students from two General Science Classes were taught by the same teacher. One class was randomly assigned to the conceptual change oriented instruction (experimental group), while the other class used traditionally designed science texts (control group) for a duration of four weeks. Analysis of covariance was employed, with logical thinking ability serving as a covariate. The conceptual change oriented instruction led to significantly greater achievement in understanding heat and temperature concepts compared to the traditionally designed instruction. However, there were no significant differences between the experimental and control groups in terms of attitudes toward science as a school subject (Başer & Geban, 2007) and regarding gender differences, there were no significant differences between female and male students in terms of learning heat and temperature concepts and attitudes toward science.

Başer (2006) investigated the effectiveness of cognitive conflict-based physics instruction compared to traditionally designed physics instruction on preservice primary school teachers at the second grade level. The study included two classes. One class was randomly assigned as the experimental group, while the other class served as the control group. Both groups were taught by the same instructor. The experimental group received cognitive conflict-based physics instruction, while the control group received traditionally designed physics instruction. According to Başer (2006), the interaction between gender difference and treatment had a significant contribution to the variation in achievement, indicating that the instructional approach had a differential effect depending on gender. However, there was no significant difference in achievement between genders.

The study introduced four basic ideas of teaching and learning physics energy concept (transformation, transfer, conservation, and degradation) and it was emphasised that these ideas are closely interconnected. Understanding one idea requires understanding all the other ideas, which presents challenges in teaching and learning. The finding revealed that the traditional approach of teaching force and work still had some influence despite its inherent problems (Duit, 2014). In attempt to teach and learn the energy concept within the learning progression approach, it was observed that a sequence focusing on energy transformations, transfer, energy degradation, and ultimately energy conservation seemed to be prevalent. Similar to the historical development of scientific ideas, learning about energy was seen as a process of unfolding and differentiating students' initial conceptions (Duit, 2014).

In attempt to determine the underlying conceptual structure of the thermal concept evaluation (TCE), to assess students' conceptual understanding of thermal concepts in everyday contexts across different school years, and to analyse the variables that influence students' thermal conceptual understanding, a study was conducted by Chu, Treagust, Yeo and Zadnik (2012). The findings indicated that the duration of schooling, current science subjects, and prior exposure to physics topics correlated with the development of students' conceptual understanding, particularly in areas related to heat transfer, temperature scales, specific heat capacity, homeostasis, and thermodynamics and although students demonstrated improvement in their conceptual understanding as they advanced in school, they still encountered difficulties in relating scientific concepts to their everyday experiences (Chu, Treagust, Yeo & Zadnik, 2012).

In teaching the concept of energy, Bezen, Bayrak and Aykutlu (2016) argued that due to the teachers' lack of knowledge, the teaching of energy could not align with the constructivist approach, however, the teachers believed that energy as a topic is compatible with the constructivist approach. These authors suggested that teaching energy could enhance students' awareness of the concept and its application in daily life. Again, incorporating real-life examples, videos, simulations, laboratory experiments, and field trips could facilitate more effective learning experiences (Bezen, Bayrak & Aykutlu, 2016).

A research aimed to evaluate the impact of an integrated sensory model, including a thermal equilibrium visualisation, on students' revision of disruptive experientially supported ideas about why objects feel hot or cold and their understanding of thermal equilibrium found that students in the experimental tactile group, who received the intervention, demonstrated better performance compared to the control group on post tests and delayed post-tests (Clark, & Jorde, 2003). They exhibited improved abilities not only in providing tactile explanations but also in explaining thermal equilibrium.

Schnittka and Bell (2010) in their study about students' conceptual understandings of heat transfer and thermal energy, as well as attitudes towards engineering found that the engineering design curriculum with targeted demonstrations was significantly more effective in inducing desired conceptual change compared to typical instruction and the engineering curriculum without targeted demonstrations. These findings have implications for how teachers should be prepared to incorporate engineering design activities in science classrooms to facilitate conceptual change.

Yeo and Zadnik (2001) in their study aimed to develop a pen and paper instrument, called the Thermal Concept Evaluation, to assess students' understanding of thermal phenomena and their beliefs about it, found that the instrument was able to distinguish belief changes in two populations: year 11 students and first-year university physics students. The study highlights the utility of the Thermal Concept Evaluation in assessing students' understanding of thermal concepts and tracking changes in their beliefs.

2.4.2 Challenges and Misconceptions of Teaching the Concepts of Thermal Physics

Carlton (2000) argued that students encountering thermal physics at introductory level often have difficulty distinguishing between heat and temperature, and that challenging misconceptions by experiment and through discussion can quickly enable them to acquire the necessary concepts to equip them to develop their understanding of thermal physics.

Nottis, Prince, and Vigeant. (2017) examined the use of inquiry-based teaching to promote understanding of critical engineering concepts and found that students often enter the classroom with tightly held misconceptions about the physical world that are not effectively addressed through traditional teaching, as a result, students are frequently able to solve problems that have been explicitly taught, but are unable to apply course concepts to solve real problems not seen in class.

Kellner, Gullberg, Attorps, Thoren and Tarneberg (2011) investigated pre-service teachers' ideas about pupils' difficulties, at a topic-specific level, upon beginning the teacher education programme, and found out that the initial ideas correspond with earlier research on pupils' difficulties, which could provide a potential resource when creating a scaffolding context in teacher education programmes where PCK development was stimulated.

Prima, Utari, Chandra, Hasanah and Rusdiana (2018) proposed to construct science knowledge and contextual problems to support students' conception of the nature of science, and eight new heat and temperature experiment designs were developed. According to this result, the students were only able to explain the simple science phenomenon because some learning activities have not followed good scientific inquiry as a fundamental aspect of the nature of science.

Tanahoung, Chitaree and Soankwan (2010) investigated the alternative conceptions held by Thai first year science students and found that students' written responses had some common specific misconceptions and different levels of understandings, which may imply the teaching style in Thai high schools that might be problematic.

Teaching the concept of thermal energy in physics faces specific challenges and misconceptions. Students often struggle to differentiate between heat and temperature, and have difficulty understanding the flow of heat energy. They also tend to have misconceptions about the first law of thermodynamics, thermal processes, and the interdependencies of certain quantities. Traditional teaching methods do not address these misconceptions and fail to present the conservation of energy as a general principle. However, innovative teaching interventions, such as scaffolding and peer discussions, have shown promise in improving students' understanding of thermal physics. These interventions have led to significant improvements in learning outcomes and a reduction in misconceptions. (O'Connell, 2019).

Kacovsky (2015) examined students' misconceptions in the context of everyday thermal phenomena. The research involved nearly 500 Czech grammar school students from 24 classes who completed a reduced version of the Thermal Concept Evaluation. The study aimed to assess the effectiveness of traditional instruction in eliminating scientifically incorrect ideas. The findings indicated a poor overall effectiveness of instruction in rectifying misconceptions. Notably, Czech students performed poorly in areas related to phase transitions but surprisingly well compared to foreign studies regarding the perception of "cold" as a scientifically disproved concept.

Students, pre-service teachers, and practicing science teachers often struggle to connect scientific concepts with everyday experiences, leading to the formation of misconceptions. Factors contributing to these misconceptions include lack of prior knowledge, faulty knowledge (misconceptions), and incorrect initial concepts. Scientific language, or the lack thereof, has also been identified as a contributing factor (Safwan, Jawaid, Sultan, & Hassan, 2018). However, there is a lack of literature exploring the preconceptions and prior knowledge of female Saudi students, as well as the role of vernacular language, terminology, textbooks, and teachers' practical knowledge. To address these gaps, Safwan, Jawaid, Sultan and Hassan (2018) investigated the level of understanding of thermal energy concepts among Year 11 Saudi female students and their teachers to understanding of thermal concepts, the misconceptions they held, the thermal conceptual understanding of the teachers, and the sources of students' misconceptions related to thermal physics.

The findings revealed that, following instruction, the students still exhibited up to 75% of alternative conceptions in all four categories of thermal concepts. Ambiguous textbook language, limited access to laboratory equipment and modern science resources, and the use of non-standard units of measurement were identified as factors contributing to misconceptions and hindering deep understanding among the students. Regarding the sources of students' misconceptions, limited exposure to modern sciences, lack of laboratory access, and discrepancies between scientific language and official or everyday Arabic language were identified as possible reasons. The study also highlighted the low level of thermal conceptual understanding among Saudi female teachers

Student have difficulties in distinguishing between the concepts of heat and thermal energy. Students would explain heat as "a type of energy stored in matter" and believed that heat comes out as "a result of frictions that occur while particles of matter collide with each other." These explanations were influenced by common misconceptions, such as the idea of "heat loss" or the belief that the energy lost during friction turns into heat (Kizilcik & Tan, 2018).

Paik, Cho and Go (2007) did a study aimed to explore the conceptions of young students regarding heat and temperature, concepts that are important in school science curricula and relevant to daily life, focusing on questions related to temperature, thermal insulation, and heat equilibrium. The results indicated that younger students tended to perceive temperature as "size" or a "summation of numbers," and this tendency gradually decreased in older students. Many students, regardless of age, held alternative conceptions of thermal insulation, although the reasoning behind their conceptions varied with age. Younger students were more inclined to view insulation as a property of materials, while older students displayed a greater tendency toward rational conceptions of heat and temperature. Furthermore, most students, irrespective of age, did not possess clear concepts of heat equilibrium and instead held numerous alternative conceptions.

A study aimed to validate the Thermal Concept Evaluation (TCE) test for university students' misconceptions of thermal concepts in everyday contexts. The participants consisted of 643 first-year students from six different tertiary education departments in Greece. The study examined the impact of socio-demographic and academic variables on students' performance. The assessment revealed that a significant majority of students held alternative conceptions regarding thermal concepts. The findings indicated that these variables had an influence on students' understanding of thermal concepts. Overall, the study highlighted the prevalence of alternative conceptions among university students regarding thermal concepts and emphasised the importance of addressing and correcting these misconceptions (Stylos, Sargioti, Mavridis & Kotsis, 2021).

Turgut and Gurbuz (2012) did a study that focused on students' misconceptions regarding heat and temperature and investigated the effectiveness of conceptual change text instruction on students' understanding of these concepts and their attitudes towards science. The study used conceptual change and traditional instruction methods as teaching approaches. The study highlights the importance of using effective teaching strategies to identify and address students' misconceptions, thereby enhancing their understanding of heat and temperature concepts. The findings, according to Turgut and Gurbuz (2012) indicated that students held misconceptions about heat and temperature. The experimental group, which received conceptual change text instruction, demonstrated better success in eliminating these misconceptions compared to the control group. Regarding attitudes towards science, there were no significant differences between the attitudes of students in the experimental and control groups both before and after the teaching intervention. This suggests that the instructional methods employed did not have a significant impact on students' attitudes towards science.

2.4.3 Contextual Factors that Affect the Acquisition and Use of PCK in Teaching Physics

The use of a comprehensive, school-based programme, emphasising peer collaboration, can be a promising scenario for professional development of mathematics teachers in Tanzania as mentioned in this paper, which has the potential of supporting teachers with diverse levels of expertise and experience in teaching (Kitta, 2004).

Factors that contribute to the development and enhancement of teachers' Pedagogical Content Knowledge (PCK) in physics include the construction of Content Representations (CoRes) and reflective peer discussions (Aydeniz & Gurcay, 2013). Teacher training intervention programmes that focus on reflections about teaching and allow for progression towards innovative teaching and learning processes also contribute to the development of PCK (Melo, Canada-Canada, Gonzalez-Gomez & Jeong, 2020). Additionally, designing teaching activities with web 2.0 tools and utilising emerging technologies can help teachers develop their PCK with technology (Alev, Karal-Eyuboglu & Yigit, 2012). The use of different instructional representations and strategies, such as life examples and experiments, can also enhance teachers' PCK (Jang, Tsai, & Chen, 2013). Furthermore, the knowledge transformation process, which involves deepening subject matter knowledge and increasing awareness of pedagogical issues, is crucial for the development of PCK in science teacher education (Sperandeo-Mineo, Fazio & Tarantino, 2006).

2.5 Science Teachers' Knowledge of their Students' Learning

Shulman (Shulman, 1986b as cited in Ijeh, 2013) made a proposal that included two components of PCK; the knowledge which was tagged 'representations' and also referred to as 'instructional strategies' and knowledge of students' subject matter 'learning difficulties'. Shulman suggested to teachers the use of instructional strategies such as illustrations, analogies, explanations and demonstrations to make subject matter understandable to their students. Learning difficulties comprises knowledge about students' misconceptions, naive ideas gained through interpretation of prior learning experiences, or preconceived ideas about a topic, as well as knowledge of any other possible barriers to learning subject matter knowledge (Lee, Brown, Puthoff, Fletcher & Luft, 2005).

Knowing about subject matter, classroom experience and good emotional attributes helps in development of effective strategies and handling of students (Childs & McNicholl, 2007). School science teachers' knowledge about their students' learning is more of what and how pupils learn. In many cases, teachers simply pass on information to students without directly engaging pupils in the process. The objective obviously, is to get notes into books, then leave the learning to the pupils (Hodkinson, 2009).

Over-confidence in content knowledge can also produce poor quality lessons, perhaps of the type Hodkinson (2009) described. A teacher may be so engaged in the process of declaiming his knowledge, rather than presenting this appropriately for students' interest. The confidence of an experienced teacher may be vulnerable when faced with the prospect of teaching an unfamiliar science topic, resulting in reversion to novice practices. The emphasis changed to strategies used to elicit methods and students' approach to leaning. These are of interest, as these indicate ways in which researchers have adapted a range of methodologies and developed new techniques to tackle students' learning difficulties.

Instructional strategies, learning difficulties and misconceptions are some of the components of pedagogical content knowledge that are used in teaching a particular topic in a specific subject area (Penso, 2002). This study by Penso on the PCK of pre-service science teachers, placed emphasis on how student teachers identify and describe learners' learning difficulties. The teacher used classroom observation and learners' diaries to collect data from the participants. Penso's findings showed that learning difficulties could be identified and described during teaching and by observing lessons. Penso claimed that these difficulties might have originated from the approach to teaching the lessons, which involved the content of the lesson, lesson preparation and implementation, and the learning atmosphere. Other factors were the misconceptions that the learners and the teachers have about the topic, and the cognitive and affective characteristics of the learners. Accordingly, Penso indicated that learners perceive their learning difficulties as being caused by conditions prior to the process of teaching and to those existing in the course of teaching.

While the aspect of lesson content relates to the level of difficulty and abstraction of the topic, the teaching, lesson preparation and implementation aspects are concerned with the structure and presentation of the lesson (Cazorla, 2006). Negative lesson structure conditions include overloading content and unsatisfactory sequences in the lesson. Negative lesson presentation conditions include inappropriate instructional strategies for presentation, and not contributing to the process of learning. Negative cognitive and affective characteristics encompass lack of prior knowledge about a topic that would enable learners to cope with the lesson in a meaningful way, preconceptions developed by the learners because of previous experiences, partial and inconsistent thinking, and lack of motivation and concentration. These negative cognitive and affective characteristics may result in learning difficulties in a teaching and learning situation if it is not properly handled. Cazorla studied how science and mathematics teachers teach in elementary and secondary schools and teacher training colleges, and reported that these teachers seemed to encounter teaching and learning difficulties and generate leaning difficulties during teaching. This author was of the view that, misconceptions and the ways in which lessons are taught are among the factors that contribute to learners' learning difficulties. In addition, most teachers do not have adequate knowledge of the curriculum and the necessary approaches to the teaching and learning of science and mathematics. This, according to Cazorla, leads to poor content delivery in the classroom, and consequently affects learners' performance.

Jong (2003), in his research on exploring science teachers' pedagogical content knowledge, used a teacher's log, concept mapping, interviews, and convergent and inferential investigation techniques and notes in order to identify and resolve misconceptions and learning difficulties. Jong indicated that convergent and inferential techniques may be used by the teachers during classroom practice. These refer to data collection techniques in which questions are developed in short-answer and multiple-choice formats to probe the preconceptions and misconceptions of learners in a topic (Jong, 2003). In conclusion, inadequate subject matter knowledge and inappropriate instructional strategies used in classroom practice can generate misconceptions and learning difficulties among learners in lesson delivery. On the other hand, learning difficulties can be resolved if teachers have developed adequate PCK to help cater for them, which, in turn, can lead to improved learner achievement.

Jong (2003) and Gess-Newsome and Lederman (2001) indicated that convergent and inferential techniques may be appropriate in measuring teachers' knowledge of learners' preconceptions and learning difficulties in science. The convergent and inferential technique involves the use of predetermined verbal descriptions of teacher knowledge made up of multiple choices and short-answer questionnaire. A multiple-choice item test is a series of questions with several possible answers, from which a person has to choose the correct one. The multiple-choice format can be used to rate individual performance and ability in a test, as well as to compare the performance between participants (Bontis, Hardie & Serenko, 2009).

Shulman (Shulman, 1986a as cited in Ijeh, 2013) recommended that teacher education should draw upon the growing research on the pedagogical structure of students' conceptions and misconceptions, on those features that make particular topics easy or difficult to learn. Jenkins (2010) stated that, within that domain, knowledge of students' thinking is credited with substantially influencing instructional practices and improving student learning.

Empson and Jacobs (2008) characterised students' thinking in terms of the strategies students use when solving problems, the representations they use, the reasoning they provide, and the conceptual understanding they display. Ball, Thames and Phelps (2008) described knowledge of content and students as a component of pedagogical content knowledge, which includes the ability to anticipate what students think and find confusing as well as the ability to interpret students' ideas and representations. In Barker's (2007) model of knowledge integration, knowledge of learners pertains to student thinking, misconceptions, or habits related to or influencing how students learn scientific or mathematical topics of lessons.

2.6 Conceptual Framework

Shulman's initial model of PCK (Shulman, 1987 as cited in Ijeh, 2013), which was supported by several studies (Burn, Childs & McNicholl, 2007; Justi & van Driel, 2005; Kumar, 2005; Hora & Ferrare, 2013; Mthethwa-Kunene, 2014), tagged PCK as the specific teacher knowledge that allows a teacher to thoroughly demonstrate the understanding of transforming content knowledge into a more conceptually accessible version for learners. This conceptual framework (figure 1) is grounded in this assertion. As explained by Shulman (Shulman, 1987 as cited in Ijeh, 2013), PCK results from the blending of content knowledge and pedagogical methods. This model of PCK has not only included subject matter knowledge, pedagogical knowledge, but also curriculum knowledge as suggested and indicated by Shulman's initial model. This idea has been interlaced with the context of this study and represented diagrammatically in Figure 1.

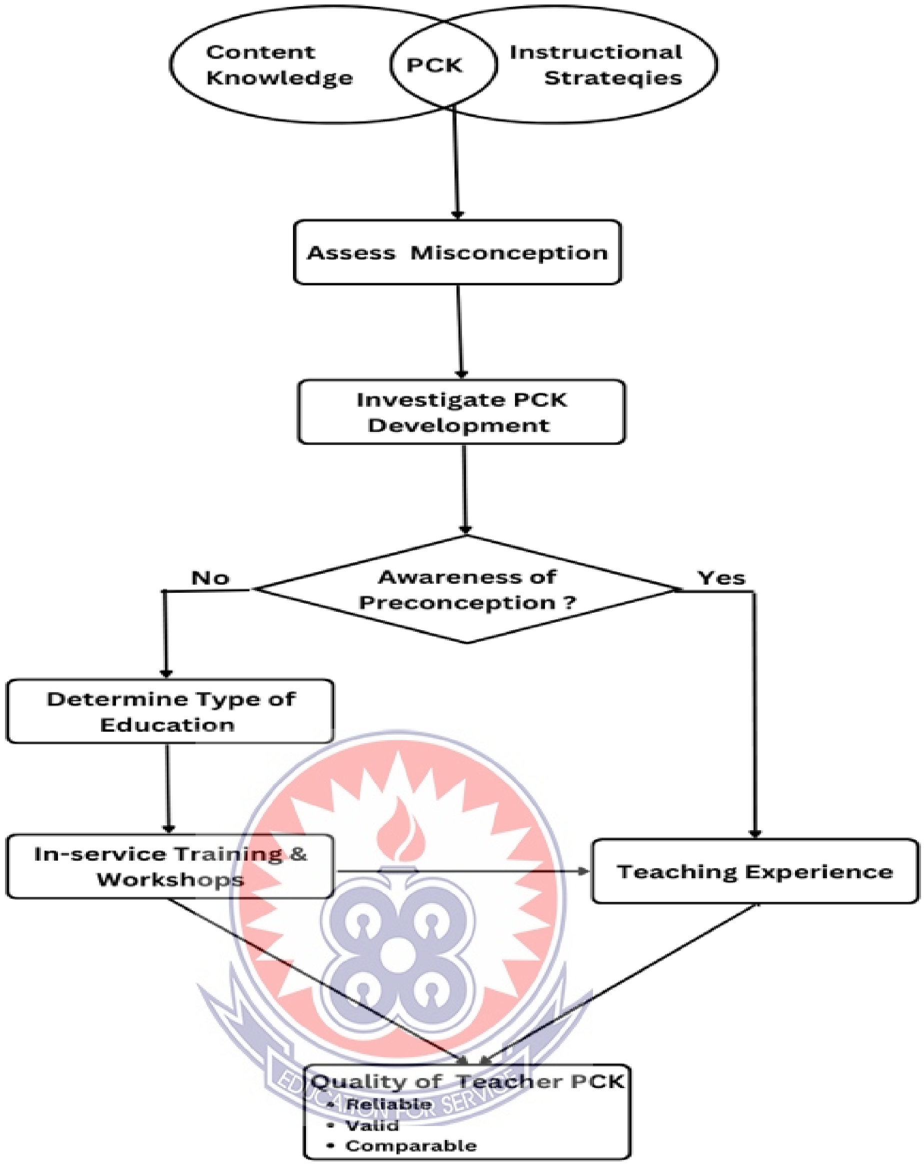

Figure 1. Conceptual Framework Based on Shulman's Initial Model of PCK

The conceptual framework explores the quality and status of pedagogical content knowledge (PCK) among physics teachers, specifically focusing on the teaching of thermal physics concepts. The framework encompasses various components, including content knowledge, instructional strategies, awareness of preconceptions, and professional development opportunities.

At the core of the framework lies the intersection of content knowledge and instructional strategies, represented as the ‘PCK’ node in the flowchart. Physics teachers who possess a strong understanding of the subject matter (content knowledge) and are equipped with effective instructional strategies have the potential to develop high-quality pedagogical content knowledge.

To assess students' learning needs and address their misconceptions, teachers engage in activities such as assessing misconceptions and investigating knowledge development. These activities allow teachers to gain insights into their students' preconceptions about thermal physics concepts, paving the way for tailored instructional approaches.

The framework highlights the importance of awareness of preconceptions as a foundational step in developing PCK. Physics teachers are encouraged to actively identify and understand their students' preconceptions and learning difficulties. If teachers lack this awareness, the framework suggests two paths for gaining it.

The first path involves formal teacher training education, where teachers acquire content knowledge through dedicated courses on thermal physics and engage in methods courses focused on effective physics teaching. By grounding their pedagogical practices in formal education, teachers enhance their understanding of the subject's nature and effective teaching methods.

The second path revolves around classroom teaching experience. Physics teachers develop their pedagogical knowledge by creating and implementing lesson plans related to thermal physics topics. Through hands-on experience (Bayuo, Abukari, Alagbela & Bornaa, 2022), teachers align their instructional strategies with their understanding of the subject matter, taking into account their students' prior knowledge. Additionally, they used recommended physics textbooks and the physics syllabus to refine their content and pedagogical knowledge.

The framework also emphasises the significance of professional development opportunities, specifically in-service training and workshops. Attending workshops that focus on teaching challenging topics like thermal physics provides teachers with additional opportunities to learn relevant instructional strategies. These workshops further enhance their pedagogical content knowledge and contribute to the overall quality and status of their teaching practices.

Ultimately, the framework aims to foster the development of high-quality pedagogical content knowledge among physics teachers. By combining strong content knowledge with effective instructional strategies, raising awareness of students' preconceptions, and embracing professional development opportunities, teachers can enhance their ability to effectively teach thermal physics concepts. This, in turn, leads to improved student learning outcomes and the overall quality and status of pedagogical content knowledge among physics teachers.

2.7 Summary

Over the last thirty years, research on teacher knowledge has grown significantly, especially regarding the significance of subject-specific knowledge for effective teaching. Authors highlighted the necessity for teachers to possess a profound grasp of the subjects they teach, encompassing facts, concepts, theories, and the ability to connect and organised ideas within the subject. This knowledge varies across disciplines and involves understanding the distinct cognitive approaches associated with each field. Inadequate subject knowledge can lead to students developing misconceptions. Strategies have been developed to enhance science teachers' subject knowledge, seen as pivotal for effective teaching. Teachers lacking subject knowledge might struggle to explain concepts and resort to simplistic teaching or focus solely on procedures. Some argued that pre-service teachers are more receptive to developing subject-specific pedagogical knowledge beyond their specialisation. Authors emphasised the role of confidence and emotional attributes in teaching effectiveness. Unanimously, integrating subject knowledge and pedagogical content knowledge is vital, requiring guidance on effective utilisation in teaching. School-specific subject knowledge differs from academic knowledge and challenges the notion that a strong academic background is the sole requirement for effective teaching.

Pedagogical knowledge according to the authors, pertains to the expertise and techniques associated with teaching that teachers acquire through practice. It covers diverse elements like classroom management, questioning methods, differentiation, and instructional strategies. This knowledge includes the understanding of teaching and learning processes, encompassing educational objectives, values, and aims. It goes beyond subject-specific expertise and involves students' holistic development, lesson planning, execution, and assessment. Deep pedagogical knowledge enables teachers to comprehend how students learn, develop skills, and foster positive learning attitudes, drawing from cognitive, social, and developmental theories. Over time, pedagogical knowledge has evolved from managing classrooms to comprehensively grasping teaching and learning processes. Effective teaching necessitates both subject knowledge and proficient pedagogical skills to create a productive learning atmosphere. Professional development is vital for educators to enhance pedagogical skills and adapt to changing educational demands. Crafting effective lesson plans is a crucial facet of pedagogical knowledge, guiding purposeful and engaging instruction.

Pedagogical content knowledge (PCK) is crucial for effective science teaching, involving specialised skills and knowledge that teachers possess for teaching specific subjects like science. PCK according to the authors, goes beyond content knowledge, this involves how to teach it engagingly and comprehensibly. PCK consists of orientations towards teaching, science curriculum familiarity, understanding students' grasp of topics, assessment and instructional strategies. Shulman's work introduced PCK, emphasising its role in making subject matter understandable during instruction. Different PCK models, transformative or integrative, have been proposed. Professional development is essential for enhancing teachers' PCK. A proposed model includes school, subject, and pedagogic knowledge, linked by a teacher's personal subject construct. School knowledge adapts subject knowledge for teaching, while pedagogic knowledge involves teaching practices and the subject-school relationship. Teachers' personal subject construct combines learning experiences, teaching beliefs, and subject purpose. Unlike Shulman's view, this model incorporates learning theories and didactic transposition. PCK significantly guides effective science teaching practices.

Researches indicated that pedagogical content knowledge is a product of time and classroom experience. Having solid content knowledge is crucial for PCK growth. Studies examined the impact of interventions on PCK, revealing that training often prioritises content knowledge over PCK. Collaborative interactions with experienced teachers were found to foster PCK development in trainees and new teachers. Equipping trainee science teachers with lesson planning frameworks and facilitating teaching case discussions enhanced PCK. Collaborative teacher efforts that integrate content knowledge and teaching strategies are especially effective for PCK growth. These studies underscored that PCK isn't inherent; instead, it's cultivated through skills and knowledge acquisition during the transition to becoming professional science educators.

Authors emphasised the significance of pedagogical content knowledge for effective science teaching, which combines subject expertise and teaching methods. Strong PCK enables teachers to explain scientific concepts, encourage inquiry-based learning, and address student misconceptions. Research focuses on PCK's development and components, highlighting the integration of content and pedagogical knowledge. Professional development and mentorship impact PCK, underlining continuous learning and reflection. Further studies are suggested to explore PCK's growth over time, its impact on student learning, and contextual factors shaping it. PCK's development is intricate, rooted in content and student understanding. Grasping PCK's evolution and structure enhances teachers' knowledge and advances science education practices.

Teaching thermal physics in undergraduate courses poses challenges due to its abstract nature, misconceptions, and mathematical complexities. Effective strategies include the thinking frames approach for addressing naive conceptions. Incorporating modern examples and highlighting operational, mathematical, and philosophical aspects enhances engagement. Challenging misconceptions through experiments and discussions is crucial for comprehensive understanding. Balancing simplicity and subject integrity is vital, as oversimplification can undermine content integrity. Different science disciplines define heat differently, with physics and chemistry focusing on energy transfer, while other disciplines relate it to molecular kinetic energy.

Teaching thermal physics concepts poses challenges due to abstraction and student misconceptions. Effective strategies include the thinking frames approach, modern examples, model-eliciting activities, interactive demonstrations, and the REACT teaching model. Multisensory experiences, like touch and thermal imaging, enhance understanding. Conceptual change-oriented and cognitive conflict-based teaching, along with the 5E model, boost conceptual grasp. Tracking progression and addressing alternative conceptions is important, using tools like the Thermal Concept Evaluation. Energy teaching aligning with constructivist approaches and integrating engineering design activities aid conceptual change in science classrooms.

Teaching thermal physics concepts is challenging due to confusion between heat and temperature and misconceptions about heat energy flow. Effective strategies like experiment-based learning, inquiry teaching, scaffolding, and peer discussions improve understanding. Real-life examples, contextual problems, and modern tools also aid conceptual clarity. PCK is pivotal, developed through peer discussions, reflective training, and technology integration. Diverse instructional methods and deep subject knowledge enhance PCK, facilitating successful teaching of thermal physics concepts.

Pedagogical content knowledge regarding learners' challenges involves instructional strategies and understanding students' difficulties. Teachers should use techniques like illustrations, analogies, and explanations to aid comprehension. Identifying misconceptions and preconceived notions hindering learning is crucial. Recognising content difficulty, lesson structure, and students' cognitive and emotional traits contribute to addressing challenges. Methods like teacher logs, interviews, and concept mapping help uncover and rectify misconceptions. Adequate PCK helps teachers tackle difficulties, improving student achievement. Awareness of students' thinking informs teaching methods, ultimately integrating content and student knowledge for effective education.

The conceptual framework of the study is grounded in Shulman's initial model of PCK as it explored the tendency of developing and ensuring quality PCK of physics teachers through time-tested experience and professional development programmes.

Consequently, it is very difficult to conclude from the studies reviewed that content knowledge has a bearing on teachers' PCK and how teachers understand their students' learning construct. What is more, in spite of all the strategies, approaches and models of PCK propounded by these researchers, no mention have been made of the status and quality of science teachers' PCK in Ghana. Since these studies have different contextual background, they cannot be holistically applied everywhere, so, it is imperative to conduct this study to ascertain the quality and status of physics teachers' PCK in Ghana.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter discusses the research methodology that was used to explore the nature of participating physics teachers' pedagogical content knowledge and how it was acquired. The chapter begins by providing an explanation of the research paradigm; the research design and case studies; the participants' selection and procedure employed; the development and validation of data collection instruments. The suitability of the research paradigm and procedures used in this study is also discussed and justified. The chapter concludes by discussing the pilot study and ethical considerations.

3.1 Research Method and Design

Cohen, Manion and Morrrison (2007) describe research method as a variety of approaches that are utilised in educational research in order to gather data, which is later interpreted to provide explanations. Mackenzie and Knipe (2006) argue that research method presents systematic procedures or tools which are used for collection and analysis of data. In a similar vein, Pavan and Kulkarni (2014) argue that research methods refer to the techniques used by a researcher to conduct research.

In this study, a qualitative research approach within an interpretive paradigm (Merriam, 2009) was used to explore the research questions. A qualitative research approach was chosen since the main purpose of the study was to provide in-depth information and rich descriptions of the participating teachers' existing PCK profiles which was premised in teaching the concept of thermal energy. The aim of research from interpretive perspective is to describe, understand and interpret the phenomenon under investigation (Merriam, 2009). Creswell (2008) asserts that studies are conducted in close contact with the participants since these interactions are seen as important contexts for understanding what the participants say and do. On the wings of this assertion, data collection which was personal and interactive, using qualitative methods was predominant in this worldview (Mertens, 2010). Mack (2010) indicates that research of this kind is subjective and is observed from the inside, through the direct experience of people. This paradigm made room for a deeper understanding of the selected teachers' PCK by observing their lessons and carrying out interviews which further supported the aim and purpose of the study. Therefore, qualitative method under this circumstance was most suitable for this study as the participants were made up of only six physics teachers who were observed within their own working contexts. Lesson observations and interviews were used to get an in-depth view of the participants' reality.

A qualitative approach was deemed most suitable for conducting this study on the basis that qualitative research design is applicable when there is a need to gain insight into a problem. Avraamidou (2013) asserted that the value of a qualitative research design is in providing deep understanding of a phenomenon in comparison to a quantitative research design which provides numeric data in order to measure differences, make predictions and test hypotheses. Also, quantitative research design is most suitable when there is a desire to make generalisations from a sample of a population (Merriam, 2009; Yilmaz, 2013). On the other hand, qualitative research design is most suitable when there is a need to develop a deep understanding of a problem in order to explain it (Bahari, 2012; Merriam, 2009). The purpose of this study is not measuring differences, making predictions, testing hypotheses, or generalisation of the findings outside of the local setting but rather to get a deep understanding of the selected physics teachers' pedagogical content knowledge. As such, data collection included lesson observations, lesson plan (lesson artifact) analysis and interviews. These multiple sources were used and were enough to generate rich, thick data that facilitated an understanding of the problem.

The focus of the study is to get in-depth understanding of these teachers' practice with regards to teaching the concept of thermal energy. In order to get such understanding, a research design which uses qualitative data and inductive analysis to generate rich descriptions of the events as they unfold over a period of time, was chosen. There are many research designs in educational research but for the purposes of this research, case study research design was selected. The use of case study design would help explore physics teachers´ PCK and to unpack all that goes into these teachers' delivery of better quality education. A case study is an in-depth exploration of a bounded system, in the form of an activity, event, process, or individual, based on extensive data collection which is carried out in a natural setting, and within a stipulated period and scope (Creswell, 2008).

In this study, a qualitative case study design, an in-depth description and analysis of a bounded system (Bogdan & Biklen, 2007; Creswell, 2012; Merriam, 2009) was adopted based on its boundaries which were similar to those of the case studies conducted by Hanuscin, Lee and Akerson (2011) and Park, Jang, Chen and Jung (2011) in which similar aspects of classroom practices were explored. The boundaries of this case study were defined by the six physics teachers - a small participant pool and the research site, an elective physics performing school in the Volta Region of Ghana. The study chose a descriptive research design (McMillan & Schumacher, 2010), using the case study approach (Merriam, 2009). A descriptive study seeks to find out what happened and describes current or past status of something (McMillan & Schumacher, 2010). It is assumed that the teachers have developed their PCK, and the interest lies in what they have differently from other teachers and the way in which this was developed over time. The study involved a multiple-case study (Creswell, 2008; McMillan & Schumacher, 2010; Merriam, 2009), consisting of six cases in which the phenomenon of individual teachers' PCK and its development were studied and how it was assumed to have developed, constituted the unit of analysis of this study.

Merriam (2009) described a case as a single entity to be studied around which there exist boundaries enabling the researcher to focus the research. Case studies can be designed as single or multiple cases. Thus, a study may contain more than a single case and when this occurs, the study is noted to be a multiple case study (Yin, 2003). This study is focused on six participants; each participant constitutes an individual case; hence, this study constitutes a multiple-case design (Yin, 2003). Merriam (2009) indicated that inclusion of multiple cases within a case study provides the room to strengthen and enhance the external validity or generalisability of study findings.

For a number of reasons, the case study design was best fit for data collection and analysis for this study. In the first place, the case study has a distinctive advantage over other research designs since the strategy employed in this study is to investigate 'what', 'how' or 'why' a contemporary set of events and phenomena over which the researcher has no control happened (Yin, 2003). A case study is an approach that is used when one wants to gain an in-depth understanding of a complex issue in a real-life context (Zainal, 2007; Bertram & Christiansen, 2014). Bertram and Christiansen (2014) contended that case studies aim to describe what it is like to be in a particular situation and are therefore descriptive in nature.

Case studies aim to capture a close-up view of a participant's lived experiences and their feelings and thoughts about a particular situation (Cohen et al., 2007). Because case studies involve observing a phenomenon in its natural setting, it is therefore regarded as a naturalistic design (Crowe, Cresswell, Robertson, Huby, Avery & Sheikh, 2011). The teachers in this study were observed within their working environments in order to gain a better understanding of the PCK that they displayed in their teaching of physics. This presented the opportunity to get an in-depth understanding of the participants' lived classroom realities and to keep a detailed record of their lessons.

A case study design is also preferred when there are multiple forms of data (Yin, 2003). Patton (2002) and Yin (2003) stated that reliance on multiple sources of evidence presents a unique strength for case study research design. In this study, multiple forms of data were gathered from classroom observations of participants teaching specific content related to the concept of thermal energy. A semi-structured interview (Patton, 2002) was conducted prior to and following classroom observations. Data were collected from teachers' lesson notes (including PowerPoint slides) and students' exercise books. All data were gathered within a real-life context as teacher participants were observed demonstrating their acquired PCK relating to the teaching of thermal physics.

Case study design has the tendency to provide certain specific insight into how individuals confront and solve problems. Merriam (2009) described case study as particularistic, descriptive, and heuristic, indicating that case study is a design that lends itself to a specific event and has the tendency to provide significant enormous insight into how individuals handle problems through a holistic and impeccable view of the situation.

Case study research, however, has some methodological limitations. It is usually criticised for its inability to lend itself to generalisability or transferability of findings since it deals with one or a few cases (Merriam, 2009; Rule & John, 2011). Adding to this, multiple-case researchers end up looking for similarities and tend to ignore differences (Rule & John, 2011). Despite the inherent shortcomings and associated criticism, science education researchers (Appleton, 2008; Brown, Friedrichsen, & Abell 2013; Lowery, 2002; Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008) keep using the case study design productively. These researchers used case study in most studies on teachers' PCK owing to its strength, such as providing a rich and detailed description of the case in a natural setting (Merriam, 2009). Since the strengths of case study far outweigh the weaknesses, this design was considered suitable for this study and was used to gather data. This was to gain better insight into the PCK of these well-performing physics teachers and to find out what they do differently to promote and improve teaching and learning of physics in their school.

3.2 Population and Sample

Population and sampling involve the identification of a particular group of interest and the selection of a representative subset for statistical analysis. Specifically, population sampling involves the systematic selection of individuals from a larger population in order to gather data for analysis (Jordan, 2018). As noted by Forsyth (2017), it is important to recognise that the sample is the actual data at hand, whereas the population represents the data that could have been observed had all variables been taken into account. Finally, the estimation of the population mean is achieved through the examination of the sample.

3.2.1 Population

Population is the group of individuals who have the same characteristics (Creswell, 2012), and specifying the research population, makes room for sampling and selecting its related resources (Cohen, Manion & Morrison, 2007).

This study was conducted in Volta Region, which is one of the 16 regions in the Republic of Ghana with 18 educational districts. The population of the study is the senior high school elective physics teachers' population of the region which is 120 from 55 schools. This population was chosen since it contained the crop of physics teachers whose students were consistently producing impressive results.

3.2.2 Sample and Sampling Procedure

Sampling is the act, process, or technique of selecting a suitable sample, or a representative part of a population for the purpose of determining parameters or characteristics of the whole population (Fridah, 2002). As specified by Creswell (2013), with qualitative research it is suitable to be purposefully selective with the research sample, as it helps the researcher to best answer the research question.

In this study, purposive sampling technique (Creswell, 2007) was used to select six physics teachers, from two senior high schools, whose students performed well in five consecutive years in end of programme examination, to participate in the study. In purposive sampling approach according to Etikan, Musa and Alkassin (2016), the researcher deliberately makes a choice in selecting a participant due to the qualities that the participant possesses. The researcher decides what is to be known and sets out to find people who can or are willing to provide information by virtue of knowledge or experience. A stringent approach which served as an elimination process to selecting the participant teachers was employed based on certain criteria: teachers of students whose West African Secondary School Certificate Examination (WASSCE) performance in elective physics was impressive; and recommendations by subject specialists at the regional directorate of Ghana Education Service (GES) was used to select the six teachers who participated in the main study. According to Merriam (2009), a researcher should list the attributes that are important to the study so as to proceed to locate units to match the list. The selection criterion was that these teachers should consistently have 70% of their total number of students completing having minimum grade of C6 in the WASSCE elective physics for five or more years, thus from 2017 – 2021. This grade (C6) is the minimum grade requirement that qualifies a student to Ghanaian public tertiary institutions. The use of learner performance as the selection criteria is in line with Ornstein's (2003) assertion that expert teachers are usually identified through administrator nominations, student achievement scores, or teacher awards. Therefore, the use of learner performance in this study may be justified. The participant teachers' selection procedure through purposive sampling was conducted following these steps (Figure 2).

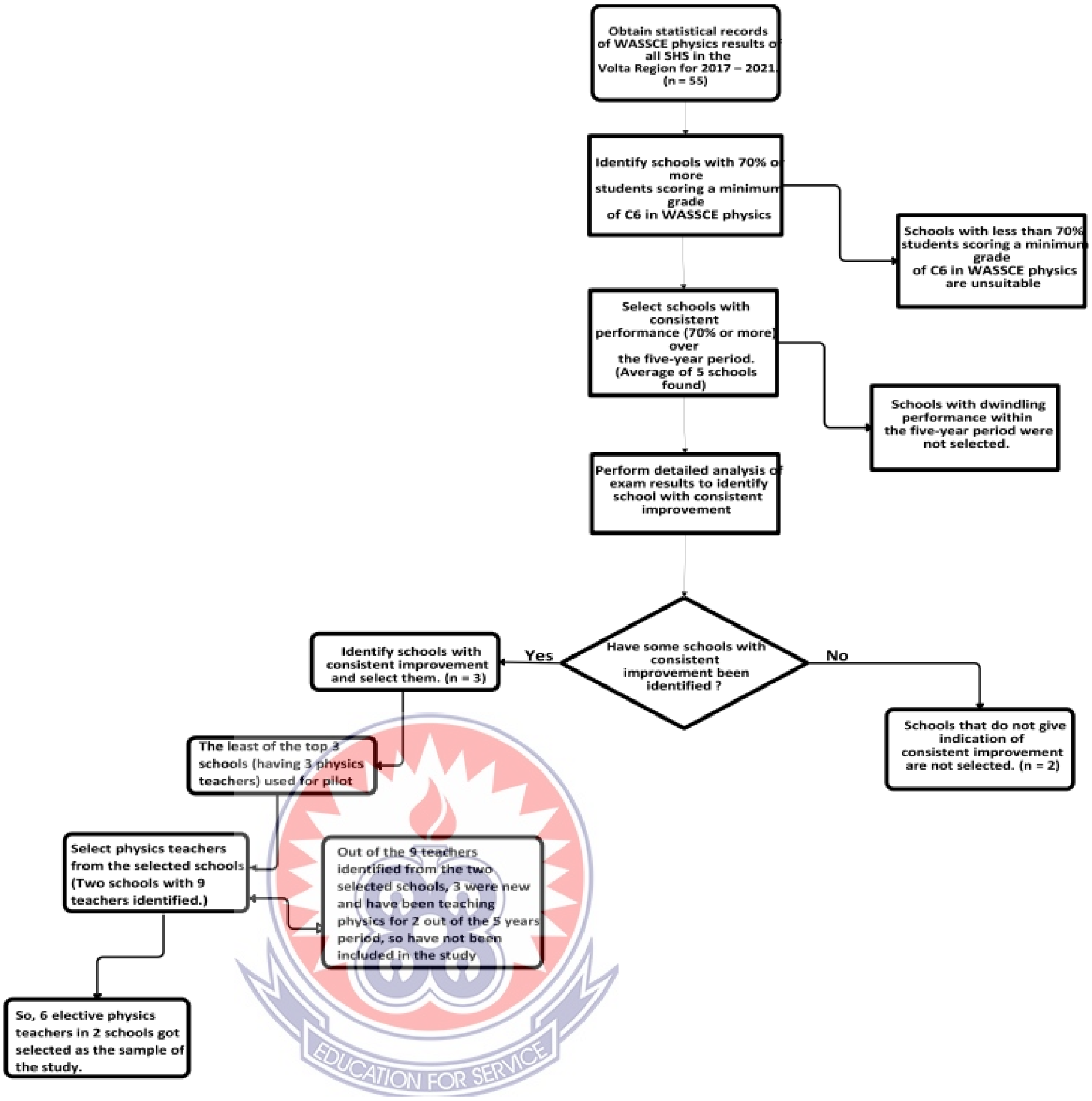

Figure 2. Flowchart of Participant Selection Based on Purposive Sampling

In this study, the six outstanding teachers were identified as follows: First, statistical records (WASSCE Physics Results Analysis) of performance in senior high school elective physics examination results of all senior high schools in the Volta Region from the West African Examination Council (WAEC) for each of the five years (2017 – 2021) were obtained from Volta Regional Education Office and used to identify best performing schools (Appendix N). The Regional Examination Officer (from Planning Unit of GES) was consulted to supply these statistics (Appendix O). Second-ly, schools that had 70% of their completing students producing minimum grade of

C6 which is a credit pass in five years were identified. This exercise yielded 6 out of 52 schools in 2017; 5 out of 52 schools in 2018; 4 out of 52 schools in 2019; 6 out of 53 schools in 2020; and 5 out of 55 schools in 2021. Third, schools that consistently had 70% of their students producing C6 and above and their names were recurring throughout the five years were selected. This produced only three schools from the entire region. The three schools formed the pool of schools from which the sample of teachers could be drawn. These three schools consistently had their names repeated from 2017 to 2021. Comparatively, from the three identified schools which satisfied the performance criterion of 70% pass rate of C6 or more consistently for the past five years. The fourth criterion was that, analysis from the details of their exam results indicated that two schools had their results constantly and progressively increased in terms of quality of grades (very few grades C6 and more grades A and B) and number of students excelling, while the results of the remaining one school dwindled with time though within the 70% pass mark range. So these two schools which had 70% of their students increasingly and constantly produce C6 and above in WASSCE elective physics results for five years were selected for the study. The remaining school which is the least of the top three schools was used in the pilot study. Lastly, the selected teachers should have taught the final year students who produced these results within these specified period when success was achieved.

Permission to carry out the study in the selected schools was sought and obtained from regional education office (Appendix A) and the school heads (Appendices B & U). In this school, nine (9) elective physics teachers were identified and they were all said to have been teaching every level including final year students. Out of the nine teachers, six (6) had been teaching in that school for the past five years and the remaining three (3) came barely within the last two years. So, these six elective physics teachers in these two schools who have been teaching in these schools for more than 5 years, and consistently produced over 70% credit passes in WASSCE in the specified period even when chief examiner's report indicated that there was a general decline in students' performance, were selected for the study. This sampling approach had been employed by other researchers such as Ijeh (2012), Mthethwa-Kunene (2014) and Morrison and Lederman, (2003), when they conducted in-depth studies to explain teachers' pedagogical content knowledge in their own studies. The sampled teachers were referred to by pseudonyms as Ben, Kalulu, Carl, John, Daniel and David.

3.3 Data Collection Instruments

In this study, data were collected using physics lesson observation schedules, semi-structured interview schedule, researcher field notes, audio-recordings as suggested by Patton, (2002). Other sources of data included lesson artefacts such as lesson plans, hand-outs, PowerPoints slides, students' exercise books and elective physics syllabus. One important advantage a case study design offers is that many sources of evidence can contribute to the data collection (Yin, 2003). Patton (2002) noted that data collected from multiple sources is a form of triangulation, thus consistency of findings generated from different data sources within the same method can be compared. Yin (2003) suggested that multiple sources of evidence is a strength of the case study since multiple sources of evidence give room for triangulation of the data sources.

In this study, sources of evidence used included: live physics lesson observations, one-on-one semi-structured interviews with each one of the physics teachers (Patton, 2002), researcher notes, video recordings, lesson plans, students' class exercise books, physics syllabus and lesson artefacts. Observations made of the participants were compared with their statements and explanations during interviews to establish consistency or otherwise of their knowledge of content matter, PCK and teaching and learning strategies in general. Figure 3. helps visualise the procedure and the data gathering techniques of the study.

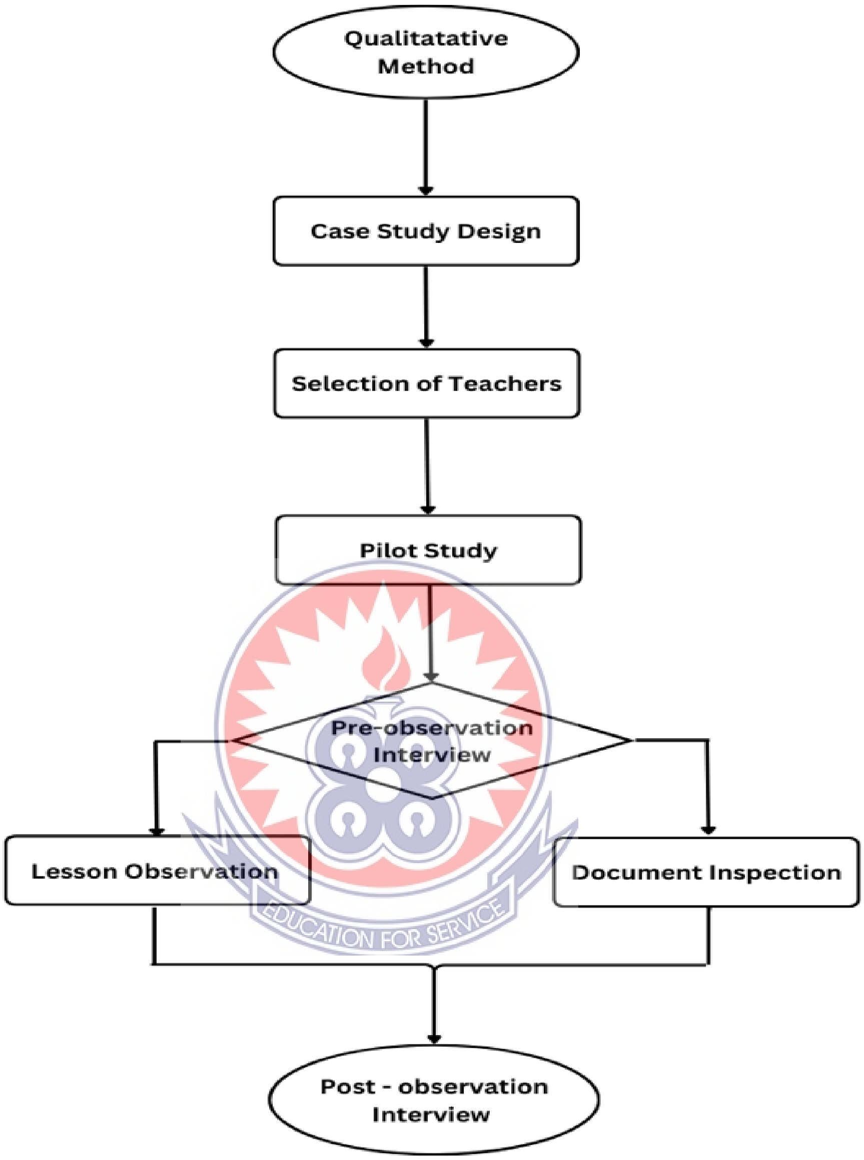

Figure 3. Research Approach

From Figure 3, after selecting the participant teachers, pilot study was done to ascertain the practicability of the study process and to test the validity of the instruments. Pre-observation semi-structured interview was conducted to probe for participants' views on their content knowledge, PCK, teaching strategies and students' preconceptions. Lesson observations were then carried out and document review and analysis were done concurrently to reinforce each other and to look out for consistency. Data from document review and emerging issues from the lesson observations were used to conduct post-observation interview.

In this study, the major instruments used are lesson observation and interview. Other instruments, namely lesson plans, and document analysis (lesson artefacts), were used for triangulation as summarised in Table 2.

Table 2. Research Instruments and Research Questions Addressed

S/n	Research questions	Research instruments
1	What content knowledge of thermal physics do the well-performing physics teachers have and demonstrate during classroom practice?	• Teacher lesson plans. • Teacher pre-lesson interview schedule on their lessons plans. • Lesson observation schedule on their classroom practice on teaching thermal physics.
2	What instructional strategies do the well-performing physics teachers use in teaching the concept of thermal physics?	• Teacher lesson plan on thermal energy. • Teacher pre-lesson interview schedule on concept of thermal energy. • Lesson observation schedule on classroom practice. • Document review / analysis.
3	What knowledge of learners' preconceptions and learning difficulties do the physics teachers have and demonstrate during classroom practice?	• Teacher pre-lesson interview schedules on concept thermal energy of their lesson plans. • Teacher lesson plan on thermal physics. • Lesson observation schedule on classroom practice' • Teacher post-lesson interview about usual areas of learners' difficulty. • Document analysis – learners' work sample.
4	What factors and practices contribute to the development of pedagogical content knowledge among well-performing physics teachers in teaching thermal physics?	• Teacher post-lesson interview schedule about teachers' background. • Document analysis – learners' work sample and curriculum documents

Lesson observation and interview happened to be the major research instruments for data collection and the others, namely lesson plans, and document analysis (lesson artefacts), were used for triangulation.

3.3.1 Interview

Conducting interview is one of the methods of inquiry humans make use of to understand their experiences (Creswell, 2012; Seidman, 2013). Adding to that, interviewing is necessary when it is not possible to observe behaviours, feelings or how people interpret the world around them (Merriam, 2009).

3.3.1.1 Pre-observation interview.

In this study, after collecting and studying the lesson plans, and prior to the field observation, a pre-observation, semi-structured one-on-one interview (Patton, 2002) was conducted. A semi-structured interview is one in which the interviewer is allowed to ask probing questions in addition to a set of predetermined questions purposefully developed to guide the process (Augustine, 2014; Cresswell, 2012; Merriam, 2009; Tripp & Rich, 2012). The purpose of the pre-observation interview was to explore the nature of teacher knowledge held by these physics teachers within the areas of learners, curriculum, instruction, and assessment strategies related to the concept of thermal energy, as well as, the participants' orientation to teaching of physics. The interviews were conducted within the premises of the senior high school of the participant prior to the observation.

Creswell (2012) cautioned that participants may get tired if the interview is made lengthy. Based on this caution and guided by Kinghorn (2013), the interview sessions were made to last for a maximum of 45 minutes. The teachers were interviewed about their lesson plans before each observed lesson with the intent of determining their knowledge of the concept of thermal energy, the content knowledge to be taught; instructional strategies that were to be employed in delivering this specific concept and students' preconceptions and learning difficulties in relation to the topic of study and how they planned to teach the lessons. The participants were asked to give brief explanation on their planning and explain their decisions to include specific strategies, representations, assessments found in the lessons.

While carrying out the interview, written notes were taken and these sessions were at the same time audio-recorded with permission from the participant teachers. Information from audio-recorded interviews was useful as it provided the researcher with a reliable data set long after the interview session (Merriam, 2009; Tripp & Rich, 2012). Audio-recording of the interview sessions gives room to the researcher to interact with the data at his own pace for longer periods after the interview was conducted (Nguyen, 2015). Audio-recording of the interview sessions provides the researcher with the space and time to gather pieces of information that could have been missed during the interview sessions (Bogdan & Biklen, 2007; Lodico, Spaulding & Voegtle, 2010). The interviews were then transcribed in readiness for coding (Appendix C for pre-observation interview schedule). The teachers were then observed teaching the lessons using a semi-structured observation schedule to determine their content knowledge of thermal energy, knowledge of instructional strategies, and students' preconceptions and learning difficulties, if any.

3.3.1.2 ***Post-observation interview.***

In this study, each lesson observation was followed with a brief individual post-observation interview (Appendix E) to seek clarification or thoughts about observed classroom events and approaches noted by the observer that would explain the 'what' and ‘how’ questions about teacher PCK. This included questions bordering on teachers’ educational background to ascertain how their PCK was presumed to have been developed. Interviews provide flexible opportunities to probe for greater depth than what video recordings or field notes can capture. The focus of the research was not only to identify the manifestations of teacher knowledge but also to gain insights into the thinking and reasoning that took place in the process of knowledge transformation, and the teacher’s reflection over an action (Park & Chen, 2012). Teacher interviews were used in the study to clarify, supplement and support what was observed in the classroom and provide information that could not be captured by observations alone.

The interviews were conducted in the premises of the participants’ school; these interviews were conducted between 30 and 45 minutes. The participants were asked to reflect upon the lesson and explain; their concerns for student comprehension of content; their choice of instructional strategies and representations; kind of questions asked and feedbacks that were given to students and their use of formative assessment strategies to gauge students’ learning. Participants were also asked how they modified their instruction to address student learning difficulties during the lesson. This interview session was audio-recorded to provide a record for future reference. The interviews were then transcribed in readiness for coding. The transcribed data gathered from each participant, along with the interpretation, were packaged and given to them to crosscheck and gain insight into indicate whether the interpretations were accurate accounts of what they communicated during the interviews, lesson observation and in their written lesson plans.

3.3.2 Classroom Observations

Observation is one of the techniques used to collect the required data. Classroom observation is a technique of directly observing teacher's real time classroom activities as they unfold in the course of lesson delivery (Hora & Ferrare, 2013). It is a very good way of watching and listening to an interaction as it takes place (Kumar, 2005). Classroom observation allows the researcher to observe first-hand what transpires during the lesson. The observation provides useful information and gives an opportunity to obtain rich data about teachers' pedagogical application and teaching strategies, which are the reflection of teachers owned PCK and its components.

In this study, lesson observations were conducted in the participants' school and classroom (Appendix D for observation schedule) to find answers to the research questions. In all instances a copy of the participant's lesson plan was collected and studied ahead of the commencement of the lesson. Accordingly, four classroom observations were conducted in each class over a two-week period; each observation lasted for an hour. In the observation, it was aimed to observe teachers' knowledge of the content of 'thermal physics', by looking out for; accuracy of scientific facts presented; flexibility of presentation; sequential representation of facts; flow of ideas and hierarchical presentation of facts. In terms of knowledge of teaching strategies, the study set out to look for organisation of the lesson; choice of examples; representations, use of

chalkboard and appropriate teaching strategies. However, about the question of knowledge of learners' conceptions (misconceptions and pre-conceptions) with regards to the topic under discussion, the observer set out to observe how the followings were done; assessing learners' understanding; identifying errors learners made; addressing learners' difficulties, and determining sources of such difficulties; identification of misconceptions and elimination of these misconceptions by the use of probing questions; and using appropriate tasks. The observation protocol schedule (Appendix D) which assessed how teachers presented their lessons was designed based on Shulman's original conceptualisation of teachers' PCK (Shulman, 1986a as cited in Ijeh, 2013) which; assessed how teachers assist learners in comprehending the topic; how the teachers assessed their learners' after the lessons; the teaching strategies that they employed; and how the teachers dealt with misconceptions and learner difficulty during lesson presentation. Glen and Dotger (2013) used lesson observations to collect data for a qualitative research study aimed at understanding how science teachers used writing in science lessons.

During the lesson delivery, video-recordings were made as the observer sat all alone at the back of the classroom to avoid posing disruption to the lesson. The researcher played the role of a non-participant observer, recording in narrative form details of the instructors' instructional roles or pedagogical content knowledge to see how much it is consistent with the practices. There was no communication between the observer and the participants during the lesson delivery. Inferences drawn, questions to be asked of the participants and details that needed to be clarified with participants were noted for discussion in post-observation interview. Chick and Harries (2007) used classroom observation when they studied the pedagogical content knowledge of some mathematics teachers. Observations were also used by Kilic (2006) when he studied the components of pedagogical content knowledge of pre-service teachers at a certain university.

The transcribed data gathered from each participant, along with the interpretation, were packaged and given to them to crosscheck and indicate whether the interpretations were accurate accounts of what they communicated during the interviews, lesson observation and in their written lesson plans.

3.3.3 Document analysis

Classroom observations, though very important and useful in collecting data on teacher quality and content knowledge, they cannot provide all the answers to the questions that would be asked about teachers' classroom practices. Another, more scalable, broader and reliable source of data collection which measures teaching behaviours and provides vital answers to frequently asked questions (Jacobs, Martin & Otieno, 2008) is document review which usually takes the form of critical analysis of teachers' writings such as lesson plans and lesson artefacts such as physics syllabus, handouts, PowerPoints slides and students' class exercise books. Dotger and McQuitty (2014) and Knight, McNeill, Corrigan, Barber, Knight, Knight, and Barber, (2013) used science lesson plan analysis in their studies.

Teachers' lesson plans can offer meaningful insights into their content knowledge as they always make numerous decisions about selecting and sequencing content that depend on their knowledge pool of the subject area (Ferreira, 2015). Rusznyak and Walton (2011) indicated that having control over the content knowledge necessarily precedes the design of a learning process and is inseparably intertwined with teachers' PCK.

In this study, and on the strength of the above assertion, copies of teachers' lesson plans and PowerPoint slides of the physics lessons being observed were collected for analysis to determine the amount and accuracy of content knowledge displayed as well as finding out about their PCK and how it was developed. The physics syllabus and textbooks were examined to assess how the teachers developed their PCK in teaching the concept of thermal energy. Students' class exercise books were reviewed with the intention of determining the instructional strategies and considerations of learners' preconceptions and learning difficulties. Lesson plans were reviewed to identify overt and covert content knowledge and PCK acquired and findings recorded (Appendix F) and areas for further probing with the participants were recorded on the instrument and addressed during the post-observation interview session.

3.4 Development of Research Instruments

Each of the data collection instruments and their development as well as the procedure used in scoring them have been described in this section.

3.4.1 Pre-observation Interview Schedule

In attempt to gain insight into physics teachers' content knowledge, knowledge of instructional strategy and knowledge of learners' preconception and learning difficulty, semi-structured pre-observation interview schedule was used (Appendix C). Even though interviews are sometimes criticised for being deceptive since some participants may provide false information and perception so as to please the researcher (Creswell, 2008; McMillan & Schumacher, 2010), a lot of researchers (Drechsler & Van Driel, 2008; Ijeh, 2012; Ijeh & Onwu, 2013; Park & Chen, 2012; Mthethwa-Kunene, 2014) have continued to use interviews in PCK research. One advantage researchers gain from using semi-structured interviews is obtaining detailed responses from the participants through probing (Creswell, 2008).

In this study, the interview schedule used was developed by adapting questions from other researchers (Kapyla, Heikkinen & Asunta, 2009; Mthethwa-Kunene, 2014; Ozden, 2008; Rollnick et al., 2008). So, questions were developed to in the first place, gather teachers' demographic information (years of teaching experience, academic qualifications, and major subjects), which was meant to present a general profile for each participant. In addition, the teacher's preparation and considerations that went into the design of lesson, were examined, such as; the exact content to be taught; the instructional objectives of the lesson; what the teacher took into account in planning the lesson; the instructional strategies used in teaching the concepts of thermal physics and reasons for the choice of teaching method adopted.

The PCK being assessed in the study formed the basis for categorisation of the inter-view questions. This approach of categorisation has been used by other researchers (Ijeh, 2012; Kapyla et al., 2009; Mthethwa-Kunene, 2014; Rollnick et al., 2008) in their various studies.

The first three questions requested piece of background information such as; how long they have been teaching physics; if they teach other subject as well; their academic qualifications while the last asked them to talk about their lesson plans and how they would conduct the lesson.

The following specific prompts within categories of PCK adapted from Loughran, Berry and Mulhall (2012) and Mthethwa-Kunene (2014) were used to analyse the teachers' description of their lesson plan;

What is (are) the concept or big idea to be taught in this lesson?

What do you want the students to know about this idea?

Why is it important for students to know this?

What else do you know about the concept, which you do not intend your students to know yet?

What teaching procedures are you going to use to teach this concept and what are your particular reasons for using these to engage with this concept?

What difficulties/limitations are connected with teaching this idea? (Loughran et al., 2012, p.17)

The experiential nature of PCK, which does not make it easy for teachers to explain, could in a way impede the effectiveness of interviews in assessing PCK (Kapyla et al., 2009). Interviews, therefore, should be interlaced with other methods, such as lesson observation as lesson observations often reveal the association between what the teacher thinks and what he practises in the classroom (Kapyla et al., 2009).

3.4.2 Lesson observation schedule

In order to explore participating teachers' content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties as set out by the study, a semi-structured lesson observation schedule was employed.

In this study, the schedule was developed based on the standard requirements for normal classroom practice by the Ghana Education Service (GES), the regulatory body for pre-tertiary institutions in Ghana. The Ghana Education Service code of conduct for teachers (GES, 2021) requires all pre-tertiary teachers to plan and prepare relevant and adequate daily lesson notes of all lesson that would be taught prior to the commencement of the lesson. The teacher lesson notes should contain basic minimum information such as; the date of the lesson, the period, and the name of the class; the topic or activity to be dealt with; the books and teaching and learning materials to be used; the activities to be carried out by the teacher; all learner activities; evaluation questions and these must be systematically arranged in the notebook (GES, 2021).

This notebook should be presented to the head of department for vetting and approval before the start of the lesson.

The schedule focused on the concepts of thermal physics content that were taught, teacher explanations and teaching approaches, as well as activities carried out in class. Special attention was paid to; the prior knowledge teachers had of their learners' pre-conceptions, if any, of the lesson topic; the strategies used in classroom teaching to identify learners' preconception or leaning difficulties and how these learning difficulties were handled. What the learners said, the clarifications they asked for, their requests for more explanations, and their answers to their tasks were taken note of.

The observation guidelines sought to pay attention to; lesson objectives; learners' prior knowledge of the concept being taught; lesson introduction; content presented and how it was presented; learners' preconceptions; learners' difficulties; teaching strategies and activities; presentation of lessons (the blend of content and pedagogical knowledge); learner's involvement; conclusion of lesson and evaluation questions (Appendix D).

The data from the observation schedule were categorised into the three PCK components, as defined, as content knowledge of the concept thermal energy, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties. Specifically, content knowledge was assessed through the content taught, pedagogical knowledge through the lesson objectives, and instructional strategies used and knowledge of learners' preconceptions and learning difficulties through lesson plan and teacher probing activities and learners' response to feedback. Lesson observation has been used for similar purposes in other studies (e.g. Brown, Friedrichsen & Abell, 2013; Ijeh, 2012; Mthethwa-Kunene, 2014; Ijeh & Onwu, 2013; Rollnick et al., 2008).

3.4.3 Post-observation interview schedule

In this study, information on how these physics teachers developed their PCK, namely, content knowledge of thermal energy, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties in the context of teaching the concept of thermal energy was tapped by the use of semi-structured post-lesson interview schedule (Appendix E). In the course of development of this interview schedule, some findings from researchers such as Ijeh (2012), Van Driel, De Jong, and Verloop (2002) and Mthethwa-Kunene (2014) were used to guide the construction of the questions. In order to get an insight into their PCK, the participants were made to answer questions bordering on the courses that they read in university, sources of knowledge in teaching this concept, teaching experience, continuing professional development sessions they had had and collaboration and the nature of academic interactions they had with colleagues in their department. The questions were categorised based to the PCK components of the study, thus; content knowledge, instructional strategy, learning difficulties and professional developments. A lot of researchers (Ijeh, 2012; Mthethwa-Kunene, 2014; Rollnick et al., 2008) adopted this approach to grouping interview questions.

The first question touched on teachers' educational background to ascertain if the teachers' formal education and the courses they read at university contributed to their ability to better teach the concept of thermal energy, hence leading to the development of teachers' content knowledge and knowledge of instructional strategies. The next question posed to teachers was about the years of experience in teaching physics to determine if this had influenced their classroom delivery. Teachers' views were solicited in questions 3 and 6 about the effectiveness of their general physics lessons and the instructional strategies they always use in solving learners' learning problems. Teachers' knowledge of their students' learning difficulties in course of learning the concept of thermal energy was captured by questions 4 and 5 of the interview schedule while items 7 and 8 sought information about the influence of continuing professional development sessions on development of teachers' PCK.

3.4.4 Document analysis

In this study, for the purpose of triangulating data from lesson observations and interviews, document analysis was done, using various documents that contributed to the profiling of teachers' PCK. The documents included the West African Examination Council's physics syllabus (WAEC, 2017) physics textbooks being used, handouts such as instructional support materials that the teachers provided to learners, and the learners' notebooks and class exercise books. These documents were analysed to determine the teachers' compliance with curricular recommendation for teaching thermal physics at senior high school level.

Curriculum document review gave an indication that teacher participants were going by policy guidelines and recommendations for teaching and learning in terms of their teaching approaches and assessment procedures or otherwise. These six selected physics teachers, individually prepared lesson notes for each lesson, as expected of all teachers in pre-tertiary public schools (GES, 2021). So, as it was in the case of this study, each of the six teachers had to prepare weekly lesson plans for teaching the concept of thermal energy. The teachers' lesson plans and PowerPoint slides were analysed to find out the contents that were taught, the instructional strategies and activities that teachers used in teaching the concept and if any, of learners' preconception and learning difficulties were identified.

3.4.5 Video-recording

In the course of teaching the concept of thermal energy, the participating teachers' lessons were video-recorded. These video-recordings were purposively done to triangulate the data gathered from the lesson observations. The video transcripts were used to explore the participants' content knowledge and how that knowledge was used in classroom practice, as well as the instructional strategies the teachers demonstrated in teaching the concept of thermal energy. In order to promote discussion and reflection of participant's lessons, video clips were used during pre-lesson and post-lesson interviews. These discussions were design to corroborate the researcher's interpretations of observations made during lessons.

3.5 Validity

For a research to have high quality, it should have increased validity. Cohen et al., (2018) indicated that, a lot of things that raise the quality of a research, among them are, clear research purpose and research questions, correct choice of methodology, validity, characteristic examples, and detailed descriptions. On the same breath, Bryman (2012) indicated that validity is an important quality criterion of a good research. Though validity and reliability are considered important in assessing research quality, many have questioned their relevance for qualitative since they seem to be more applicable to quantitative research (Cohen et al., 2018).

The study made use of several techniques so as to meet the high quality standard of trustworthiness in terms of validity (Creswell, 2008). The validity of the study was enhanced mainly through triangulation. Different data collecting approaches, including interviews, observation and document review, were used to meet the high credibility standard of the findings and to ensure consistency of results with the data (McMillan & Schumacher, 2010; Merriam, 2009). The processes of validation and piloting were used to improve the validity of the study.

3.5.1 Validity of teacher pre-observation interview schedule

In this study, the completed pre-observation interview schedule (ref. 3.4.1.) was given to three physics experts to content-validate using the provided set of criteria. The specialists were asked (Appendix G) to comment on the clarity of the interview items and indicate if they are suitable enough to be used to assess the physics teachers' demographic information which was needed to create their general profiles, content knowledge, knowledge of instructional strategies, and knowledge of learners' preconception and learning difficulties. The three physics experts, one a tutor in one of the colleges of education and two university lecturers, were made to assess the content validity of the schedule prior to its use in the pilot study. They all hold PhD degrees in physics education. One lecturer is a veteran physics education professor. All three experts are experienced researchers who have been teaching in their institutions for more than ten years and have published a lot of articles in refereed journals. The experts worked independently of each other to scrutinise the instruments. Additionally, the experts were asked to note grammatical errors. The reviewers' comments and suggestions were noted before the schedule was used in the pilot study. This process was used to improve the validity, hence ensuring that the study contained the necessary information for assessing the demographic information, content knowledge, knowledge of instructional strategies, and knowledge of learners' preconception and learning difficulties.

3.5.2 Validity of lesson plan and lesson observation schedule

The physics experts were again tasked to validate the developed lesson plan and lesson observation schedule (ref. 3.4.2). The task of the physics experts was to determine if the lesson plan and observation schedule contained adequate and relevant information to assess normal classroom practice in accordance with Ghana Education Service curriculum and policy guidelines (Appendix H). The reviewers, after scrutiny confirmed that the schedule contained the requisite information to assess normal classroom practice and was designed in line with the provisions of Ghana Education Service curriculum.

3.5.3 Validity of post-lesson interview schedule

In this study, the focus of the semi-structured post-lesson interview schedule (Appendix F) was to explore the educational background that might have contributed to the development of physics teachers' PCK in teaching the concept of thermal energy. The three physics experts were once again made to validate the interview schedule (ref. 3.4.3) using the prescribed criteria (Appendix I). The experts worked independently of each other in scrutinising the instrument to determine if it had the needed information to explore the participating teachers' educational background for developing PCK. Even though the reviewers' responses unanimously indicated that there was adequate and requisite information for assessing how the participating physics teachers developed their PCK in teaching this concept, there were some few grammatical issues which were taken care of.

3.6 Pilot Study

Within the constraints of a school setting, a pilot study was done with the purpose of improving, validity of the instruments and the practicability of administering the research instruments (Cohen et al., 2007).

Apart from testing the validity of the research instruments, pilot studies are useful in testing the clarity and comprehensibility of the instruments' items and instructions given to participants; getting feedback on the design and methodology; assessing the logistics feasibility of administering the research instruments and improving on the procedure for the main study, when it becomes necessary (Cohen et al., 2007).

In this study, three willing physics teachers from the least of the top three senior high schools which consistently had their names repeated from 2017 to 2021 in the sample selection process (ref. 3.2.2) participated in the pilot study. The teachers were purposely selected based on the good performance of their school in physics in WASSCE for at least five years. All three teachers hold a Bachelor of Science Education degrees with physics as their major subject. They have been teaching the physics curriculum for more than eight years and their school has obtained consistent credit pass rates of at least 70% in physics for at least five years.

The researcher sought permissions to carry out the study in the selected pilot school and obtained them from regional education office (Appendix A) and the school headmaster (Appendix J). The teachers agreed to sign letters of consent (Appendix K), which explained to them the purpose of the study, the roles they were expected to play, their right to freely participate or withdraw from the research process, as well as confidentiality issues. These research instruments; pre and post-lesson interview schedules; lesson plan schedule and lesson observation schedule were administered to the pilot participants after they (instruments) had been validated by the three physics experts. The teachers were asked to note the time taken to answer the questions, and to be open enough to pass comment on the clarity of questions and grammatical errors identified.

The pilot participants wrote lesson notes on the concepts of thermal energy as has been the practice. The teachers designed the lessons to be taught on the physics periods as scheduled on the school timetable and they were not restricted to any source of information. Prior to the commencement of the observation, copies of the lesson plans were taken for assessment and analysis. The researcher took time to assure the pilot participants of confidentiality of data and findings. The pilot participants were then interviewed individually using the pre-lesson interview schedule before the lesson observations to ascertain the content they intended to teach and how they planned to teach it. The interviews were audio-recorded for future reference. The teachers were observed teaching their lessons on the concept of thermal energy. Creswell (2008) indicated that classroom observations could provide the platform to record information as it occurred in the classroom while studying the behaviour of the participating teachers to determine their PCK in teaching the concept. Classroom observations, provided first-hand information about what the teachers knew and how they taught the concept of thermal energy in their classrooms. The researcher played the role of a non-participant observer while sitting at the back of the classroom to avoid unnecessary disruptions. Every bit of the lesson observations was video-recorded to provide comprehensive information of what took place in the classroom. These videos were later played back repeatedly for recall of detail (Berg, 2001; Flick, 2009). Brief discussions with the pilot participants designed to tap more information and clarification of some emerging issue on what had transpired during the lessons was organised just after the lesson observations. Individual face-to-face teacher post-lesson interviews were carried out using the post observation interview schedule (ref, 3.4.3; Appendix F) to determine how the teachers developed their PCK. Similar pilot studies were conducted by Mthethwa-Kunene (2014), Ijeh (2012) and Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, (2008) in their quest to investigate teacher PCK development.

Findings from the pilot study were used to improve the research process and to revise the items of the instruments. The findings were also used to establish the approximate duration of each instrument by finding an average of the period taken by the three pilot teachers. The administration of the instruments presented the opportunity to check for logistics problems that might pop up during the main study. Issues of arrangement of convenient time for post-observation interview came up as some teachers looked too tired to grant interviews. This practical problem necessitated arrangement of suitable time at the end of lesson observation period after taking a short break. It was established that the pre-observation interview needed an average of 30 minutes, while the post-observation interview required 45 minutes. The average duration determined was used to guide the main study. The comments made by the pilot teachers were considered and further factored into the review of the schedules before being used for the main study.

3.7 Administration of the Main Study

The six sampled senior high school physics teachers of Volta Region, Ghana participated in the study. The main study was administered using the same approach as the pilot study. The validated and piloted research instruments (pre-observation interview schedule, lesson plan and lesson observation schedule, post-observation interview schedule, and document analysis) were administered to the participants. On agreed dates, as supported by the school timetable, a total of four (4) double-period lessons for each participant were observed by the researcher in two weeks. This number of lesson observations was done based on certain factors:

(1) The study focused on teaching thermal physics: heat energy, temperature, thermometers, thermal expansion, transfer of heat, heat capacity and latent heat because they were seen to be crucial and involved so much thinking, analysis, huge calculations and application of knowledge. This is one of the concepts according to WAEC physics chief examiner, learners find difficult to learn and understand (WAEC, 2019).

(2) The scope of this topic could only allow maximum of two weeks' duration (4 double-periods).

(3) The lesson observations were prefixed and post fixed with in-depth interviews and other data collecting sources such as analysis of lesson plans. This two-week engagement would not get the teachers overwhelmed.

(4) The two weeks' lesson observation is considered sufficient for a case study as was done elsewhere by Ijeh (2012) and Mthethwa (2014). Researchers for instance, Rollnick et al. (2008) in exploring science teachers' PCK of mole and stoichiometry, did at least two lesson observations for each of the two teacher participants.

Prior to the commencement of each of the four lesson observations, the physics teachers prepared a lesson plan and were interviewed on the content and strategies highlighted in their plans. These interview sessions were audio-recorded. The teachers were observed teaching their lessons on the concept of thermal energy. The researcher played the role of a non-participant observer while sitting at the back of the classroom to avoid unnecessary disruptions. Every bit of the lesson observations was video-recorded to provide comprehensive information of what took place in the classroom. The interviews were conducted with the participants to tap more information and clarification of some emerging issue on what had transpired during the lessons, just after the lesson observations. At the end of the two-week period, the teachers were interviewed once again to determine factors that might have contributed to the development of their existing PCK in teaching the concept of thermal energy.

3.8 Data Analysis Procedures

Since the study employed qualitative method and case study design, qualitative data analysis approach was chosen. Qualitative data analysis involves organising, accounting for and explaining the data (Cohen et al.,2007) thus, interpreting data so as to project the participants' definitions of the situation, identifying patterns, themes, categories and regularities. Mouton (2001) in similar vein, describes qualitative data analysis as a process of bringing order, structure and meaning to the data collected by breaking it up into manageable themes, patterns, trends and relationships.

In this study, data gathered from various instruments were analysed as follows;

- For easy access during analysis and write-up of the findings, data were given pseudonyms and organised according to the participating teachers.
- To obtain accurate and comprehensive records of the conversations and observations, all audio and video recordings of the interviews and lesson observations were transcribed verbatim by the researcher.
- Notes from review of documents of participant teachers' response were personally typed by the researcher.
- To get a clear and distinct idea of what the participating teachers said, data were read severally and recordings listened to repeatedly.

- Predetermined categories of content knowledge, pedagogical knowledge and knowledge of learners' preconceptions and learning difficulties were used to code data to obtain each participating teacher's PCK profile and the way it was deemed to have been developed. This approach had to do with reading and comparing teachers' responses to questions about each of the aspects of PCK from each of the used research instruments for triangulation.
- To identify common patterns, similarities and differences the participant teachers' PCK profiles were compared.

3.9 Ethical Considerations

Ethics are very important in research and all research studies should consider certain ethical principles namely; autonomy, non-maleficence and beneficence (Bertram & Christiansen, 2014).

In this study, in order to adhere to the principle of autonomy (Bertram & Christiansen, 2014) which refers to respecting the participants and obtaining their voluntary consent, permission to conduct the study was obtained from the University of Education, Winneba (Appendix L). Getting access to the schools, permission was sought and obtained from regional education office of Ghana Education Service (Appendix A) and the heads of the schools (Appendix B & U). Informed consent was sought from the selected teachers. Through a letter of consent (Appendix M), the purpose of the study was declared to the participant teachers without deception and informed consent was sought. In addition to this, the participants were also made to know of their rights of voluntary participation and withdrawal from the study at any stage. This made the researcher earn the participants' supports. The letter indicated to the participants the approximate time and what was expected of them in terms of data collection and the plans for using the results (Creswell, 2008). The letter asked for participants' consent to audio and video-record interviews and lessons respectively.

For confidentiality, pseudonyms were used to identify the schools and participants, and label audio-recordings, video-recordings, field notes and transcriptions, and similarly, in analysing and reporting data. At the tail end of data collection process, the researcher thanked the teachers for participating in the study as this satisfied the issues of non-maleficence (Bertram & Christiansen, 2014).

The participants were assured that the audio and video recordings would only be used by the researcher to cross-check the transcriptions and reflect on the teachers' performance during data analysis and would not be published. The participant benefited as they had the opportunity to reflect on their lessons in terms of knowledge of learners' preconceptions, learning difficulties, and pedagogical skills and practices using video shots. The reflections were reciprocity and might have helped teachers address the challenges faced in the teaching and learning the concept since it promoted beneficence (Bertram & Christiansen, 2014).

3.10 Summary

This chapter provided a detailed account of the research methodology used and all the approaches that went with it, which included; qualitative method and a case study design. The population and sampling procedure outlined all the steps taken to select the six participating physics teachers whose schools were performing well in WASSCE within the selected period of 2017 to 2021 in spite of the declining performance of other public schools. The data collection instruments and the procedure for developing and validating the research instruments were discussed in detail. The purpose of the pilot and its outcome were used to set the stage for the administration of the main study. A description of the data analysis was provided. This chapter also justified the choice of the topic 'the concept of thermal energy' for this study. To conclude, ethical considerations and trustworthiness of the research were also explained. The succeeding chapter presents and discusses the data collected.

CHAPTER FOUR

RESULTS OF THE STUDY

4.0 Overview

This chapter presents the results and findings of classroom observations, interview schedules and related documents. The presentation includes how the case teachers' presumed pedagogical content knowledge was used in the teaching the concept of thermal energy. The results of the study are presented beginning with teachers' demographic information. The case profiles presented are based upon multiple data sources including observations of participants teaching lessons on the concept of thermal energy, semi-structured interviews conducted prior to and following observations, researcher field notes, and teacher lesson plans and other classroom artefacts associated with the lessons. The chapter concludes with the chapter summary.

4.1 Teacher Demographic Profile

A total of six male teachers were made to participate in this study. The participant teachers were referred to by pseudonyms as Ben, Kalulu, Carl, John, Daniel and David. The demographic profiles of the six teachers are presented in Table 3.

Table 3. Teachers' Demographic Profiles

Teacher	Qualifications	Number of years teaching physics	Subjects taught	Class or level
Ben	B.Ed. (Physics)	20	Physics and Int. Science	1-3
Kalulu	B.Ed. (Physics)	15	Physics and Int. Science	1-3
Carl	B.Sc. (Physics) and PGDE	12	Physics and Int. Science	1-3
John	B.Ed. (Physics)	13	Physics and Int. Science	1-3
Daniel	B.Ed. (Physics)	15	Physics and Int. Science	1-3
David	B.Ed. (Physics)	16	Physics and Int. Science	1-3

From Table 3, all six teachers who took part in the study, had a minimum degree of Bachelor of Science with physics as their major subject and they have since been teaching it. The minimum teaching qualification of professional teachers at the senior high schools is a Bachelor's degree in Education designed in the appropriate subject(s) for that level, or a BA/BSc (in a teaching subject) in addition to a post-graduate diploma in education (PGDE) or its equivalent (MOE, 2012). The teachers, therefore, have the basic teacher qualification as acclaimed by GES and have their teaching experience ranged from 12 to 20 years. Since they all have been teaching for at least ten years, they could as well be regarded as experienced teachers. According to Morrison and Lederman (2003), experiences of teachers in diagnosing and addressing students' preconceptions and learning difficulties in science class is key.

Finding 4.1

Five teachers out of six have Bachelor of Science Education degree and the remaining one has a minimum degree of Bachelor of Science and PGDE in accordance with GES teacher qualification recommendations. Elective physics is their major subject and they have their teaching experience ranged from 12 to 20 years. So they are qualified and experienced physics teachers.

4.2 Pre-observation Teacher Interview

One item, in the pre-observation teacher interview schedule, required the participants to individually discuss their lesson plans and describe how they intended to present their lessons on the concept of thermal energy. This question was asked with the intention of assessing their subject matter content knowledge, knowledge of instructional strategies, and knowledge of learners' preconceptions and learning difficulties (Appendix C). The recorded interviews were transcribed verbatim by the researcher and transcripts were analysed based on the three components of PCK.

4.2.1 Content Knowledge

In the interviews, the teachers stated the aspects of concepts of thermal energy they intended to teach and what they wanted their learners to know about those concepts. John, Ben, Carl and David stated that they had planned first to explain heat as form of energy, temperature and its SI unit after which they would discuss thermometers. They would then continue to teach the concept of thermal expansion, modes of heat transfer and conclude with measurement of heat which involved some calculations involving specific heat capacities and latent heat. Carl however indicated that he would not be bordering his students with details when it comes to modes of heat transfer since the syllabus did not state that details should be taught. These teachers indicated that they would end these concepts with their related real life applications.

Kalulu and Daniel however stated that, they would start with getting them to define thermal energy and stating the possible sources of heat energy. Kalulu and Daniel indicated that they would teach them the concept of temperature and temperature scales after which they would discuss the thermometer and their types with them. These two teachers stated that they would get the students to state the differences between heat and temperature after which they would take them through the applications of these concepts in real life situations. Kalulu and Daniel would then continue to teach the concept of thermal expansion and its life applications, modes of heat transfer (conduction, convection and radiation) and conclude with measurement of heat which involved specific heat capacities and latent heat. These two teachers indicated that they would bring life application of each sub-topic after teaching it.

The next item in the interview schedule required teachers to state their reasons why they deemed it important for their students to know what they planned to teach them. All the teachers responded by saying that these concepts are part of the elective physics syllabus and since they are there they had no option but to teach them. They again stated that the students needed to understand the world around them and should be in position to explain the effect heat energy has on objects. Ben and David added that as growing scientists, the students needed to understand what happens to objects when they gain or lose heat and should be able to give meaning to every scientific occurrence in science since scientists hold the believe that the world is knowable. Carl and John added that getting them to understand these concepts will give them strong foundation for their future studies in university and beyond.

One other pre-observation question asked the teachers was about what else they knew about the concepts that they did not intend to teach their learners. In all, the teachers' responses indicated that the teachers knew a lot more content than they were required to teach senior high school elective physics students. Ben and David for example referred to knowledge of the kinetic theory of gases. Kalulu, Daniel and John said they could extend the topic by teaching molecular interpretation of temperature. Carl indicated some aspects of thermometry and thermocouple as part of his knowledge of thermal physics.

Finding 4.2.1

The finding indicated that all six teachers knew a lot more content than they were required to teach senior high school elective physics students. Carl however indicated that he would not be bordering his students with details when it comes to modes of heat transfer since the syllabus did not indicate the need for details.

4.2.2 Knowledge of Instructional Strategies

One of the questions in the pre-observation interview schedule required teachers to state teaching procedures they would use and give reasons for their chosen procedure. Ben, David and Daniel indicated that, experience has thought them the tricks of asking students to do some advance reading on the topic before coming to class. These three teachers stated that this is done to prepare the students' mind prior to the lesson delivery, and they ensured that students do some reading on the topics by assessing them at the beginning of the lesson. Sometimes, Ben would ask his students to do presentation on what they had read. This, according to Ben would give him some indication of the areas in which they have misconceptions or difficulty in grasping the concept of thermal physics.

David, Carl, Ben and Kalulu however stated that they would use familiar contexts to arouse interest to introduce the lesson as they begin from the known and gradually move to the unknown. All six teachers would ask the students to explain what they understand by the term 'thermal energy'. John would further ask students to explain what they think is the science behind hot objects getting cooled. All six teachers would then explain the concept thermal energy, clear any misconception that they have found in the students' idea of thermal energy and introduce the learners to the new concept as they explain how cold and hot objects attain thermal equilibrium. The teachers indicated the need to organise practical lesson for the learners later to do investigation about some concepts.

Carl preferred using to a large extent, lecture method to teach because according to him, it is quicker and it offers the platform to cover more topical areas. All six teachers stated that they would use illustrations and diagrams to explain the concepts. Kalulu, John and Daniel stated the importance of illustrations and video simulations to help learners conceptualise abstract topics. John held the view that, without the use of teaching and learning materials and some basic experiments, it would be difficult for students to understand this concept of thermal physics. With regards to teaching the concept of temperature scale, Kalulu, Daniel and David stated that they had given students assignment to read around the topic in their textbooks and handouts and attempt to answer questions about the topics to be taught. At the beginning stage of the next lesson, they would discuss and review the assignment and address learners' difficulties identified in the course of marking their assignments. Ben, David and Daniel would sometimes start their lessons by reviewing the previous lesson by the use of questioning techniques if it is a continuation of what they had started, otherwise, they would start with an appropriate relevant previous knowledge. All six teachers indicated in their statements that they would use illustrations, scientific charts and diagrams to help learners visualise and understand the concept. In addition, Ben, David, Kalulu, Daniel and John indicated that they would use good and frequent oral questioning techniques for immediate feedback, class works and assignments to assess students' understanding of the concepts being taught.

Finding 4.2.2

With regards to instructional strategies, the teachers had planned to use different teaching approaches and procedures for different reasons. Topic specific strategies included prior reading, presentations and peer teaching for Ben, David and Daniel; illustration for Kalulu and John and demonstrations and examples for Carl. Ben, Daniel and David used frequent oral questioning techniques to get immediate feedback. The teachers indicated the need to organise practical lesson for the learners later to do investigation about some concepts.

4.2.3 Knowledge of Learners' Preconceptions and Learning Difficulties

In the write-ups of their lesson plans, the six teachers did not indicate anywhere the kind of preconceptions about the concepts thermal energy that students were likely to come to class with and if they had designed any classroom activities which could help clear them. It was only Ben and David, in their responses to one of the pre-observation questions stated that if they found some preconceptions in students' responses to reading assignment in the introductory stage of the lesson, they would clear them.

All six teachers stated that they would adopt good questioning techniques to ascertain the students' entry behaviour, level of understanding of the concept at all stages of the lesson. Ben, Kalulu, David and John would pay close attention to their responses to questions and outcomes of class exercises and home works.

In conclusion, the content of the lesson plans of the six teachers indicated that they focused on teaching 'the definition of thermal energy', 'explanation of thermal equilibrium', 'sources of heat', 'effects of heat on substance', 'temperature scale', 'methods of heat transfer' and 'measurement of heat energy'. All these sub-topics conformed to the provisions of the WAEC physics teaching syllabus.

Secondly, the six participating teachers used peer teaching, questioning technique, class and homework assignments, and illustrations including diagrams and charts to teach the concepts of thermal physics. None of the six teachers included in their lesson plans activities aimed at identifying learners' preconceptions and learners' learning difficulties. The WASSCE physics teaching syllabus, Ghana Association of Science Teachers' (GAST) physics textbooks for senior high schools and some other textbooks were listed as the main sources of information for the lesson delivery. The teaching objectives were derived mainly from the syllabus.

Finding 4.2.3

All six participating teachers would use peer teaching, questioning technique, class and homework assignments, and illustrations including diagrams and charts to teach the concepts of thermal physics. None of the six teachers included in their lesson plans activities aimed at identifying learners' preconceptions and learners' learning difficulties.

4.3 Lesson Observation

The analysis of lesson observations and results are presented through six case studies of six individual teachers: Ben, Kalulu, Carl, John, Daniel and David. Each case study includes an analysis of four thermal physics lessons taught by the respective teacher. All six teachers taught the same thermal physics topics, and the observation schedule (Appendix D) was designed to look out for; lesson introduction, content and how it was presented, teaching strategies and activities, the main lesson delivery, learner involvement, learning difficulties and post-lesson activities such as assigning homework. The analysis focuses on four thermal physics lessons, each lasting 60 minutes, taught by all six teachers to form 2 class at the senior high school. The lessons were observed on four separate occasions within the classroom setting. The video recordings of the lessons were used in conjunction with written observation notes in the form of triangulation to provide a comprehensive understanding of what occurred during each lesson.

4.3.1 Case 1: Description of classroom observations for Ben

4.3.1.1 Ben's Content Knowledge

Ben's lesson observation analysis indicates that he possesses the necessary content knowledge to teach thermal physics at the level observed. At the beginning of the lesson, he provided a clear definition of thermal physics, took the learners through the derivation of the SI unit of heat energy. He established the relationships among these concepts and linked them to related ones such as change in temperature and thermal equilibrium which happens to be the end point of heat transfer. Thus, teachers' content knowledge goes beyond just understanding a concept; they must also comprehend why it is so since it is an important subdomain of what the teacher requires for unique teaching (Ball, Thames & Phelps, 2008). In other words, teachers should possess not only factual knowledge but also a deeper understanding of the underlying principles and the relationships among different concepts. It was noticed in course of the observation that, Ben employed schematic diagrams and the use of realia to support some explanations. In addition, Ben used familiar examples and analogies of common objects that the learners encounter in their daily experiences to aid their understanding of these seemingly abstract concepts. In particular, Ben used the analogy of the red hot stone placed into in a metallic plate in an open space (Appendix P, first observation lesson line 2). By using this analogy, Ben facilitated the learners' comprehension of the complex concepts by presenting them in a simple and relatable context. Furthermore, Ben's practical illustrations also revealed the link between heat, temperature difference, change of state, water cycle and methods of heat transfer, helping to deepen the learners' understanding of the subject matter. (Appendix P, third lesson observation lines 1-3).

During the lesson observation, Ben encountered instances where the learners provided incomplete definitions of temperature in response to his probing questions (Appendix P, first lesson observation lines 5-6). In such cases, Ben corrected learners' responses by drawing upon his declarative knowledge, which refers to the teacher's knowledge of stating and explaining facts or theories included in the subject matter.

Once Ben had covered the fundamentals of thermal physics, including definitions, SI units, temperature scales, change of state and water cycle, he proceeded to link them to the methods of heat transfer and measurement of heat. In doing so, he used his procedural knowledge, which denotes knowledge of sequential and systematic presentation. Ben explained unit conversion, bimetallic thermometer, thermocouples, water cycle, land and sea breeze and thermos flask using diagrams (Appendix P, first lesson observation lines 4, 9-10: second lesson observation lines 21 and 23). Additionally, he used realias (Appendix P, first lesson observation line 8: second lesson observation line 10) to support his explanations and to emphasise the significance of these concepts. By doing this, Ben demonstrated his ability not only to describe thermal processes and its related concepts but also to explain their importance and relevance to learners.

Ben demonstrated yet another type of knowledge when some of the learners expressed difficulty in differentiating between different types of energy radiated by the sun as they stated that heat energy emitted by the sun supports photosynthesis (Appendix P, second lesson observation line 6). Specifically, he explained that even though the sun radiates both heat energy and light energy almost at the same time, they are two different forms of energies and it is sunlight that supports photosynthesis. This ability to explain concepts clearly helps learners to clear some doubts and misconception.

Finding 4.3.1.1

In terms of teacher content knowledge, Ben displayed adequate teacher content knowledge during his lessons. This was displayed in the ability to state and explain thermal physics concepts using straightforward facts and theories. Ben carefully and systematically explained the significance concepts taught. By demonstrating proficiency in all these areas, Ben exhibited a well-rounded and comprehensive understanding of the subject matter and an ability to effectively teach it to his learners.

4.3.1.2 ***Ben's Knowledge of Instructional Strategies***

Ben employed a specific instructional strategy for introducing new concepts, which involved assigning learners to read the relevant textbook material and present it to the class in the form of peer teaching. For instance, when teaching about sources of heat and effects of heat on substances (Appendix P, second lesson observation lines 4-27), the learners were tasked with reading ahead and making presentations in class. Following these presentations and subsequent discussions, Chinnici, Neth & Sherman (2006) argued that experiments and demonstrations can be beneficial in helping learners understand complex and abstract scientific concepts and processes especially when they are the ones providing the information with little assistance from the teacher. Ben employed a range of instructional techniques to enhance his learners' understanding of concepts of thermal physics, including the use of real materials like liquid-in-glass thermometers and electric water heater in a demonstration lesson to the class (Appendix P, first observation lesson line 8: second observation lesson line 10).

In addition, he used familiar contexts to introduce topics and made them more engaging, and frequently used questioning techniques to achieve instructional goals. Sometimes, he probed when he did not get the desired answers. One teaching strategy Ben employed to arouse the learners' interest and to get them actively involved in the lesson was frequent use of motivation (Appendix P, second observation lesson line 3: third observation lesson line 7). Occasionally, Ben would pick on learners who would not volunteer to answer question or make contributions in class. This teaching strategy got all learners almost all the time ready to contribute in class when picked on (Appendix P, second observation lesson line 30). However, some of his questioning techniques tended to focus on whole-class directed questions. These limited opportunities for individualised questioning, hence encouraging chorus answers which may be considered a weakness of his teaching strategy.

Ben, therefore displayed adequate knowledge of instructional strategy in his bit to teach this concept. This was showcased in introductory activities by teaching from known to unknown, his use of familiar situations, his demonstrations, proper use of teaching and learning resources, his probing questions and his questioning techniques. By demonstrating proficiency in all these areas, Ben exhibited a well-rounded and comprehensive pedagogical skills. He therefore has adequate instructional strategy to effectively teach this concept to his learners at this level.

Finding 4.3.1.2

Ben, displayed adequate knowledge of instructional strategy. Ben taught from known to unknown, used familiar situations, engaged students in group presentation. demonstrations, appropriate teaching and learning resources, probing questions and good oral and written questioning techniques. Ben made use of labelled diagrams. By demonstrating proficiency in all these areas, Ben exhibited a well-rounded and comprehensive pedagogical skills. He therefore has adequate instructional strategy to effectively teach this concept to his learners at this level.

4.3.1.3 *Ben's Knowledge of Learners' Preconceptions and Learning Difficulties*

Ben was able to identify learners' misconceptions and learning difficulties through their individual presentations. Ben's teaching strategy, which included the use of familiar situations, demonstrations, learner presentations, analogies, diagrams, and oral questioning techniques, exhibited a good profile of teacher content knowledge. However, his use of sometimes whole-class directed questions was not very effective in identifying individual learners' understanding and misconceptions.

Finding 4.3.1.3

The finding is that, Ben was able to gain insight into learners' misconceptions and learning difficulties primarily through their individual presentations and oral questioning during the lesson. However, there was no evidence that he had assessed learners' preconceptions and difficulties before the lesson.

4.3.2 Case 2: Description of classroom observations for Kalulu

4.3.2.1 Kalulu's Content Knowledge

During the lesson observation, Kalulu demonstrated that he possessed the necessary content knowledge to teach thermal physics to his senior high school students. He began by introducing students to the foundational concepts of heat energy, thermal equilibrium, SI units of heat energy, and thermometer and thermometry substances. He then guided learners through the measurement of heat and heat transfer, providing factual information about their effects and real-life applications based on his extensive declarative content knowledge (Appendix Q, first lesson observation lines 7; fourth lesson observation lines 5).

Kalulu employed systematic calculation of the quantity of heat involving specific heat capacity and latent heat, encouraging learners to participate in the process and asked questions to deepen their understanding. To aid learners in visualising abstract concepts, Kalulu used various instructional materials, including diagrams sourced from the internet and some he drew on the marker board and manila cards. For instance, he used these materials to help students understand seemingly difficult phenomena such as convection currents, land and sea breeze (Appendix Q, fourth lesson observation lines 8; third lesson observation lines 7).

Kalulu included the use of relatable, real-world examples to enhance learners' comprehension of thermal physics. Familiar examples such as room ventilation, car cooling systems, and refrigerators were used to demonstrate key concepts and encourage students to apply these ideas to their everyday experiences (Appendix Q, third lesson observation lines 6, 8). Additionally, Kalulu conducted practical demonstrations using electric coil heaters to heat water from the top and bottom of a bucket to reinforce understanding (Appendix Q, first lesson observation lines 6, 6).

On some occasions, students provided unsatisfactory answers to classwork and homework questions, which included incomplete or inadequate definitions of certain concepts, such as specific heat capacity and latent heat of vaporisation (Appendix Q, fourth lesson observation, lines 18, 20, 25). In such cases, Kalulu intervened and rectified the issue by drawing upon his content knowledge. Additionally, inaccurate responses that entailed suggesting methods to minimise heat transfer in a vacuum flask (Appendix Q, third lesson observation, line 29) was also corrected by the teacher (Appendix Q, fourth lesson observation, line 30). In this case, Kalulu used his procedural knowledge to address the issue and guided the students towards the correct answer.

Finding 4.3.2.1

Kalulu's teaching demonstrated his expertise in thermal physics and his ability to convey complex and abstract concepts in a clear and engaging way by presenting factual (declarative) information, systematic presentation of content matter. Kalulu explained relationships among concepts and led the learners to provide correct and adequate responses to their inadequate responses. Kalulu has demonstrated that he possesses adequate content knowledge to teach this concept.

4.3.2.2 Kalulu's Knowledge of Instructional Strategies

In the course of lesson delivery, Kalulu made use of variety of teaching strategies to engage and enhance the learning experience of his students. At the beginning of his thermal physics lesson, he employed the questioning technique, which is an effective way to get learners actively involved in the learning process. By asking questions about the familiar situation of heating food in the kitchen, he made the lesson more relevant and relatable, thereby capturing the learners' attention and arousing their interest.

To further enhance the learners' understanding of the lesson, Kalulu made use of illustrations, labelled diagrams and familiar situations (Appendix Q, third lesson observation lines 7, 11). By doing so, he not only stimulated their curiosity but also challenged them to think critically about the topic, thereby deepening their understanding of it.

In addition to these strategies, Kalulu also made use of written classwork and homework to assess how well the learners had understood the lessons (Appendix Q, first lesson observation line 11; fourth lesson observation lines, 21, 23). By doing so, he was able to provide feedback and identify areas where further clarification was needed. During classwork, learners worked individually and sometimes in small groups, which fostered a cooperative learning environment that encouraged peer-to-peer support and collaboration. This approach did not only help learners to develop their social skills but also promoted a deeper understanding of the subject matter.

Finding 4.3.2.2 Overall, Kalulu's teaching strategies were highly effective in promoting student engagement and enhancing the learning experience. By employing variety of teaching strategies and a range of techniques such as familiar situations, constructive feedback, illustrations, labelled diagrams and good questioning technique, Kalulu was able to cater to the diverse learning needs of his students and foster a supportive and collaborative learning environment that facilitated deeper understanding and knowledge retention. Kalulu explained how processes work and calculations are done and why they are important by providing justifications (procedural and conditional knowledge). Though Kalulu's questioning skills appeared good, they could not uncover learners' preconceptions as he was unable to probe.

4.3.2.3 Kalulu's Knowledge of Learners' Preconceptions and Learning Difficulties

Kalulu gave an indication that he understood the importance of recognising learners' preconceptions and learning difficulties in order to effectively guide their learning. In this regard, he made a conscious effort to identify and address the misconceptions and difficulties that his learners faced (Appendix Q, second lesson observation line 8; fourth lesson observation lines 18, 20).

Through marking their responses to classwork, Kalulu became aware of his learners' inaccurate conceptions and learning difficulties, including incomplete definitions of specific heat capacity and heat capacity. He realised that in order to effectively teach his students, he needed to address these misconceptions and difficulties directly.

To do this, he assigned his learners to read the relevant chapter in their textbook for homework, and to answer questions about the concepts to be taught prior to the lesson on modes of heat transfer. By marking their homework prior to the lesson, Kalulu was able to identify their misconceptions and difficulties, which he used as starting-off points in teaching the third lesson.

During the classwork and homework review sessions, Kalulu attempted to address his learners' difficulties through engaging with individual learners and facilitating collective class discussions. Kalulu provided personalised attention to each learner, using their specific difficulties as a basis for guiding their learning. This approach helped him to create a supportive and encouraging learning environment that allowed each learner to progress at their own pace.

Finding 4.3.2.3 Kalulu's knowledge of his learners' preconceptions and learning difficulties was derived through analysing and correcting their classwork and homework during the lessons. By monitoring his learners' progress, he was able to identify areas where they were struggling, and provided the necessary support to help them overcome their difficulties.

4.3.3 Case 3: Description of classroom observations for Carl

4.3.3.1 Carl's Content Knowledge

During the lesson Observations, Carl demonstrated that he had the necessary content knowledge to teach thermal physics at senior high school level. To initiate his lesson on heat energy, he engaged his students by prompting them to describe the direction of a flowing river relative to the topography of the land. Through this discussion, Carl successfully drew parallels between the flow of a river and the flow of heat energy. Eventually, he arrived at a concise definition of heat energy as the transfer of energy from regions of higher temperature to regions of lower temperature (Appendix R, first lesson observation line 3).

Throughout his instruction, Carl predominantly employed declarative knowledge (as described by Juttner, Boone, Park, & Neuhaus, 2013) to present factual information (Appendix R, first lesson observation line 4; third lesson observation line 7). When teaching about temperature scales and the effects of heat on substances, he focused on stating established facts using declarative knowledge. Subsequently, he proceeded to cover the topics of quantity of heat, including specific heat capacity, specific latent heat and concluded with modes of heat transfer. Carl did not seem to be delving into details by teaching the step-by-step stages of the processes. For instance, he defined conduction as the mechanism through which heat is transferred by direct contact, while convection was explained as the process responsible for heat transfer via fluid motion (Appendix R, fourth lesson observation lines 2,4). In each instance, Carl relied on declarative content knowledge to present facts and guide the learners in identifying real-life applications of the concepts taught (Appendix R, second lesson observation line 10; fourth lesson observation line 4).

Finding 4.3.3.1 In overall, Carl's content knowledge, as evidenced by his teaching approach, primarily comprised declarative knowledge as he duelled on familiar contents and situations. Carl did not seem to be delving into details by teaching the step-by-step stages of the processes but touched on their rationale and effect. This was attributed to the syllabus not requiring details of that concept. Carl demonstrated that he had the necessary content knowledge to teach thermal physics at senior high school level.

4.3.3.2 Carl's Knowledge of Instructional Strategies

Carl employed a number of teaching strategies to facilitate learners' understanding of thermal physics concepts. He made use of illustrations and relatable examples to explain key ideas. For instance, he incorporated diagrams from the learners' textbook to clarify concepts like conduction and convection (Appendix R, third lesson observation, line 11; second lesson observation, line 23). To enhance comprehension of modes of heat transfer, Carl used illustrations and labelled diagrams on cards, exemplifying phenomena such as land and sea breeze (Appendix R, fourth lesson observation, lines 3-4). Moreover, he used familiar examples like room ventilation and refrigerator cooling systems to illustrate convection currents (Appendix R, fourth lesson observation, line 4).

When introducing his lesson, Carl would either use a familiar context to arouse learners' interest or review the previous lesson to establish a link, before progressing (Appendix R, first lesson observation, lines 1-3; second lesson observation, lines 1-6). For instance, in his first observation lesson, Carl applied the teaching strategy of starting from the known to the unknown, drawing an analogy between the flow of a river (known to learners) and the flow of heat energy (yet to be known) (Appendix R, first lesson, lines 1-3). Carl also took time to explain the analogy in detail, following the recommendation of Treagust and Harrison (2000) that teachers should highlight the shared and unshared attributes between the analogy and the target concept for better student comprehension.

Carl predominantly adopted a teacher-centred teaching approach, relying on lectures as the primary method. Occasionally, Carl employed demonstration strategies, such as showcasing the 'change of state' using a piece of ice (Appendix R, second observation lesson, line 8) and showing to students some thermometers (Appendix R, first observation lesson, line 11).

Finding 4.3.3.2 Carl used diagrams and relatable examples to explain thermal physics concepts and engaged students with captivating introductions and often used familiar con-

texts to introduce new ideas. Employing analogies, he related known concepts to unfamiliar ones, emphasising shared attributes. Carl's teaching approach was predominantly teacher-centred, blending lectures with illustrations, diagrams and occasional demonstrations to enhance comprehension of complex topics. No teaching models were used and the questioning techniques employed by Carl did not probe for learning difficulties and preconceptions.

4.3.3.3 Carl's Knowledge of Learners' Preconceptions and Learning Difficulties

During the observed lessons, Carl appeared to lack awareness of the learners' preconceptions and learning difficulties. There was no indication that he possessed prior knowledge regarding the misconceptions or existing beliefs held by the students before the instruction commenced. This absence of understanding hindered his ability to effectively address and challenge the learners' preconceived notions.

Furthermore, Carl did not actively seek to elicit or uncover the preconceptions of the students during the lessons. Eliciting preconceptions involves encouraging students to express their initial ideas or beliefs about a topic before providing them with new information. By omitting this crucial step, Carl missed an opportunity to identify and address any misconceptions or knowledge gaps that the learners might have had.

Additionally, there was no evidence to suggest that Carl identified the specific learning difficulties faced by the students during the observed lessons. Learning difficulties can manifest in various forms, such as struggles with comprehension, problem-solving, or critical thinking. Recognising and addressing these challenges is vital for effective teaching and ensuring that all students can actively engage with the material.

The lack of awareness of preconceptions and learning difficulties limits the teacher's ability to tailor the instruction to the specific needs of the learners. By overlooking these important aspects, Carl missed opportunities to provide targeted support, clarification, and corrective feedback, which are crucial for facilitating deep understanding and meaningful learning experiences for all students.

Finding 4.3.3.3
Carl appeared to lack awareness of the learners' preconceptions and learning difficulties. There was no indication that he possessed prior knowledge regarding the misconceptions or existing beliefs held by the students before the instruction commenced and he did not actively seek to elicit these preconceptions and learning difficulties.

4.3.4 Case 4: Description of classroom observations for John

4.3.4.1 John's Content Knowledge

During the lesson observation, John demonstrated his proficiency in teaching thermal physics at that level through his display of necessary content knowledge. He began the lesson by imparting the fundamental concepts of heat energy, including the definition of heat energy, the SI unit of heat energy, and temperature scales. John's specified objectives aligned with the objectives of the physics syllabus. Leveraging his expertise, John established connections between these new concepts of heat energy and its S.I unit and previously taught concepts such as forms of energy, fundamental and derived units. This approach aimed to help learners recognise the connections between these ideas and concepts (Appendix S, first lesson observation line 1).

To explain concepts like thermal energy, quantity of heat, specific heat capacity, and modes of heat transfer, John relied on factual statements and used his declarative content knowledge (Juttner et al., 2013). For more challenging notions concerning the interrelationships among these concepts, John employed diagrams from textbooks and the internet to aid learners in visualising the practical and scientific foundations of these ideas. To enhance comprehension of modes of heat transfer, particularly convection currents, he drew upon familiar examples such as the usage of air conditioners and heating water on a stove (Appendix S, fourth lesson observation line 8).

During the lesson observation, John noticed that learners occasionally provided unsatisfactory responses to homework and formative oral questions, such as incomplete definitions of convection current and specific heat capacity (Appendix S, third lesson observation lines 5; fourth lesson observation lines 9). As a teacher, John rectified these issues by using his content knowledge, specifically his declarative knowledge.

In the sequence of his teaching, John proceeded from discussing thermal energy, quantity of heat, specific heat capacity, and the effects of heat on substances to addressing modes of heat transfer. In explaining the modes of heat transfer, he explained the processes of conduction, convection, and radiation, drawing on his understanding of how each process occurs and the respective mediums involved. This aspect of John's teaching can be referred to as procedural knowledge (Juttner et al., 2013). To illustrate the process of convection, John presented a chart depicting the occurrence of land and sea breezes, allowing learners to visualise how these phenomena lead to the cooling of the Earth's surface (Appendix S, fourth lesson observation line 9). He concluded his discussion on the process of convection by emphasising its significance in cooling the Earth (Appendix S, fourth lesson observation line 9).

Finding 4.3.4.1
John demonstrated his proficiency in teaching thermal physics at that level through his display of necessary content knowledge. He relied on factual statements and used his declarative content knowledge. Overall, John's content knowledge encompassed both declarative and procedural knowledge, displaying his comprehensive understanding of the subject matter. He emphasised the significance of the concepts taught. John’s specified objectives aligned with the objectives of the physics syllabus.

4.3.4.2 John's Knowledge of Instructional Strategies

Regarding knowledge of instructional strategies, John primarily employed the didactic 'chalk and talk method' in his teaching approach. This instructional strategy operates under the assumption that learners enter the classroom with blank slates, ready to absorb information presented as established facts. Throughout the lessons, John predominantly relied on direct instruction, delivering information to the students in a traditional lecture-style manner. However, it was noted that occasionally, John incorporated a questioning technique to encourage active participation and engagement from the learners (Appendix S, fourth lesson observation lines 1, 4, 6, 11). By soliciting examples and insights from the students, he aimed to stimulate their thinking and deepen their understanding of the subject matter.

In addition to the didactic method, John employed homework and assignments as a supplementary instructional strategy. Assigning tasks to be completed outside of class time allowed students to further practise and consolidate their knowledge. These assignments served as opportunities for students to apply the concepts they had learnt and develop their problem-solving skills. Furthermore, during subsequent class sessions, John dedicated time to reviewing and discussing the homework with the students. This approach allowed for feedback and clarification on any misconceptions or difficulties encountered by the learners.

Finding 4.3.4.2

By combining didactic teaching approach with periodic questioning techniques, homework, and their subsequent review, John aimed to create a balanced instructional environment that facilitated knowledge acquisition and encouraged active student involvement in the learning process. John used strategies such as familiar examples, diagrams and charts to support his lessons.

4.3.4.3 John's Knowledge of Learners' Preconceptions and Learning Difficulties

Regarding John's knowledge of learners' preconceptions and learning difficulties, there was no indication that he took into account the learners' pre-existing conceptions of thermal physics before the lesson. During the observed lessons, there was no evidence to suggest that he actively sought out or assessed the learners' preconceived notions of the concepts being taught. The absence of such consideration implies that John did not specifically address any potential misconceptions or prior knowledge that the students may have possessed related to thermal physics.

However, during the homework evaluation process, John did identify certain learning difficulties exhibited by the students. Notably, he noticed incomplete definitions of convection and specific heat capacity among the students' responses. Recognising these challenges, John made efforts to address the learners' difficulties by conducting a review of the homework within the classroom setting. This review session allowed him to provide explanations, clarification, and further guidance to the students, aiming to improve their understanding and rectify any misconceptions or incomplete understanding they might have had.

Finding 4.3.4.3

While John did not explicitly explore learners' preconceptions of thermal physics, his identification of learning difficulties during the homework and subsequent review indicated his responsiveness to the students' learning difficulties. John addressed these difficulties and sought to support the students in overcoming their learning difficulties and enhancing their overall comprehension of the subject matter.

4.3.5 Case 5: Description of classroom observations for Daniel

4.3.5.1 Daniel's Content Knowledge

Daniel demonstrated extensive content knowledge throughout his lessons. He effectively communicated fundamental concepts of thermal energy, temperature, and heat transfer, providing clear definitions and practical examples that clarified these abstract ideas. For instance, in the initial lesson, he explained thermal energy by comparing it to a hot cup of tea and how it transfers to the surrounding air (Appendix V, Lesson 1, Line 1), which made the concept more relatable for students. He accurately described heat energy as being measured in joules and kilojoules and discussed thermal equilibrium with appropriate examples, such as how heat transfers between objects until they reach the same temperature (Appendix V, Lesson 1, Line 4).

In subsequent lessons, Daniel showcased his understanding of temperature scales by detailing Celsius, Fahrenheit, and Kelvin, and explaining their practical applications and conversions (Appendix V, Lesson 1, Lines 5 and 6). His ability to illustrate the effects of heat on materials such as metal expanding when heated and ice melting into water (Appendix V, Lesson 1, Lines 7 and 8) further highlighted his strong grasp of the subject matter. In the third lesson, Daniel introduced the formula for calculating the quantity of heat and related it to everyday experiences, such as boiling water (Appendix V, Lesson 3, Line 3). Daniel's explanations of specific heat capacity, using examples like metals and water (Appendix V. Lesson 3, Line 5), demonstrated his comprehensive knowledge of how different substances absorb and transfer heat.

Additionally, Daniel effectively covered modes of heat transfer (conduction, convection, and radiation) in the fourth lesson. His demonstrations, such as heating a metal rod to explain conduction (Appendix V, Lesson 4, Line 7) and observing convection currents in fluids (Appendix V, Lesson 4, Line 8), showcased his deep understanding of these processes. By linking these concepts to everyday activities, such as cooking and heating systems (Appendix V, Lesson 4, Line 9), Daniel effectively bridged theoretical knowledge with practical applications.

Finding 4.3.5.1
Daniel exhibited adequate understanding of thermal energy, temperature, and heat transfer. He provided clear definitions, practical examples, and accurate descriptions that made abstract concepts more relatable and understandable for students. Daniel explained relationships among concepts and led the learners to provide correct and adequate responses to their inadequate responses. His comprehensive knowledge was evident in his detailed explanations of temperature scales, effects of heat on materials, and the modes of heat transfer. This deep content knowledge enabled him to effectively bridge theoretical concepts with real-life applications by presenting factual (declarative) information,

4.3.5.2 Daniel's Knowledge of Instructional Strategies

Daniel employed a variety of instructional strategies that facilitated student engagement and comprehension. He began each lesson by relating new concepts to familiar experiences, which helped students connect abstract ideas to their everyday lives. For example, he used the analogy of a hot cup of tea to introduce thermal energy (Appendix V, Lesson 1, Line 1) and linked temperature scales to practical uses (Appendix V, Lesson 1, Lines 5 and 6).

Throughout his teaching, Daniel used inquiry-based methods to encourage active learning. He asked questions to gauge students' prior knowledge and to guide their understanding, fostering a participatory classroom environment. His approach included addressing students' questions and facilitating discussions, which promoted critical thinking and deeper engagement with the material (Appendix V, Lesson 1, Lines 3 and 4).

Daniel incorporated demonstrations and hands-on activities to reinforce theoretical concepts. In the lesson on heat transfer, he performed experiments to visually illustrate conduction, convection, and radiation. These practical activities helped students grasp complex concepts by experiencing them first-hand. For instance, he used a heated metal rod to demonstrate conduction (Appendix V, Lesson 4, Line 7) and observed convection currents in different fluids (Appendix V, Lesson 4, Line 8), which provided tangible evidence of the principles being taught.

His use of real-life applications in examples and activities further enhanced the relevance of the content. By relating theoretical concepts to everyday experiences, such as cooking and heating systems (Appendix V, Lesson 4, Line 9), Daniel made the material more accessible and engaging for students. He also used group activities to promote collaborative learning, encouraging students to explore and present their findings on heat transfer modes (Appendix V, Lesson 4, Lines 12 and 13).

At the end of each lesson, Daniel summarised key points and assigned relevant homework to reinforce learning and provide additional practice (Appendix V, Lesson 4, Lines 14 and 15). This strategy helped consolidate students' understanding and allowed them to apply the concepts independently.

Finding 4.3.5.2

Daniel's instructional strategies effectively engaged students and facilitated comprehension. By connecting new concepts to familiar experiences, employing inquiry-based methods, and incorporating hands-on activities and real-life applications, he created a participatory and dynamic learning environment. His use of demonstrations, group activities, and relevant homework assignments reinforced theoretical concepts and promoted active learning and critical thinking among students. Daniel explained how processes work and calculations are done and why they are important by providing justifications (procedural and conditional knowledge). Though Daniel's questioning skills appeared good, they could not uncover learners' preconceptions as he was unable to probe.

4.3.5.3 Daniel's Knowledge of Learners' Preconceptions and Learning Difficulties

Daniel did not explicitly address students' misconceptions of thermal physics before the lessons, nor was there evidence that he actively assessed or sought to understand their prior knowledge. The lack of such consideration suggests that he did not specifically address any potential misconceptions or prior knowledge related to thermal physics. However, during the homework evaluations, Daniel identified learning difficulties such as incomplete definitions of convection and specific heat capacity. He addressed these challenges by reviewing the homework in class, providing explanations and guidance to help students improve their understanding (Appendix V, Lesson 4, Lines 14 and 15).

Finding 4.3.5.3

Daniel's knowledge of learners' preconceptions and learning difficulties was derived through analysing and correcting their classwork, homework and incorrect answers during the lessons. By monitoring the learners' progress, he was able to identify areas where they were struggling, and provided the necessary support to help them overcome their difficulties.

4.3.6 Case 6: Description of classroom observations for David

4.3.6.1 David's Content Knowledge

David demonstrated a deep understanding of content throughout his lessons. He effectively communicated core concepts of heat and specific heat capacity, providing clear definitions and practical examples to clarify these abstract ideas. For instance, he described the quantity of heat as the energy transferred between objects at different temperatures and used practical experiences like heating water to make the concept more relatable (Appendix W, Lesson 1, Line 4).

David clearly explained specific heat capacity as the heat required to raise the temperature of a unit mass of a substance by one degree Celsius. He used examples like metals and water to illustrate how different substances absorb and transfer heat differently (Appendix W, Lesson 4, Line 3). His thorough explanations underscored his strong understanding of the subject.

In the lesson on calculating heat quantity, David introduced the formula $Q=mc\Delta T$ and did some sample calculations with the class (Appendix W, Lesson 4, Line 5). His ability to explain the formula and guide students through practical examples, such as heating some amount of water, indicated his comprehensive knowledge of heat measurement.

Additionally, David effectively handled the modes of heat transfer—conduction, convection, and radiation. He used real-life examples to explain conduction (Appendix W, Lesson 3, Line 3), and described convection in heating systems (Appendix W, Lesson 3, Line 8). His explanations of radiation, including its role in solar energy (Appendix W, Lesson 3, Line 10), reflected his deep understanding of these processes.

Finding 4.3.6.1

David exhibited a good understanding of heat and specific heat capacity. He provided clear definitions, practical examples, and accurate descriptions that made abstract concepts more relatable and understandable for students. His comprehensive knowledge was evident in his detailed explanations of specific heat capacity, the effects of heat on materials, and the modes of heat transfer. This deep content knowledge enabled him to effectively bridge theoretical concepts with real-life applications.

4.3.6.2 David's Knowledge of Instructional Strategies

David employed a range of instructional strategies to engage students and enhance their understanding. He began each lesson by linking new concepts to prior knowledge, which helped students build on what they already knew. For example, he connected the quantity of heat to previous topics on thermal energy and temperature (Appendix W, Lesson 4, Line 1).

David used inquiry-based methods to promote active learning. He asked questions to assess students' understanding and guide their learning, fostering a participatory classroom environment. His approach included addressing students' questions and facilitating discussions, which encouraged critical thinking and deeper engagement with the material (Appendix W, Lesson 3, Line 3).

He also incorporated demonstrations and hands-on activities to reinforce theoretical concepts. In the lesson on specific heat capacity, he used examples and guided students through calculations to help them understand how to measure heat transfer (Appendix W, Lesson 4, Line 5). These practical activities allowed students to experience complex concepts first-hand.

David enhanced the relevance of the content by relating theoretical concepts to real-life experiences, such as heating water and cooking (Appendix W, Lesson 3, Line 6). He also used group activities to promote collaborative learning, encouraging students to calculate heat quantities and compare their results (Appendix W, Lesson 2, Line 7).

At the end of each lesson, David summarised key points and assigned relevant home-work to reinforce learning and provide additional practice (Appendix W, Lesson 1, Line 15; Appendix W, Lesson 2, Line 16). This approach helped consolidate students' understanding and allowed them to apply the concepts independently.

Finding 4.3.6.2
David's instructional strategies effectively engaged students and facilitated comprehension. By connecting new concepts to prior knowledge, employing inquiry-based methods, and incorporating hands-on activities and real-life applications, he created a participatory and dynamic learning environment. David, displayed adequate knowledge of instructional strategy. David taught from known to unknown, used familiar situations, engaged students in group presentation. demonstrations, appropriate teaching and learning resources, probing questions and good oral and written questioning techniques. David made use of labelled diagrams His use of demonstrations, group activities, and relevant homework assignments reinforced theoretical concepts and promoted active learning and critical thinking among students.

4.3.6.3 David's Knowledge of Learners' Preconceptions and Learning Difficulties

David identified learners' misconceptions and difficulties through individual questions. His teaching strategy, which included familiar situations, demonstrations, group work, analogies, diagrams, and oral questioning, showed a strong profile of content knowledge. However, his use of whole-class questions was less effective in pinpointing individual learners' understanding and misconceptions.

Finding 4.3.6.3

The finding is that, David was able to gain insight into learners' misconceptions and learning difficulties primarily through their individual questions and his own oral questioning during the lesson. However, there was no evidence that he had assessed learners' preconceptions and difficulties before the lesson.

4.4 Post-lesson Teacher Interview

In the post-lesson teacher interview which was designed to ascertain how the participating teachers developed or claimed they developed their PCK in teaching thermal physics at senior high school level, they were asked of the courses leant at university which might have helped them teach thermal physics.

All six teachers (Ben, Kalulu, Carl, John, Daniel and David) reported that during their Bachelor of Science programmes they had studied physics courses, which had given them content knowledge about thermal physics that was sufficient to teach senior high school physics. They also claimed to have done methods courses in their B.Ed. programmes (Ben, Kalulu, John, Daniel and David) and in Post Graduate Diploma in Education (Carl) programmes, which enabled them to use appropriate instructional strategies to adapt their good content knowledge to the senior high school level curriculum. They learnt how best to make the topics accessible to novice science learners. They claimed the content knowledge developed through university courses enabled them to explain thermal physics concepts and respond to learners’ questions during lessons.

Finding 4.4.1

University physics courses, according to all six teachers provided content knowledge while method courses provided appropriate knowledge of instructional strategies which helped them teach thermal physics.

In the post-lesson teacher interview participating teachers were asked how teaching concept of thermal physics over the years helped them teach the topic better, all six teachers confirmed its positive impact. They have gained awareness of the challenges learners face when initially introduced to thermal physics. This awareness has prompted them to modify their teaching methods accordingly. For example, Ben, Daniel and David incorporated group work and discussions, while Kalulu used written classwork exercises. Additionally, Ben employed peer teaching to facilitate group presentations (Appendix P, second lesson observation lines 11–12, 29), John used illustrations like charts and drawings to illustrate conduction and convection (Appendix S, third lesson observation line 5), and Kalulu incorporated written exercises during class (Appendix Q, second lesson observation line 29; third lesson observation line 12). The years of teaching thermal physics have contributed to the development of their Pedagogical Content Knowledge (PCK), which has evolved as they continued to adapt their teaching approaches.

Finding 4.4.2

Teaching experience impacted positively on the teachers' knowledge of content, instructional strategies and knowledge of learners' learning difficulties by making them teach better.

In the post-lesson teacher interview, the participating teachers were asked about how they assess the effectiveness of their current approach to teaching thermal physics

(Appendix E, item 3). All six teachers relied on various indicators, including learners' performance in tests and examinations, analysis of classwork and homework assignments, and feedback from the learners themselves. Ben, Daniel and David for instance, mentioned that they gauged the effectiveness of their teaching by observing improvements in learners' performance in external examinations compared to when they first started.

Finding 4.4.3 The teachers indicated that, they assess the effectiveness of their lessons through learner performance in classwork, homework, tests and examination.

When the teachers were asked to discuss the common learning difficulties faced by students in studying thermal physics and identified factors contributing to these challenges (see Appendix E items 4-5). Ben, and David identified several areas of difficulty among their learners, such as distinguishing between heat capacity and specific heat capacity, performing calculations involving specific heat capacity and latent heat, and accurately understanding temperature changes, particularly when substances are said to have lost heat. The teachers believed that the abstract nature of certain thermal physics concepts and the involvement of large numbers in calculations posed challenges for students, primarily due to their relatively weaker mathematical background.

Kalulu and Daniel mentioned that their students frequently mix up terms such as specific heat capacity and heat capacity, as well as specific latent heat and latent heat. They also struggle with solving calculation problems related to thermal physics. Kalulu and Daniel attributed these difficulties to the abstract nature of certain concepts in thermal physics and their inadequate mathematical foundation.

Carl noted that students often face challenges with thermal physics terminology and solving problems related to "quantity of heat." He believed that these difficulties could arise from both the teaching approach employed by the teacher and the mathematical nature of such problems, which involve calculations with large numbers.

According to John, learners commonly confuse various thermal physics terms, such as "thermal equilibrium," "convection and convection current," "specific heat capacity," "specific latent heat," and "thermocouples." They struggle to comprehend and effectively use these terms in their explanations. John attributed these challenges to the fact that these terms are encountered for the first time in thermal physics, as they are not taught at lower school levels.

Finding 4.4.4

According to teachers, students often encounter difficulties with the specific terminology used in thermal physics.

Students tend to misuse terms.

Students struggle to differentiate between some physics terminologies and sometimes incorrectly use some terms.

Students find it difficult to do calculations involving specific heat capacity and latent heat.

The teachers believed that these difficulties in learning thermal physics mainly stem from the abstract nature of the subject matter, unfamiliar nature of subject matter and students' inadequate mathematical background.

In the post-lesson teacher interview, as a follow up question, the participating teachers were asked what they do to help resolve the challenges faced by learners in the cause of learning thermal physics. They responded.

When Ben and David were asked to state what they do to help learners to understand thermal physics lessons, they indicated that, they responded to these difficulties by adjusting their teaching approaches, providing more practice opportunities and encouraging students to explain concepts to one another. To address these challenges, Kalulu and Daniel revisited parts of their lessons at a slower pace and have individual discussions with students to provide additional support. To address these issues, Carl mentioned that he reviewed tests and examination questions with the class to mitigate the difficulties. Additionally, he occasionally engaged in one-on-one discussions with individual students to provide further assistance. In the same vein, John claimed to assist learners by employing different teaching methods, assigning additional readings, take time explain these unfamiliar terms to them, providing extra practice exercises, and encouraging peer assistance among students.

Finding 4.4.5

The participating teachers employ various strategies, including changing their teaching approaches, providing individual attention, assigning additional reading, allowing peer support and giving room for more practice to address these learning difficulties.

The teachers were asked about their participation in physics teacher development workshops and the benefits they gained as physics teachers (see Appendix E items 7, 8). The purpose was to explore how these workshops might have contributed to the development of their PCK. All six teachers confirmed attending workshops organised by the Ghana Education Service (GES), their teacher unions (GNAT, NAGRAT), and subject union (GAST), with physics educators serving as facilitators. Although none of the workshops specifically focused on thermal physics, three teachers mentioned that they covered challenging topics for learners, such as nuclear and atomic physics, graph work, and thermal physics in general. However, Carl and David recalled a workshop that specifically addressed the calculation aspect of thermal physics concepts.

During these workshops, the teachers gained new insights and expanded their knowledge of teaching activities and strategies. For instance, Ben, David, Daniel, and Carl mentioned being taught how to source teaching and learning materials from the internet, a practice they all adopted. John and Kalulu learned how to incorporate illustrations and activities like simulation experiments, slide shows, and scientific charts to explain phenomena like land and sea breeze. The use of a chart depicting land and sea breeze in John's lesson (Appendix S, second lesson observation line 5) was learned from this workshop. The teachers also emphasised the valuable opportunities provided during these workshops to engage in discussions about teaching specific physics topics with their peers, which further enhanced their PCK development.

Finding 4.4.6

Although all six teachers have attended physics workshops dealing with different aspects of physics teaching. The teachers stated that they engaged in discussions about teaching specific physics topics with their peers, which further enhanced their PCK development. Ben, Dniel, David and Carl mentioned that they were taught how to source teaching and learning materials from the internet, a practice they all adopted. John and Kalulu learned how to incorporate illustrations, and activities like simulation experiments, slide shows, and scientific charts.

The teachers were asked about their participation in thermal physics-specific teacher development workshops and the benefits they gained as physics teachers (see Appendix E item 8). The purpose was to explore how these workshops might have contributed to the development of their PCK. All six teachers confirmed attending workshops organised by the Ghana Education Service (GES), their teacher unions (GNAT, NAGRAT), and subject union (GAST), with none of the workshops specifically focused on thermal physics.

Finding 4.4.7 Although all teachers have attended physics workshops dealing with different aspects of physics teaching, none of the workshops specifically focused on teaching thermal physics.

In the post-lesson teacher interview, the participating teachers were asked if they collaborate with other teachers in their department about teaching and if they do, how has that helped them.

To assess the impact of collaboration with departmental colleagues on the teaching of thermal physics (see Appendix E item 9), John, Daniel and David expressed that working with colleagues who had extensive experience in teaching thermal physics helped them better understand how to effectively present challenging topics, such as the concept of convection current. Thus, an experienced colleagues served as sources of PCK development for John, Daniel and David. Carl mentioned collaborating with his colleagues, although he noted that most of his less-experienced colleagues benefited from him in terms of teaching. Carl in turn, gained insights from his colleagues regarding the development of continuous assessment questions and procedures. On the other hand, Ben, Daniel, David and Kalulu mentioned that long service coupled with informal discussions with colleagues about teaching in general, rather than specifically focusing on thermal physics helped them teach better. John added that long service coupled with on the job learning over time helped him develop his PCK.

In addition to collaboration, the teachers highlighted other sources of PCK development for teaching thermal physics. These included recommended textbooks, curriculum documents (such as the WASSCE physics syllabus), and the Internet. These resources were primarily used during lesson preparation and provided the teachers with thermal physics content knowledge, simplified explanations for concepts, alternative illustrations, and examples.

Finding 4.4.8 All the teachers indicated that they collaborate with departmental colleagues but only one benefited from such sharing about teaching thermal physics. Ben, Daniel. David and Kalulu mentioned that long service coupled with informal discussions with colleagues about teaching in general, rather than specifically focusing on thermal physics helped them teach better. John stated that long service coupled with on the job learning over time helped him develop his PCK. All six participating teachers indicated textbooks, study guide and internet as their other sources of information mostly provided by the school.

4.5 Document Analysis

For the purpose of triangulating data from lesson observations and interviews, document analysis was done, using various documents that contributed to the profiling of teachers' PCK. The documents included, teachers' lesson notes, learners' exercise books and curriculum documents such as; the West African Examination Council's physics syllabus (WAEC, 2017), physics textbooks being used, handouts such as instructional support materials that the teachers provided to learners, and the learners' notebooks.

4.5.1 Lesson notes

Prior to the lesson observation, copies of teachers' lesson plans of the physics lessons being observed were collected for analysis to determine the accuracy of content knowledge displayed, teaching strategies that would be used as well as finding out what knowledge of learners' misconceptions and learning difficulties these participating teachers have.

4.5.1.1 Knowledge of content matter

On analysing the six participating teachers' lesson plans, all six teachers' lesson plans contained accurate information about the concepts on thermal physics that they were about to teach which may imply that they have knowledge about the content they were about to teach. John, Ben, David and Carl indicated that they would first explain heat as form of energy, temperature and its SI unit after which they would discuss thermometers. They would then continue to teach the concept of thermal expansion, modes of heat transfer and conclude with measurement of heat which involved some calculations involving specific heat capacities and latent heat. These teachers indicated that they would end these concepts with their related real life applications. Kalulu's sequence of content matter was however a bit different. He would start with getting learners to define thermal energy and stating the possible sources of heat energy. Kalulu and Daniel indicated that they would teach them the concept of temperature and temperature scales after which they would discuss the thermometer and their types with them. Kalulu stated that he would get the students to state the differences between heat and temperature after which he would take them through the applications of these concepts in real life situations. Kalulu would then continue to teach the concept of thermal expansion and its life applications, modes of heat transfer (conduction, convection and radiation) and conclude with measurement of heat which involved specific heat capacities and latent heat.

Finding 4.5.1.1 All lesson plans of the six participating teachers contained accurate and factual information about thermal physics in spite of the sequencing of the content

knowledge. The six teachers' lesson plans displayed that they all have adequate content knowledge on thermal physics.

4.5.1.2 Knowledge of instructional strategy

The analysis of the lesson plans of the six participating teacher sought to find out the type of teaching strategies employed, the lesson activities stated in the plan, the sequence of lesson delivery and if assessment activities aligned with objectives and skills set to be developed.

Ben, Daniel and David indicated that they would begin the lesson with questions after asking the learners to do some prior reading. From the lesson plan, the learners would be asked to come and do some presentations of what they read about the topic. Ben indicated in the lesson note that this strategy would give some indication of the areas in which they have misconceptions or difficulty in grasping the concept of thermal physics.

Carl, Ben, Daniel, David and Kalulu however stated that they would begin the lesson with very familiar and known questions like; 'What happens when you place water in a cooking pot on fire?' 'To which direction do rivers flow, in terms of their topography?' From this angle, it could be analysed that this approach is teaching from 'known and gradually move to the unknown'. All six teachers would ask the students to explain what they understand by the term 'thermal energy'. John would further ask students to explain what they think is the science behind hot objects getting cooled. All six teachers would then explain the concept thermal energy, clear any misconception that they have found in the students' idea of thermal energy and introduce the learners to the new concept as they explain how cold and hot objects attain thermal equilibrium. It is clear that 'question and answer' techniques are being used. From the activities indicated in the lesson plan, the sequence of the lesson delivery is systematic. Carl, to a large extent, used lecture method since there are very few questions indicated in his lesson notes. Carl would always be explaining to the learners. All six teachers stated that they would use illustrations, scientific charts and diagrams to explain the concepts. With regards to teaching the concept of temperature scale, Kalulu, Daniel and David stated that they would be giving students assignment to read around the topic in their textbooks and handouts. In addition, Ben, David, Kalulu, Daniel and John indicated that they would use good questioning techniques, class works and assignments to assess students' understanding of the concepts being taught.

In all, the teaching strategies indicated in the teachers' lesson plan appeared to be adequate for presenting the concepts in thermal physics. All these strategies indicated in lesson plans were also observed during lesson presentation. The teachers intended to approach the lesson activities was indicated in the lesson plan with the teachers' activities as well as the learners' activities stated. Some teachers (Ben, David, Daniel, Kalulu and John) specifically, indicated in their lesson plans that as part of their teaching strategies, they would first revise work that was done previously, explain and demonstrate how to use some procedures and approaches to teaching the concepts. They would then organise learners into groups and then monitor and assist learners in the various groups. The teachers' assessment activities were aligned with their objectives stated and skills developed. The six teachers' knowledge of teaching strategies of thermal physics was seen adequate.

Finding 4.5.1.2
The teaching strategies indicated in the teachers' lesson plan appeared to be adequate for presenting the concepts in thermal physics.
All these strategies indicated in lesson plans were also observed and their approach

to the lesson activities was indicated in the lesson plan with the teachers' activities as well as the learners' activities stated. The teachers' assessment activities were aligned with their objectives stated and skills developed.

The six teachers' knowledge of teaching strategies of thermal physics was seen adequate with the use some visual teaching and learning materials.

4.5.1.3 Knowledge of learners' preconceptions and learning difficulties

In the write-ups of their lesson plans, the six teachers did not indicate anywhere the kind of preconceptions about the concepts thermal energy that students were likely to come to class with and they did not design any classroom activities which could help resolve them. It was only Ben, in his lesson plan did indicate that the learners' group or individual presentations were likely to raise issues of preconceptions and learning difficulties. In his pre-observation interview, Ben stated that if he found some preconceptions in students' response to reading assignment and presentation, he would correct them.

Finding 4.5.1.3

All the six teachers did not indicate anywhere the kind of preconceptions and learning difficulties about the concepts of thermal physics that students were likely to come to class with and they did not design any classroom activities which could help resolve them.

4.5.2 Learners' exercise and notebooks

The analysis of the learners' notebooks belonging to the six participating teachers, namely Ben, Kalulu, Carl, John, Daniel and David, provided some insights into their teaching methods and the concepts they covered. The notebooks contained notes encompassing various aspects of thermal physics, including facts, definitions, descriptions, and calculations related to heat energy, temperature scales, effects of heat on substances, quantity of heat, and heat transfer. This indicated that the teachers pre-dominantly employed declarative content knowledge in teaching these concepts.

Further examination of Ben, David, Daniel, Kalulu, and John's learners' notebooks revealed that their notebooks included systematic steps outlining the processes of convection, convection current, and calculations involving quantity of heat. This suggested that these three teachers actually implemented procedural content knowledge while teaching the concepts they had planned to cover. Additionally, all six teachers' learners' notebooks featured illustrations and diagrams illustrating the occurrence of the phenomena of conduction, convection current, and land and sea breeze.

The learners' documents further indicated that five teachers (excluding Carl) used homework and assignments to assess the students' understanding of the thermal physics lessons. Kalulu and David also employed classwork for the same purpose. Marked learners' work from Ben, Daniel, David, Kalulu, and John's classes highlighted specific areas where students faced difficulties, such as providing accurate definitions of specific heat capacity and specific latent heat, as well as executing systematic and step-by-step calculations involving quantity of heat. In contrast, the review of learners' notebooks in Carl's class indicated that he did not assign any exercises in the form of classwork or homework.

The evaluation of learners' written exercises, again revealed that none of the six teachers employed any instruments in the form of appraisal forms or written comment to identify and address students' preconceptions regarding the thermal physics concepts being taught.

Based on the aforementioned analysis, it can be concluded that the six teachers taught the concepts of heat energy, temperature scales, effects of heat on substances, quantity of heat, and heat transfer using a combination of descriptions, examples, diagrams, classwork, and homework. The review of learners' notebooks aligned with the teachers' responses during interviews and observations of their teaching practices. However, it was evident that learners encountered challenges in comprehending topics such as convection current and its application, specific heat capacity, specific latent heat, and calculations involving quantity of heat. In essence, the analysis of learners' notebooks provided confirmation of the teachers' instructional approaches and the difficulties faced by students, aligning with the information obtained from interviews and lesson observations.

Finding 4.5.2

It is indicated that the six teachers taught the concepts using a combination of descriptions, examples, diagrams, classwork, and homework.

The review of learners' notebooks aligned with the teachers' responses during interviews and observations of their teaching practices. However, it was evident that learners encountered challenges in comprehending some topics.

The analysis of learners' exercise books provided confirmation of the teachers' instructional approaches and the difficulties faced by students, aligning with the information obtained from interviews and lesson observations.

4.5.3 Curriculum documents

The curriculum documents provided significant insights into the teaching practices of six teachers, namely Ben, Kalulu, Carl, John, Daniel, and David. The analysis revealed that the West African Senior School Certificate Examination (WASSCE) physics syllabus played a central role in guiding their instructional content, particularly concerning the concepts to be taught. The syllabus provided some descriptions of these concepts, serving as a comprehensive resource for all six teachers.

The WASSCE physics syllabus also influenced the instructional sequencing and organisation for Ben, Kalulu, John, Daniel, and David specifically, with regard to the teaching of thermal physics concepts. These teachers relied on the syllabus to establish a logical progression of topics, ensuring a coherent and structured delivery of the material.

While the WASSCE physics syllabus served as the primary source for content and sequencing, the recommended physics textbooks also played a crucial role in the teaching process. However, their usage varied slightly among the teachers. The textbooks served primarily as supplementary resources for all six participating teachers, providing further descriptions, explanations, and detailed illustrations, including valuable diagrams.

Finding 4.5.3

Overall, this analysis highlights the significant influence of the WASSCE physics syllabus on the instructional practices of the six teachers, shaping the content selection, sequencing, and organisation of thermal physics concepts. While the recommended physics textbooks supplemented the syllabus content with further explanations and illustrations, they played a secondary role compared to the syllabus itself.

4.6 Chapter Summary

Chapter Four started by providing demographic information about the six participating teachers. The main study's results were then presented based on the data collection instruments used. The chapter included in-depth analyses of the teachers' observed lessons, focusing on the three central themes: content knowledge, pedagogical knowledge, and understanding of learners' preconceptions and learning difficulties, which were derived from the data. Following the analyses, summaries of the observations and findings were provided. Additionally, various documents, such as teachers' lesson notes, learners' notes, exercise books, and curriculum documents, were analysed. In Chapter Five the main findings of the study will be discussed.

CHAPTER FIVE

DISCUSSION

5.0 Overview

Chapter Five presents the discussion of results and the key findings of the study. This discussion is guided by the study's main research questions thus the kind of pedagogical content knowledge the participating individual physics teachers have in teaching thermal physics and the factors and practices that contribute to their PCK development, which consists of the participating teachers' content knowledge, the type of instructional strategies employed and their knowledge of learners' learning difficulties.

5.1 Teacher PCK Profile and Development

This part of the study focused on the three components of thermal physics-related content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties in order to discuss the summary of each participating teacher's PCK profile and development.

5.1.1 Ben's PCK Profile and Development

The discussion begins by examining Ben's classroom practice and how Ben applied pedagogical content knowledge when teaching thermal physics. In the pre-lesson interview concerning lesson plans (Appendix C, item 1), Ben stated the objective for the students: to explain heat as a form of energy, temperature, and its SI unit, followed by a discussion on temperature scales. Ben also expected students to understand the concept of thermal expansion, the effects of heat on objects, and conclude with the measurement of heat, which involved calculations based on specific heat capacities and latent heat, as outlined in the recommended textbooks. All of these illustrated Ben's use of declarative knowledge to convey information.

Regarding other thermal physics concepts such as conduction, convection, and radiation, which involve understanding heat transfer processes, Ben planned to provide step-by-step descriptions of these processes and highlight the differences between them in effect, making use of procedural knowledge. Ben also aimed to provide clear explanations of why these concepts are important to teach, which points to the use of conditional knowledge. Indeed, the content dimension of Ben's PCK profile can be seen as reflecting the three categories of declarative, procedural, and conditional knowledge (Krathwohl, 2002).

Ben planned and executed thermal physics lessons using recommended physics textbooks and the curriculum document as primary sources of information. During the lessons, Ben started by presenting straightforward facts about thermal physics concepts, including heat as a form of energy, temperature and temperature scales, thermal expansion, quantity of heat, and modes of heat transfer (Finding. 4.3.1.1). Ben then proceeded to explain the relationships and differences among the various concepts of temperature, heat, and the different modes of heat transfer, relying on conceptual knowledge (Krathwohl, 2002). In teaching these concepts, Ben primarily used declarative conceptual knowledge, which is necessary for stating and explaining facts or principles related to heat transfer that students are expected to learn.

In addition, Ben demonstrated content knowledge by explaining the thermal physics processes of conduction, convection, and radiation. Ben carefully and systematically explained the significance of these processes within an object or system, particularly in terms of energy transfer, heat dissipation, and temperature regulation (Finding. 4.3.1.1). This explanation was followed by a description of the stages involved in calculating the quantity of heat energy gained or lost.

The knowledge displayed by Ben, as Ben described the processes of conduction, convection, and radiation, as well as the effects of heat on objects in a step-by-step manner, is considered procedural knowledge. This aligns with the assertions made by other researchers regarding procedural knowledge, which pertains to understanding the "how" of things or physical processes (Juttner et al., 2013; Krathwohl, 2002; Uluoglu, 2001). By providing explanations for both the "why" and the "how" of the processes of conduction, convection (including convection current), and radiation, Ben demonstrates the presence of conditional knowledge within Ben's repertoire of PCK competence. In summary, Ben's PCK encompasses declarative, procedural, and conditional content knowledge in teaching thermal physics concepts.

Ben incorporates several instructional strategies in teaching thermal physics. One of Ben's approaches involves assigning reading from the textbook as homework before introducing a new topic in class. This serves as a form of advance preparation for both learners and the teacher. Following their readings, the students are then required to engage in group presentations, where they share with their peers the material they learned (Finding. 4.3.1,2).

Ben's decision to implement this strategy stemmed from Ben's observation that learners often struggle with differentiating and effectively using terms such as specific heat capacity and heat capacity. Drawing from Ben's years of teaching experience in thermal physics, Ben acknowledged the common difficulties students faced with certain concepts. However, it was noted that Ben did not consistently incorporate this awareness into lesson plans, neglecting to address potential learning difficulties or misunderstandings (Finding. 4.4.4).

In the pre-lesson interview (Finding. 4.2.2), Ben explained that using this approach of learner prior reading and peer teaching served as a kind of advance preparation. The purpose of this approach is twofold: firstly, to ensure that learners have a basic understanding of the upcoming lesson, enabling them to actively contribute during the class; and secondly, to diagnose areas of difficulty and areas that are easily understood.

Considering the teaching context, it became essential for Ben's pedagogical content knowledge profile in teaching thermal physics to include an understanding of learners' existing knowledge, including the difficulties learners encounter when initially exposed to the topic. Learner preconceptions, errors, or misconceptions can then be used as a foundation for teaching and reinforcing accurate ideas (Cazorla, 2006). Thus, Ben's instructional strategy of identifying learners' preconceptions and learning difficulties through their presentations formed an integral part of Ben's overall PCK profile in thermal physics teaching.

Furthermore, Ben typically incorporated familiar contexts for learners when introducing thermal physics concepts (Finding. 4.3.1.2). By employing the use of real-life applications and simple demonstrations, Ben aimed to make the topic more relatable, accessible, and motivating for the students. Research has indicated that a context-based approach to teaching significantly enhances learner performance (Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Kazeni & Onwu, 2013; King & Ritchie, 2013).

Furthermore, Ben employed labelled diagrams and analogies to enhance explanations and foster conceptual understanding (Finding. 4.3.1,2). The use of real-life examples, such as the illustration of a red-hot stone losing heat on a metallic plate, proved effective in engaging the class. The use of analogies is recognised as a key feature of effective pedagogical explanations (Treagust & Harrison, 2000), and skilled teachers employ this strategy when conveying intricate abstract concepts (Coll, France, & Taylor, 2005). Therefore, Ben's topic-specific instructional strategies in pedagogical content knowledge encompassed the use of illustrations, demonstrations, and analogies.

However, Ben did not indicate in lesson plans or choice of instructional strategies that consideration was given to potential preconceptions students might have regarding thermal physics.

Ben's teaching strategy also involved frequent oral questioning to assess students' prior knowledge, understanding during lessons, and retention afterward (Finding. 4.3.1.2). During pre-lesson interviews (Finding. 4.2.2), Ben explained that this approach allowed for immediate feedback from students and identification of any misconceptions or learning difficulties they might have. However, with new or unfamiliar concepts, students sometimes resorted to finding answers directly from their textbooks when responding to classroom questions. Thus, Ben's questioning technique did not always aim to elicit students' own ideas or probe their answers or existing knowledge about the topic being taught.

Nonetheless, through learner presentations and peer teaching, Ben was able to identify students' preconceptions and errors related to concepts, such as their failure to distinguish between the types of energy used in the process of photosynthesis (Finding. 4.3.1.3). Ben's post-lesson interview (Finding. 4.4.4) suggested that he attributed the difficulties students faced with certain aspects of thermal physics topics to the abstract nature of the concepts. Additionally, the researcher's review of students' notebooks (Finding. 4.5.2) confirmed that components of Ben's PCK in thermal physics teaching emerged from his identification of students' difficulties during their classroom presentations and peer teaching. Oral questioning techniques and homework or assignments were topic-specific strategies that he frequently and purposefully employed to diagnose students' difficulties and assess their understanding.

In summary, Ben's PCK profile in teaching thermal physics encompasses declarative, procedural, and conditional content knowledge, as well as the use of topic-specific instructional strategies such as context-based teaching, peer teaching, learner group presentations, and analogical teaching. The employment of advance preparation in the form of peer teaching, simple classroom demonstrations, diagnostic questioning techniques, and homework assignments, among other aspects of classroom management and time management, define the effective pedagogical strategies employed by Ben in teaching thermal physics. However, one aspect lacking in Ben's instructional strategy during the observed lessons was a consistent follow-up with probing questions designed to uncover the reasons behind students' difficulties, errors, and misconceptions in the topic being taught.

Regarding Ben's development of PCK in teaching thermal physics, he acquired formal education and training in teaching physics through university studies. Ben holds a Bachelor of Science degree with a major in physics. Ben reported (Finding. 4.4.1) that, the thermal physics content knowledge was obtained from the B.Ed. coursework. Ben gained knowledge of teaching methods and strategies, including the use of familiar contexts for learners, through methods courses. Ben, like the other three teachers, acknowledged that the thermal physics content knowledge acquired during Ben's degree was more advanced than what was expected at the senior high school level. Consequently, Ben had to adapt and make the content accessible to Ben's students using Ben's pedagogical content knowledge.

Ben possesses approximately twenty years of experience in teaching physics at the senior high school level, specifically SHS 1–3. Insights gained from Ben's post-lesson interview indicated that Ben's understanding of teaching thermal physics has evolved over the years. Ben noted a shift in instructional strategies from predominantly delivering lectures through traditional methods ("chalk and talk") to a more learner-centred and participatory approach. Ben began involving students by assigning them textbook readings before thermal physics lessons and incorporating group presentations as a form of peer teaching. This exercise served as a means of advance preparation. According to Ben, these changes have positively impacted Ben's students' performance in physics in the West African Senior School Certificate Examination (WASSCE), stating, "learners' performance in external examinations has improved over the years compared to when I started."

To enhance teaching skills, Ben attended in-service physics workshops organised by the Ghana Education Service (GES) and teacher unions (GNAT, NAGRAT), as well as the subject union (GAST) (Finding. 4.4.6). Ben reported that these workshops had a positive influence on Ben's ability to select appropriate representations for thermal physics topics. Specifically, Ben claimed that the workshops expanded Ben's repertoire for representing thermal physics concepts, allowing Ben to differentiate between effective and ineffective representations. For example, Ben learned about the use of Teaching and Learning Materials (TLMs) and how to create them using readily available materials.

When asked about other sources contributing to Ben's pedagogical content knowledge, Ben mentioned the use of physics curriculum documents, such as the physics syllabus and recommended textbooks, to prepare Ben's thermal physics lessons. Ben explained that the syllabus served as a guide for the content to be taught and the sequence in which thermal physics concepts should be covered. Textbooks, on the other hand, provided simpler explanations, examples, and diagrams.

Through a progressive analysis of Ben's observed thermal physics lessons, it became evident that, similar to two other teachers (Kalulu and John), Ben's demonstration of content knowledge varied depending on the nature of the topic or concept. Ben became aware of students' confusion regarding thermal physics terminology through their presentations, responses to Ben's oral questions, and evaluation of their homework and assignments. Ben's knowledge of instructional strategies may have further developed through reflection on Ben's thermal physics lessons.

Interestingly, Ben appeared to have limited knowledge of students' preconceptions, which could have been used as teaching points. Ben did not report gaining or learning about such knowledge from any of the factors or sources known to influence the development of PCK. It is possible that this aspect of understanding students' conceptions and learning difficulties may not have been adequately addressed during Ben's professional development courses or workshops.

In summary, considering the evidence from Ben's responses and the progressive analysis of Ben's lessons, factors such as formal education programmes at the university, participation in in-service training workshops, classroom teaching experience using physics curriculum documents and recommended textbooks likely contributed to the development of Ben's pedagogical content knowledge.

5.1.2 Kalulu's PCK Profile and Development

During the lesson observations, it was noted that Kalulu focused on foundational concepts of heat energy, thermal equilibrium, SI units of heat energy, and thermometer and thermometry substances in thermal physics teaching. Kalulu relied on recommended physics textbooks and the physics syllabus as the primary sources of information (Finding 4.5.3). When teaching about heat as a form of energy and heat transfer, Kalulu predominantly used declarative knowledge (Finding 4.3.2.1). Kalulu provided definitions of the thermal physics concepts, followed by factual information about their principles and applications as outlined in the physics syllabus. Kalulu took time to explain the relationship among concepts such as heat transfer convection and convection current, heat capacity and specific heat capacity, and quantity of heat (Finding 4.3.2.1), drawing on conceptual knowledge. Research suggests that learners often struggle with understanding this relationship (Lewis et al., 2000). Kalulu devoted extra attention and allowed learners ample time to grasp explanations of how these concepts are interconnected within the context of energy transfer. This focused approach, combined with the attention given by both the teacher and learners, resulted in improved understanding as evident in students' correct responses to classwork questions about the effects of heat transfer on objects (Finding 4.3.2.1).

In lessons on the measurement of heat (quantity of heat) and heat transfer, Kalulu primarily relied on procedural and conditional knowledge, employing a systematic and logical approach. Kalulu first justified the process within the context of thermal physics, followed by a description of the steps involved in calculating heat gained and heat lost. Using illustrations, Kalulu described the stages in a step-by-step manner, beginning with a pre-activity of measuring the mass of a piece of ice and heating it to assess learners' prior knowledge of the concept (Finding 4.3.2.2). Kalulu then explained how the process works and the calculations involved were carried out (Finding 4.3.2.2).

A quick examination of learners' exercise books confirmed that Kalulu predominantly employed procedural knowledge in alignment with the requirements of the lesson topic as indicated in both the recommended textbooks and the physics syllabus. This knowledge component is particularly relevant in teaching thermal physics concepts. However, Juttner et al. (2013) have emphasised that in the context of teaching new knowledge in science, it is not sufficient for teachers to know the "what" (propositional knowledge) and the "how" (procedural knowledge), but they should also understand the "why." Kalulu expressed his intention for students to understand why these thermal physics concepts are important, as they would enable them to explain and justify the significance of studying how objects gain or lose heat (Finding 4.2.2.2). Throughout the lessons, Kalulu clarified that objects gain or lose heat due to temperature differences, demonstrating the three dimensions of content knowledge: declarative, procedural, and conditional knowledge. Thus, Kalulu's PCK profile in terms of subject matter knowledge is made up of declarative, procedural, and conditional content knowledge.

In one of the lessons, Kalulu typically introduced thermal physics topics using familiar examples from everyday life to engage students and make the subject more relevant to their daily experiences. Examples such as heat transfer in cooking, room ventilation, refrigeration systems, and burns from hot water and steam were tactically used to introduce the concepts of thermal physics (Finding 4.3.2.2). Current studies by Eastwood et al. (2012), Kazeni and Onwu (2013), King and Ritchie (2013), and Williams et al. (2012) indicate that incorporating familiar contexts in science teaching significantly enhances students' performance and attitudes. Therefore, the inclusion of familiar contexts aligned with Kalulu's content-driven PCK profile in teaching thermal physics.

During a post-lesson interview (Finding 4.4.4), Kalulu recognised that students often struggle with the terminology and usage of thermal physics concepts, such as thermal equilibrium and specific heat capacity. This observation is consistent with research findings by Kazeni and Onwu (2013). To address this issue, Kalulu commonly used illustrations from recommended textbooks and occasionally from the Internet, as well as diagrams and sketches on the marker board, to help students visualise and comprehend the defined thermal physics concepts being taught (Finding 4.3.2.2). Well-labelled diagrams on the marker board were employed, for example, to explain the relationship between modes of heat transfer and land and sea breeze (Finding 4.3.2,2). Works by Chattopadhyay (2005), Chinnici et al. (2006), Law and Lee (2004), and Oztap et al. (2003) suggest that the use of illustrations in science teaching supports learners in visualising concepts and enhancing comprehension. However, it was noted that Kalulu, like other teachers, did not frequently incorporate demonstrations simple experiments in their lesson plans and teaching, although they occasionally used them. This is to emphasise that physics is an experimental science. Despite exposure to teaching and learning materials during various in-service workshops (Finding 4.4.6), it is evident that the acquired knowledge and skills, if any, were not effectively demonstrated in Kalulu's classroom practice. This deficiency in the approach to teaching thermal physics, particularly in the use of teaching materials and practical demonstrations or learner-centred experimentation, is unsatisfactory in terms of making thermal physics concepts more accessible and meaningful to students. Juttner et al. (2013) and Magnusson et al. (2001) argue that the use of physical models and individual, group, or demonstration experiments are crucial science-specific instructional strategies that can assist students in learning complex and abstract concepts. Pictorial models, in particular, aid in forming mental images of intended concepts, promoting comprehension of scientific content, and facilitating the retention of conceptual knowledge (Oliveira, Rivera, Glass, Mastroianni, Wizner & Amodeo, 2013).

A significant portion of Kalulu's understanding of students' misconceptions and learning difficulties was deduced during the presentation of thermal physics lessons. This knowledge was acquired through the questioning technique, observation, and review of classroom work, homework, and assignments, as well as through gathering learner feedback (Finding 4.3.2.3). Kalulu identified students' challenges in fully defining specific heat capacity and explaining convection currents through the analysis of their responses to classwork and feedback (Finding 4.3.2.3). Similar to the other teachers, Kalulu attributed students' difficulties to the abstract nature of thermal physics concepts (Finding 4.4.4). However, the questioning technique failed to uncover students' preconceptions regarding thermal physics concepts being taught (Finding 4.3.2.2), mainly due to observed weaknesses in probing questioning techniques. This lack of knowledge regarding students' preconceptions and potential learning difficulties related to thermal physics was confirmed when Kalulu indicated in the post-lesson interview that there was no understanding of students' preconceptions (Finding 4.4.4).

All six participating teachers, including Kalulu, were found to lack sufficient knowledge of students' preconceptions and learning difficulties related to thermal physics. This is surprising considering their extensive teaching experience in the subject, as this knowledge is crucial for effective classroom practice. Numerous researchers, such as Lazarowitz and Lieb (2006) and Morrison and Lederman (2003), have emphasised the importance of teachers identifying students' preconceptions before instruction begins, using this information to adapt their teaching strategies to suit students' needs and prevent potential learning difficulties.

To summarise, Kalulu's PCK profile can be seen as a combination of declarative, procedural, and conditional knowledge. Specific instructional strategies such as using familiar examples, illustrations, and labelled diagrams were employed to teach thermal physics concepts. By identifying students' learning difficulties through analysing their responses to classwork and homework, Kalulu demonstrated awareness of their post-teaching challenges.

It can be assumed that Kalulu developed his PCK in teaching thermal physics through various academic sources. He completed a Bachelor of Science Education degree majoring in physics, gaining content knowledge of thermal physics through university courses. Additionally, teaching methods and strategies evolved over 15 years of physics teaching experience, influenced by professional development opportunities. Kalulu attended in-service physics workshops organised by the Ghana Education Service (GES), teacher unions (GNAT, NAGRAT), and the subject union (GAST) (Finding 4.4.6). These workshops taught about the importance of making topics relevant to students, incorporating technology in lesson presentations, and the significance of research beyond the textbook during lesson planning.

Kalulu mentioned that the physics syllabus and recommended textbooks were additional sources of PCK in teaching thermal physics. The syllabus provided both the content to be taught and its organisation, while textbooks were consulted for explanations, examples, and illustrations.

An analysis of observed thermal physics lessons revealed that Kalulu further developed PCK in teaching the subject (Finding 4.4.8). After realising that students struggled to respond correctly to most questions in the first lesson, the decision was made to assign reading assignments and homework exercises from the textbook before the second lesson. Reflecting on classroom delivery during the study, Kalulu likely enhanced the pedagogical component of PCK in teaching thermal physics. The intention was expressed to continue using the strategy of having students read in advance for future lessons and to incorporate more everyday life examples to illustrate concepts like the effects of heat on objects and thermal equilibrium.

In summary, Kalulu's PCK in teaching thermal physics was likely developed through formal education, participation in in-service workshops, and classroom teaching experience. Physics curriculum documents, recommended textbooks, and the Internet were used as sources of information during lesson preparation and delivery

5.1.3 Carl's PCK Profile and Development

Carl planned and conducted thermal physics these lessons centred around various concepts, including heat as a form of energy, temperature scales, the effect of heat energy on objects, quantity of heat, and modes of heat transfer. Carl relied on recommended physics textbooks and the physics syllabus as instructional guides (Finding 4.4.8). Analysis of data obtained from Carl's pre-lesson interview and lesson observation confirmed that he predominantly used pedagogical content knowledge-informed declarative subject matter knowledge to effectively teach thermal physics concepts to students (Finding 4.3.3.1).

Typically, Carl started lessons by reviewing previous lessons, specifically revisiting concepts such as heat energy and temperature that students had already learned. In a particular lesson on 'Heat Transfer,' Carl proceeded to teach and explain simple definitions of thermal physics concepts and the underlying rationale behind the heat transfer process. While briefly outlining the purposes and effects, Carl did not delve into the step-by-step stages of the processes (Finding 4.3.3.1). For instance, he defined conduction as the mechanism through which heat is transferred by direct contact, while convection was explained as the process responsible for heat transfer via fluid motion (Finding 4.3.3.1). Furthermore, Carl emphasised the significance of heat transfer to the system.

Unlike the other participating teachers who followed the same physics syllabus, Carl adopted a different teaching approach. When teaching the modes of heat transfer, Carl primarily focused on presenting factual information about their rationale and effects (Finding 4.3.3.2). Carl explained in the pre-lesson interview (Finding 4.2.1) that there was no need for learners to know the intricate details of thermal physics since the syllabus indicates that the advanced thermal physics concepts are not required. It is evident that Carl adhered strictly to the syllabus recommendations and did not believe in surpassing them. One might have thought that Carl's existing pedagogical content knowledge in thermal physics teaching would enable proper digestion of the content of syllabus and instead foster conceptual understanding. As previously mentioned, in the field of science teaching, it is insufficient for teachers to merely comprehend what and how things are; they should also comprehend the reasons behind their existence (Juttner et al., 2013).

In contrast, the other three participating teachers explained the workings of heat transfer processes by employing visual representations, including diagrams that depicted the internal aspects of each phenomenon. The difference in the interpretation of how the physics syllabus should be implemented in the classroom has implications for learners, as they may not always derive optimal benefits from these differences. Inconsistency in the implementation and alignment with curriculum goals can impact classroom practices. Regarding pedagogical content knowledge, Carl's content knowledge component appears to predominantly consist of declarative content knowledge (Finding 4.3.3.1).

Carl used relatable examples from everyday life that were familiar to students to introduce the concept of heat as a form of energy and illustrate phenomena such as conduction, convection, and convection currents (Finding 4.3.3.2). Research suggests that learners often struggle to understand the distinctions between different heat transfer mechanisms, so Carl aimed to enhance comprehension by using practical situations such as boiling water, room ventilation, and refrigerator cooling systems as examples (Finding 4.3.3.2). In the pre-lesson interview, Carl stated that the intention in using familiar situations was to connect new thermal physics concepts to students' existing knowledge and observations. For instance, Carl began a lesson on heat as energy by engaging students in a discussion about the direction of a flowing river in relation to the surrounding land topography, effectively drawing parallels between the flow of a river and the flow of heat energy. This approach aligns with the viewpoint of Knippels et al. (2005), who suggest that teaching should begin with familiar contexts to address the abstract and complex nature of certain science concepts, thereby enhancing conceptual understanding by relating the topic to students' everyday lives (Finding 4.3.3.2; Kazeni & Onwu, 2013; King & Ritchie, 2013).

When dealing with concepts that required visual representations, Carl used illustrations and labelled diagrams, to help students visualise natural phenomena such as land and sea breezes and the regulation of the Earth's surface temperature (Finding 4.3.3.2). Carl would draw carefully labelled diagrams on the board to illustrate factual information about thermal physics concepts and assist students in understanding the relationships between temperature, energy, the effects of heat energy on substances, and modes of heat transfer (Finding. 4.3.3.2). In some cases, students were referred to diagrams in their textbooks (Finding 4.3.3.2). An analysis of student notes confirmed the regular use of visual aids in the teaching of thermal physics concepts (Finding

4.5.1.2). The instructional strategies employed, such as the use of familiar contexts, examples, labelled diagrams, and illustrations, are components of the pedagogical approach to teaching thermal physics (Finding 4.3.3.1).

However, Carl's presumed PCK in thermal physics teaching did not consistently demonstrate knowledge of using teaching physical models, individual and teacher demonstrations, or simple experiments, which are considered important instructional strategies in science education (Finding 4.3.3.2; Juttner et al., 2013; Magnusson et al., 2001). Furthermore, there was a lack of understanding regarding learners' preconceptions and learning difficulties related to the thermal physics concepts taught. Integrating students' preconceptions and addressing their learning difficulties during lesson planning and teaching is crucial, as neglecting these factors can hinder effective teaching and student understanding (Finding 4.3.3.3; Riemeier & Gropengieber, 2008; Morrison & Lederman, 2003; Lazarowitz & Lieb, 2006). The questioning technique used did not probe, nor allow for wait-time for student responses, failed to elicit students' preconceptions of thermal physics concepts (Finding 4.3.3.2). Further evidence from the pre-lesson interview and lesson observation revealed that teacher-centred approaches, such as the lecture method, were predominantly used by Carl to teach thermal physics concepts (Finding 4.3.3.2). Such strategies, according to Yilmaz et al. (2011), promote rote learning rather than conceptual understanding and should be discouraged in science teaching.

When asked about potential learning difficulties that students might face in lessons, Carl stated that learners often struggle with understanding the terminology and calculations involved in thermal physics (Appendix C item 5) (Finding 4.4.4). Carl specifically stated that, there were challenges in differentiating terms such as 'specific heat capacity,' 'heat capacity,' 'specific latent heat,' 'convection,' and 'convection current,' as well as comprehending how convection currents lead to heat transfer. In addition to terminology, Carl confirmed that students faced difficulties in performing calculations related to ‘quantity of heat’, especially when dealing with large figures. These difficulties were attributed to the abstract nature of the concepts and students' limited mathematical background (Finding 4.4.4). Surprisingly, despite being aware of these potential learning difficulties, Carl did not implement any specific teaching and learning measures to address or minimise them. A review of class tests, notes, and exercises revealed that some students were unable to solve thermal physics problems due to a lack of understanding of the necessary steps and procedures involved in the calculations. It can be inferred that if the step-by-step process of calculating the quantity of heat energy had been taught, some of these learning difficulties could have been avoided.

Similar to the other teachers in the study, there appeared to be a lack of knowledge regarding students' preconceptions and learning difficulties when teaching thermal physics concepts. This indicates a deficiency in PCK regarding learners' preconceptions in thermal physics teaching. It is puzzling that despite years of teaching experience, much consideration was not given to the potential preconceptions and misconceptions that students might bring to new topics. This observation supports Kapyla et al.'s (2009) statement that years of classroom exposure alone do not guarantee the development of expertise in science teaching.

In summary, Carl’s subject matter knowledge component of PCK primarily consists of declarative knowledge. The instructional strategies employed by Carl, such as using everyday life examples and visual aids, align with PCK. However, Carl’s lack of awareness of students' preconceptions is a notable deficiency. Furthermore, the questioning technique used was ineffective in eliciting students' preconceptions, and there were limited assessment activities to gauge students' conceptual understanding.

Regarding the development of PCK in thermal physics teaching, it can be assumed that Carl's formal education, including a Bachelor of Science degree with a major in physics and a Postgraduate Diploma in Education (PGDE) (Finding 4.1), provided content knowledge. Although acknowledgment was made that university education covered more extensive topics than what was taught in class, content knowledge equipped Carl to explain thermal physics concepts with confidence. Instructional strategies were learned from education courses (Finding 4.1).

With 12 years of physics teaching experience, it was claimed that teaching of thermal physics has improved over the years as instructional strategies were modified (Finding 4.4.8). Introduction to context-based teaching during physics workshops organised by the Ghana Education Service led to the incorporation of familiar situations or contexts when introducing the topic of thermal physics. Additionally, Carl acquired knowledge about the use of physical models to aid students' understanding of thermal physics concepts during workshops organised by teacher union (NAGRAT) and subject union (GAST). However, despite this knowledge, models were not used in Carl's observed thermal physics lessons, this was attributed to a lack of time.

Regarding the sources of pedagogical content knowledge, Carl stated that the syllabus was used as a guide to determining which topics to teach and the objectives to be achieved (Finding 4.5.3). Curriculum documents were considered as the primary source of information for teaching content. Over the years, notes from various textbooks were compiled into personalised notes provided to students.

An analysis of observed thermal physics lessons indicated minimal development of PCK, except for the use of more familiar examples to teach the concept of energy transfer, which was recognised as challenging for students to grasp. However, expressed intention was to improve lessons, particularly in terms of assessment, by incorporating exercises to immediately assess students' understanding of thermal physics concepts in future teaching sessions. This approach would allow for gathering feedback from students and use it to enhance teaching.

Of particular interest in years of teaching experience was Carl’s lack of indication or demonstration of knowledge regarding students' preconceptions in thermal physics. If Carl had any of such knowledge, it was not incorporated into lesson plans or teaching strategies. Additionally, Carl neglected teaching the mechanisms of conduction, convection, and radiation, arguing that they were not required by the syllabus. However, this perspective overlooked the fact that understanding these mechanisms is crucial for students to grasp other thermal physics concepts specified in the syllabus, such as energy transfer. Being constrained by the syllabus and not viewing the topic holistically was evident in Carl’s lessons when the focus was placed only on the ‘what’ and, to some extent, the ‘why’ of conduction, convection, and radiation, neglecting the ‘how’. This observation raises questions about content knowledge and understanding of students' preconceptions, suggesting that teaching approach may have remained unchanged over the years, supporting Magnusson et al.'s (2001) assertion that teaching experience alone does not guarantee the development of PCK. Instead, reflection on learners' successes and difficulties resulting from teaching practices is suggested as a means of enhancing PCK development.

In summary, Carl's limited PCK in thermal physics teaching might have stemmed from formal teacher education programmes, classroom teaching experiences, and professional development workshops.

5.1.4 John's PCK Profile and Development

During pre-lesson interviews, John expressed a desire for students to have a thorough understanding of key thermal physics concepts, such as heat as a form of energy, quantity of heat, specific heat capacity, the effects of heat on substances, and the modes of heat transfer (Finding 4.2.1). Emphasis was placed on teaching the processes of conduction, convection, and radiation as outlined in the physics curriculum document. The aim was for students to grasp the effects of heat energy on objects, perform calculations related to 'quantity of heat,' and explain the mechanisms of conduction, convection, and radiation (Finding 4.2.1). The instructional approach was guided by proficiency in declarative and procedural subject matter content knowledge, aligning with the physics syllabus (Finding 4.3.4.1).

In lessons, John covered areas such as heat as a form of energy, temperature scales, quantity of heat, the effects of heat on substances, and the modes of heat transfer (conduction, convection, and radiation), adhering to the physics syllabus (Finding 4.3.4.1). To plan and deliver lessons, reliance John primarily relied on recommended physics textbooks and the physics syllabus as the main sources of information (Finding 4.4.8). When teaching quantity of heat and heat transfer, John focused on demonstrating declarative content knowledge (Finding 4.3.4.1). John's specified lesson objectives aligned with the objectives specified in the physics syllabus (Finding 4.3.4.1). John provided definitions and explanations for concepts like thermal equilibrium, thermocouple, conduction, convection, convection currents, and radiation, employing familiar examples to illustrate their processes and relationships (Finding 4.3.4.1). Additionally, procedural content knowledge was used to define heat capacity, specific heat capacity, and specific latent heat, along with the associated procedures and calculation steps for determining quantity of heat energy (Finding 4.3.4). John concluded the lessons by emphasising the importance of understanding these concepts and the related thermal physics processes (Finding 4.3.4.1). Thus, the pedagogical approach incorporated declarative, procedural, and conditional content knowledge in teaching thermal physics (Finding 4.3.4.2).

As part of instructional methods, John used labelled diagrams and charts on marker boards to support explanations and to facilitate students' comprehension of thermal physics processes and concepts (Finding 4.3.4.2). These teaching materials, including charts depicting land and sea breezes and the cooling of the Earth's surface, were used to help students form clear mental images of heat transfer processes (Finding 4.3.4.2). According to John, the decision to use illustrations was based on years of experience teaching the topic and awareness of students' difficulties in understanding terms like convection and convection currents. John's use of diagrams was aimed to clarify the relationship between these terms and facilitate students' comprehension (Finding 4.3.4.2). Incorporating charts into teaching thermal physics concepts aligned with the goal of enhancing learner accessibility, a strategy learned during in-service training physics workshops organised by the GES (Finding 4.4.6; Chattopadhyay, 2005).

Much like other educators, John employed physical models or demonstrations to reinforce theoretical concepts or processes in thermal physics, especially those that were liable for experimental demonstration. Nevertheless, John mentioned that practical lessons would be introduced towards the end of the programme, allowing students to engage in hands-on experiments related to thermal physics and other physics areas

(Finding 4.2.2). It appeared that John's instructional approach lacked the integration of experiments and physical models. Research has shown that the use of physical models can significantly enhance students' understanding and retention of thermal physics content, facilitating the conceptualisation and mental mapping of these abstract concepts (Chinnici et al., 2006; Oliveira et al., 2013; Lazarowitz & Lieb, 2006).

There was an apparent lack of awareness on John's part regarding students' preconceptions and learning difficulties specific to teaching thermal physics (Finding 4.3.4.3). Lesson plans did not seem to account for these factors or leverage students' existing knowledge as a foundation for instruction (Penso, 2002). However, in pre-lesson interviews, John did mention employing questioning techniques to assess students' prior knowledge of thermal physics concepts. During observed lessons, this technique was primarily used to review the previous lesson on energy transfer, with the aim of establishing connections between prior and current lessons, rather than eliciting students' ideas or preconceptions (Finding 4.3.4.2).

John primarily gained insights into students' learning difficulties, including errors and misconceptions, through feedback obtained from homework and class assignments (Finding 4.3.4.3). When correcting homework related to conduction, convection, and radiation, it became evident that some students struggled to accurately define these concepts. For instance, some defined conduction as the ‘transfer of heat through direct contact’ without considering the role of particles, as expected by the teacher. Corrections provided the expected response without emphasising how to avoid prior errors. Students also encountered challenges with calculations involving specific heat capacity and latent heat. One might speculate that if John had prior knowledge of students' preconceptions and difficulties with calculations, a more effective and systematic approach to addressing these learning challenges could have been employed before or during the lesson (Finding 4.3.4.3).

This deficiency in John's PCK pertaining to the understanding of students' preconceptions was a shared characteristic among the participating teachers. Further research is needed to comprehend why experienced teachers, despite their years of teaching experience, seem to lack knowledge of students' topic-specific preconceptions and learning difficulties, as indicated in recent studies (Ijeh, 2012).

In the pre-lesson interview, John indicated an intention to employ oral questioning (Finding 4.2.3), homework assignments, and assessments as strategies to evaluate students' comprehension of the lesson and identify learning difficulties and this was done (Finding 4.3.4.2). Students' struggles in grasping thermal physics concepts (Finding 4.4.4) were attributed to two primary reasons: first, students encountered thermal physics terminology for the first time due to a lack of exposure at lower school levels, and second, some concepts were inherently abstract and challenging for students to visualise (Finding 4.4.5). To address these challenges, diagrams were used to illustrate relationships among phenomena, teaching methods were adapted, additional readings were assigned, more practice exercises were provided, and peer collaboration among students was encouraged (Finding 4.3.4.3).

In summary, John's perceived PCK in teaching thermal physics concepts was characterised by reliance on recommended textbooks and the syllabus for lesson planning. PCK components predominantly consisted of declarative, procedural, and conditional content knowledge. Instructional strategies specific to thermal physics involved the use of familiar examples, labelled diagrams, and scientific charts to present concepts in a manner believed to be accessible to students. Awareness of students' preconceptions related to thermal physics concepts was lacking, although some students' errors and difficulties were identified through questioning techniques, homework assignments, and class assessments (Finding 4.3.4.3).

John's statements during the post-lesson interview (Finding 4.4.8) indicated that assumed PCK in teaching thermal physics concepts was primarily developed through practical experience and on-the-job learning over time. A Bachelor of Science degree with a major in physics enhanced content knowledge in thermal physics and introduced various teaching methods and strategies (Finding 4.1).

With 13 years of experience in teaching physics, John acknowledged the development of the PCK to the help of a senior colleague in the department. John attributed much of the success in the PCK developed to collaboration with experienced colleagues within the school's physics department, by benefiting from informal discussions and knowledge sharing. Collaboration with a seasoned physics teacher, in particular, helped improve explanations of challenging concepts (Finding 4.4.8).

John participated in active in-service physics workshops organised by the Ghana Education Service, teacher and subject unions (NAGRAT and GAST). These workshops focused on different teaching approaches and strategies, providing pedagogical knowledge related to the use of teaching aids and illustrations like scientific charts and diagrams when teaching physics concepts (Finding 4.4.6).

In addition to an educational background and professional development opportunities, John stated physics syllabus and recommended textbooks, as additional sources of PCK. John relied the syllabus to determine the content and sequence of topics to be taught, while various textbooks were consulted for suitable explanations, diagrams, and examples for students (Finding 4.4.8).

Through a progressive analysis of observed thermal physics lessons, John only got awareness of students' errors during the lessons and while marking homework and class exercises. After reflecting on these observations, John tried seeking ways to enhance practice, such as assigning pre-lesson readings, facilitating group discussions and presentations, using more teaching resources, and providing more detailed explanations of processes (Finding 4.4.5).

Notably, all participating teachers, including John, engaged in reflection and critical thinking about taught thermal physics lessons, contemplating how to improve teaching activities. This finding suggests that PCK, or certain aspects of it, are not static but subject to change given an enabling environment and support (Miller, 2007). However, evidence of reflective thinking in lesson plans was generally lacking among the participating teachers, indicating the need to encourage the use of logbooks or journals to record lessons, successes, failures, and improvement strategies. Weekly Continuous Professional Development (CPD) sessions could be organised for teachers to reflect on and review recorded lessons, and critical friends could be invited to observe lessons and engage in post-lesson discussions. Such practices would promote the view that PCK is dynamic rather than static.

In summary, John's development of PCK in teaching thermal physics likely stemmed from formal university education, practical classroom experience, collaboration with departmental colleagues, and participation in in-service training workshops.

5.1.5 Daniel’s PCK Profile and Development

Observations of Daniel’s lessons revealed that he concentrated on fundamental concepts such as heat energy, thermal equilibrium, SI units of heat energy, and thermometers in his teaching of thermal physics. He primarily used recommended physics textbooks and the physics syllabus as key resources (Finding 4.5.3). When teaching topics like heat as a form of energy and heat transfer, Daniel mainly relied on declarative knowledge (Finding 4.3.5.1). He defined thermal physics concepts and provided factual information about their principles and applications as per the syllabus. Daniel thoroughly explained how concepts such as heat transfer, convection and convection currents, heat capacity, specific heat capacity, and the quantity of heat are interconnected (Finding 4.3.5.1), drawing on conceptual knowledge. Research indicates that students often find these relationships challenging (Lewis et al., 2000). Daniel devoted extra time to ensure students understood these connections within the context of energy transfer. This focused approach, combined with active student engagement, led to good understanding, as reflected in students' correct answers to classwork questions about heat transfer effects (Finding 4.3.5.1).

In lessons about measurement of heat and heat transfer, Daniel predominantly used procedural and conditional knowledge, employing a systematic and logical approach. He first justified the process within thermal physics, then described the steps for calculating heat gained and lost. Using illustrations, Daniel presented the process step-by-step, starting with a pre-activity involving measuring the mass of a piece of ice and heating it to assess students' prior knowledge (Finding 4.3.5.2). He then explained how the process works and the calculations involved in these concepts (Finding 4.3.5.2).

A review of students' exercise books confirmed that Daniel's use of procedural knowledge was in line with the lesson topic requirements as outlined in both the textbooks and the syllabus. This knowledge component is especially relevant for teaching thermal physics concepts. However, Juttner et al. (2013) emphasise that, in teaching new science knowledge, it is essential for teachers to understand not only the "what" (propositional knowledge) and the "how" (procedural knowledge), but also the "why." Daniel's main aim was to get his students to understand why thermal physics concepts are important, enabling them to explain and justify the relevance of studying heat gain or loss (Finding 4.2.2.2). Throughout his lessons, Daniel clarified that objects gain or lose heat due to temperature differences, demonstrating all three dimensions of content knowledge: declarative, procedural, and conditional.

In one lesson, Daniel introduced thermal physics topics with familiar everyday examples to engage students and made the subject more relevant. Research by Eastwood et al. (2012), Kazeni and Onwu (2013), King and Ritchie (2013), and Williams et al. (2012) supports that using familiar contexts in science teaching enhances student performance and attitudes. Thus, Daniel's use of relatable examples aligned with his content-driven PCK profile.

During a post-lesson interview (Finding 4.4.4), Daniel acknowledged that students often struggle with terminology and concepts like thermal equilibrium and specific heat capacity. This observation is consistent with Kazeni and Onwu's (2013) findings. To address this, Daniel used illustrations from textbooks, the Internet, and diagrams on the marker board to help students appreciate and understand thermal physics concepts (Finding 4.3.5.2). Studies by Chattopadhyay (2005), Chinnici et al. (2006), Law and Lee (2004), and Oztap et al. (2003) suggest that illustrations aid in visualising concepts and enhancing understanding. However, it was noted that Daniel, like other teachers, did not frequently use demonstrations or simple experiments, despite their occasional use. This is essential, as physics is an experimental science. Despite attending various in-service workshops (Finding 4.4.6), it was evident that the knowledge and skills gained were not fully demonstrated in Daniel's classroom practice. The limited use of teaching materials and practical demonstrations was noted as a gap in making thermal physics concepts more accessible and meaningful. Juttner et al. (2013) and Magnusson et al. (2001) argue that physical models and experiments are vital for teaching complex concepts.

Daniel's understanding of students' misconceptions and learning difficulties was mainly inferred from his questioning technique, observations, and reviews of classroom work, homework, and assignments, as well as student feedback (Finding 4.3.5.3). Similar to other teachers, he attributed students' difficulties to the abstract nature of thermal physics concepts (Finding 4.4.4). However, his questioning did not uncover students' preconceptions about these concepts (Finding 4.3.5.2), highlighting weaknesses in probing questions. This lack of insight into students' preconceptions and potential learning difficulties was confirmed when Daniel indicated a lack of understanding of these preconceptions in the post-lesson interview (Finding 4.4.4).

All six participating teachers, including Daniel, lacked sufficient knowledge of students' preconceptions and learning difficulties related to thermal physics, despite their extensive teaching experience. This gap is surprising given its importance for effective teaching. Researchers like Lazarowitz and Lieb (2006) and Morrison and Lederman (2003) stress the need for teachers to identify students' preconceptions before instruction to adapt teaching strategies and prevent learning difficulties.

In summary, Daniel's PCK in teaching thermal physics consisted of declarative, procedural, and conditional knowledge. He used instructional strategies such as familiar examples and labelled diagrams to teach thermal physics concepts. By identifying students' learning difficulties through analysing their responses to questions, classwork, and homework, Daniel demonstrated awareness of their post-teaching challenges.

Daniel likely developed his PCK through formal education, in-service workshops, and classroom experience. His Bachelor of Science Education degree in physics provided foundational content knowledge, while 15 years of teaching experience and professional development opportunities further enhanced his pedagogical skills. Daniel attended in-service workshops organised by the Ghana Education Service (GES), teacher unions (GNAT, NAGRAT), and the subject union (GAST) (Finding 4.4.6), which emphasised relevance, technology integration, and research in lesson planning.

Daniel also used physics curriculum documents, recommended textbooks, and online resources as sources of information during lesson preparation and delivery. Observations of his lessons revealed that Daniel further developed his PCK by assigning reading and homework to address students' learning difficulties, reflecting on classroom delivery to enhance his teaching approach. He stated that he would continue using pre-lesson readings and more real-life examples to illustrate concepts like effects of heat and thermal equilibrium in future lessons.

In summary, Daniel's PCK in teaching thermal physics was shaped by formal education, in-service workshops, and practical teaching experience. He made use of curriculum documents, textbooks, and online resources to prepare and deliver lessons effectively.

5.1.6 David's PCK Profile and Development

During a pre-lesson interview about his lesson plans (Appendix C, item 5), David outlined his goals: to explain heat as a form of energy, temperature and its SI unit, and to discuss temperature scales. He also aimed for his students to understand thermal expansion, the effects of heat on objects, and to end with heat measurement, including calculations based on specific heat capacities as described in the recommended textbooks. This approach highlighted David's use of declarative knowledge.

Regarding concepts like conduction, convection, and radiation, which involve heat transfer processes, David planned to provide detailed descriptions and stating their different effects, indicating his use of procedural knowledge. He also aimed to explain the importance of these concepts, reflecting conditional knowledge. David's PCK profile therefore included declarative, procedural, and conditional knowledge (Krathwohl, 2002).

David prepared and delivered his thermal physics lessons using recommended textbooks and the curriculum document. He began by presenting basic facts about thermal physics, such as heat as a form of energy, temperature, temperature scales, thermal expansion, heat quantity, and heat transfer modes (Finding 4.3.6.1). He then explained the relationships and differences among these concepts using conceptual knowledge (Krathwohl, 2002). David primarily employed declarative knowledge to state and explain facts or principles related to heat transfer that students needed to learn.

David also employed various instructional strategies in teaching thermal physics, including assigning textbook readings as homework to prepare both learners and himself before introducing new topics. After reading, students engaged in group presentations to share their findings (Finding 4.3.6.2). This strategy aimed to help students understand upcoming lessons and identify areas of difficulty and comprehension. David's decision to use this strategy stemmed from observing that learners often struggled with differentiating terms like specific heat capacity and heat capacity. Drawing from his extensive teaching experience, David recognised common student difficulties with certain concepts. However, it was noted that he did not consistently incorporate this awareness into his lesson plans, neglecting to address potential learning difficulties or misunderstandings (Finding 4.4.4).

In the pre-lesson interview (Finding 4.2.2), David explained that the prior reading and peer teaching approach served as advance preparation, aiming to ensure students had a basic understanding and could actively contribute in class while also highlighting areas of difficulty and understanding.

For effective teaching in thermal physics, David's PCK profile should include an understanding of students' existing knowledge and their difficulties with new topics. Preconceptions, misconceptions and errors could be used as a foundation for teaching accurate concepts (Cazorla, 2006).

David also used familiar contexts to introduce thermal physics concepts (Finding 4.3.6.2). By incorporating real-life applications and simple demonstrations, he intended to make the topic more relatable and engaging for students. Research indicates that context-based teaching significantly improves learner performance (Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Kazeni & Onwu, 2013; King & Ritchie, 2013).

Additionally, David used labelled diagrams to enhance explanations and promote understanding (Finding 4.3.6.2). His instructional strategies in PCK included illustrations, demonstrations, and analogies.

However, David did not indicate in his lesson plans or instructional strategies that he considered students' potential preconceptions about thermal physics. He frequently used oral questioning to assess students' prior knowledge, understanding during lessons, and retention afterward (Finding 4.3.6.2). In pre-lesson interviews (Finding 4.2.2), David noted that this approach provided immediate feedback and helped identify misconceptions or difficulties. Nonetheless, students sometimes relied on textbook answers for unfamiliar concepts, so David's questioning technique did not always aim to elicit students' own ideas or probe their preconceptions Despite this, David identified students' preconceptions and errors through group discussions, students' oral questions and peer teaching. His post-lesson interview (Finding 4.4.4) indicated that he attributed difficulties with thermal physics concepts to their abstract nature. The review of students' notebooks (Finding 4.5.2) confirmed that elements of David's PCK emerged from his identification of difficulties during their group presentations and peer teaching. Oral questioning techniques and homework assignments were specific strategies he used to diagnose students' difficulties and assess understanding.

In summary, David's PCK in teaching thermal physics included declarative, procedural, and conditional content knowledge, along with instructional strategies such as context-based teaching, peer teaching, group presentations, and analogical teaching. His effective pedagogical strategies included advance preparation through peer teaching, simple demonstrations, diagnostic questioning, and homework assignments. However, his instructional strategy lacked consistent follow-up with probing questions to uncover the reasons behind students' difficulties and misconceptions.

Regarding David's development of PCK in thermal physics, he received formal education in physics through his Bachelor of Science degree. David reported that his knowledge of thermal physics came from his degree coursework, and he learned teaching methods and strategies, including using familiar contexts, through his methods courses. With sixteen years of experience teaching physics at the senior high school level, David noted a shift from traditional lecture-based methods to a more learner-centred approach, which positively impacted student performance in external examinations.

David also attended in-service physics workshops organised by the Ghana Education Service (GES) and teacher unions (GNAT, NAGRAT), which influenced his ability to select appropriate representations for thermal physics topics. He learned to use and create Teaching and Learning Materials (TLMs) from these workshops. David also used curriculum documents and recommended textbooks to prepare his lessons.

The analysis of David’s lessons revealed that his content knowledge varied depending on the topic. David became aware of student confusion through their presentations and responses. However, he appeared to have limited knowledge of students' preconceptions, which might not have been adequately addressed in his professional development courses.

In summary, David's PCK development in thermal physics was influenced by formal education, in-service training, classroom experience, and curriculum resources. His instructional strategies reflected a broad range of PCK competencies, though there were areas needing improvement in addressing student misconceptions and preconceptions.

5.2 Chapter Summary

The chapter began by briefly highlighting the research themes and the components of pedagogical content knowledge that served as a conceptual framework for this study. In all, the participating teachers demonstrated the necessary content knowledge in teaching thermal physics. However, their teaching knowledge mainly consisted of declarative content knowledge, which they used to convey facts and principles about thermal physics concepts, specifically focusing on heat as a form of energy and the effects of heat energy on substances. Three teachers employed procedural and conditional content knowledge to explain the processes of quantity of heat and modes of heat transfer.

Regarding instructional strategies for teaching thermal physics concepts, the teachers employed a context-based teaching approach using familiar and real-life examples, while their instructional strategies primarily involved the use of labelled diagrams and illustrations. However, all six teachers lacked knowledge of learners' preconceptions regarding thermal physics concepts. Three teachers identified learners' errors and difficulties through learners' inadequate responses, peer teaching, oral questioning techniques, classwork, homework, and assignments.

The teachers' PCK in teaching thermal physics was assumed to have mainly developed through formal university education programmes and their reliance on recommended physics textbooks and physics syllabus for lesson planning and teaching. Additionally, the teachers attended several in-service workshops, which may have contributed to their PCK in teaching thermal physics concepts. The chapter concludes with a summary of its key findings.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.0 Overview

This chapter discusses the summary of findings of the study. It brings together the research questions that guided the investigation, research findings according to their themes, and presents the conclusions, recommendations, as well as the study's contribution to knowledge.

6.1 Summary of Teacher PCK Profiles and Development

The study came out with a number of findings as summarised. It starts with teachers' content knowledge demonstrated in class, the instructional strategies used and concluded with teachers' knowledge of learners' preconception and learning difficulties exhibited.

6.1.1 Teachers' content knowledge in teaching thermal physics

The study, under teachers' content knowledge came out with three findings. These findings have been summarised as follows.

1. The Use of Declarative and Factual Knowledge: All six participating physics teachers predominantly used declarative content knowledge, focusing on stating facts and definitions to teach various thermal physics concepts such as thermal equilibrium, heat as a form of energy, specific heat capacity, and the effect of heat on substances (Krathwohl, 2002; Findings 4.3.1.1 - 4.3.6.1). These concepts are known to be challenging for learners to grasp and differentiate (O'Connell, 2019; Meltzer, 2004; Carlton, 2000; WAEC, 2017). The teachers' preference for the use of factual knowledge was probably influenced by the WASSCE syllabus, which placed significant emphasis on the importance of understanding these defi-

nitions and the effects of heat energy on substances. When it came to teaching thermal physics calculations and mechanisms like quantity of heat and modes of heat transfer, five out of the six teachers (Ben, Kalulu, John, Daniel, and David) primarily employed practical related content knowledge. They used supporting activities and illustrations to make these stages more accessible to learners, including content knowledge related to specific heat capacity and specific latent heat (Finding 4.3.1.1– 4.3.6.1). The choice to use factual or practical oriented knowledge depended on the nature of the topics being taught. However, there was some ambiguity in interpreting the syllabus regarding the details of teaching processes such as conduction and convection, which may have caused confusion. For instance, Carl, the third teacher, interpreted the syllabus differently and did not teach the stages of conduction and convection mechanisms (Finding 4.3.3.1). It is likely that Carl's pedagogical content knowledge for teaching heat concepts and effects of heat on substances consisted primarily of descriptions, as observed in the teaching approach and interview responses (Findings 4.3.3.1; ref. 4.2.1).

2. Variability in Contextual Content Knowledge: Ben, Kalulu, John, Daniel, and David made use of contextual content knowledge to explain the significance of these thermal physics processes. However, Carl lacked or did not demonstrate the use of contextual content knowledge, which aims to explain the "how and why" aspects of thermal physics concepts and principles (Juttner et al., 2013). In summary, all six teachers provided explanations of thermal physics concepts' definitions, primarily relying on factual content knowledge. Five teachers demonstrated the use of contextual content knowledge, which is very important in science teaching (Juttner et al., 2013).

3. The Development of Content Knowledge: The teachers claimed that their content knowledge was developed through formal education programmes, such as university courses, classroom teaching experiences, and the use of recommended textbooks and physics syllabus as guidance for planning and teaching thermal physics lessons (ref. 4.4.8).

6.1.2 Teachers' instructional strategies in teaching thermal physics

The study, under teachers' instructional strategies came out with four findings. These findings have been summarised as follows.

1. Teaching from Known to Unknown (Concentric Approach): The six physics teachers used innovative teaching strategies which included the use of familiar everyday-life experiences and examples, relevant scenarios, and well-known parallels. By drawing connections between these everyday situations and new thermal physics concepts, the teachers guided their students from the known to the unknown. The teachers started their lessons by either reviewing related topics previously covered or presenting scenarios that were relevant and well-known to the students. By drawing parallels between these familiar examples and the new concepts, they guided their teaching from the known to the unknown.

2. Use of Visual Aids and Interactive Learning: The teachers made use of visual teaching and learning materials such as labelled diagrams from recommended physics textbooks and the internet, along with demonstrations and group learning activities. The teachers employed these teaching strategies to facilitate students' understanding of abstract or unobservable phenomena, fostering a connection between scientific knowledge and their everyday experiences. The use

of illustrations and interactive learning encouraged active engagement, helping students visualise thermal physics concepts and generating interest in the subject matter. Illustrations, scientific charts, and familiar examples were used to enhance visualization and conceptual understanding. Analogies and realias were employed by teachers like Carl, David, and Ben to further deepen the students' comprehension (Coll et al., 2005; Oliveira et al., 2013; Treagust & Harrison, 2000). These strategies were geared towards making abstract scientific content more tangible and engaging Five of the teachers, namely Ben, David, Kalulu, Daniel, and John, incorporated demonstrations and group learning activities into their teaching approaches.

3. Omissions and Future Improvements: It is worth noting that experimental work and the use of improvised materials were not included in the observed lessons and lesson plans. This omission is a concern since learner experiments and use of improvised materials are considered essential instructional strategies in science teaching and learning. The absence of these strategies in the teaching of the thermal physics concepts was not clearly explained. Nevertheless, the teachers expressed their intention to organise laboratory experiments for the students in the following year. In post-lesson interviews, all six teachers acknowledged the need for improvement in their future teaching of the same concepts. They expressed their plans to enhance their lessons in various ways, such as incorporating videos. Reflective thinking on teaching practices is likely to improve instruction, and teachers are advised to adopt a reflective philosophy to enhance their practice and potentially improve student achievement.

4. The Development of Pedagogical Knowledge: The teachers' knowledge of instructional strategies for teaching thermal physics concepts is presumed to have developed through formal education programmes, including university methods courses and classroom practice involving planning and teaching thermal physics lessons using recommended textbooks. Additionally, their knowledge may have been further developed through attendance at in-service physics workshops and collaboration with colleagues within the school's physics department.

6.1.3 Teachers' knowledge of learners' preconceptions and learning difficulties in teaching thermal physics

The study, under teachers' knowledge of learners' preconceptions and learning difficulties in teaching thermal physics, came out with three findings. These findings have been summarised as follows.

1. Absence of Learners' Preconceptions and Learning Difficulties in Teaching: The participating teachers in the study did not show knowledge of learners' preconceptions in thermal physics teaching (Finding 4.2.3). Analysis of their lesson plans showed no evidence of prior knowledge of learners' preconceptions in these topics. To effectively plan their lessons, teachers should consider learners' preconceptions and include activities to address potential learning difficulties (Morrison & Lederman, 2003; Penso, 2002; Yilmaz et al., 2011). During pre-lesson interviews, the teachers stated that they would use the oral probing questioning technique to understand learners' prior knowledge. It is important for teachers to consider learners' preconceptions at the planning stage and incorporate activities that address these preconceptions to facilitate

effective teaching and learning. The display of little or no prior knowledge of learners' preconceptions in thermal physics teaching by all six teachers, despite their training and experience, raises concerns about their classroom practice, particularly their assessment techniques and reflective practice. Surprisingly, none of the teachers included knowledge of learners' preconceptions and learning difficulties as teaching points in their lesson plans. Effective assessment procedures should provide learner feedback, which is valuable information for teachers but often neglected. The absence of prior knowledge of learners' preconceptions in thermal physics teaching among the six teachers, despite their experience, may be attributed to the absence of reflective processes or thinking in their teaching practice. The teachers' lesson plans provided no evidence of considering or addressing learners' preconceptions in thermal physics teaching. They primarily relied on the physics syllabus and textbooks as their sources of information for teaching content and assessment (Finding 4.4.8). Reflective thinking skills are not emphasised in classrooms. However, research suggests that reflective thinking is important for teachers' success in the classroom and as a lifelong skill (Leonard et al., 2009). Therefore, reflective thinking skills should be a major objective of teacher education programmes. The finding supports Magnusson et al.'s (2001) assertion that years of teaching experience alone do not guarantee the development of pedagogical content knowledge (PCK). Reflecting on the nature and outcomes of their teaching, including the successes and difficulties learners experience, enhances the impact of teachers' classroom experience on PCK development (Drechsler & Van Driel, 2008). Encouraging teachers to reflect on their teaching is likely to foster the development of PCK (Leonard et al., 2009). Teachers who lack the skill and practice of reflection are at a disadvantage in developing rich PCK.

2. Identifying Learners' Learning Difficulties in the Middle of Lesson: It was observed that teachers only tend to identify learners' learning difficulties through classroom teaching experiences. Observations during the lessons revealed that teachers in attempt to review lessons, used oral questioning techniques to elicit knowledge about previously taught concepts, not learners' ideas about the new concepts (Finding 4.3.1.2– 4.3.6.2). The assessment techniques used by the teachers, as observed during lesson observations and document analysis, were not diagnostic in nature and did not provide insights into learners' existing conceptions (Finding 4.3.1.2– 4.3.6.2; Finding 4.5.1.2). The teachers predominantly used recall or closed-type questions, and written assessments focused on recalling facts. The absence or rarity of "why" questions, which encourage critical thinking and reasoning, was notable in the teachers' assessment procedures. Effective science teaching requires learners to understand the "what," "how," and "why" of concepts, and this has to do with factual, procedural, and contextual knowledge (Juttner et al., 2013). By using probing questioning techniques and open-ended questions, teachers can develop a knowledge base of learners' preconceptions, misconceptions, and difficulties, which informs their lesson planning. Five of the six teachers identified learners' difficulties in learning about thermal physics through oral questioning, learner presentation (peer teaching), and classwork, homework and assignments (Finding 4.3.1.3 – 4.3.6.3). These difficulties included incomplete definitions of thermal equilibrium, thermodynamics and temperature gradient and confusion with terms like 'specific heat capacity' and 'heat capacity', and a lack of understanding of

conduction and convection processes. It was sometimes unclear whether learners' difficulties were conceptual or linguistic in nature. The teachers became aware of these difficulties through classroom teaching experiences such as oral questioning, written work, and peer teaching.

3. Addressing Learners' Learning Difficulties: The teachers attempted to address learners' learning difficulties through elaborate explanations, giving group work, reviewing assignments, and learner peer tutoring (Finding 4.4.5). Peer tutoring was used because learners who have recently grasped the concepts are likely to teach their peers in a stepwise fashion, paying attention to small details that an expert teacher might overlook.

6.2 Conclusions of the Study

In conclusion, this study aimed to examine pedagogical content knowledge in teaching thermal physics among six physics teachers and the factors that contributed to the development of their PCK in this area. The study revealed the following findings:

- The six teachers had the necessary content knowledge required to teach thermal physics at the senior high school level. Their knowledge was categorised into three dimensions: factual, practical, and contextual understanding. All six physics teachers used their factual knowledge to present facts, definitions, and explanations of thermal physics concepts, terms, and processes. However, five of the teachers primarily relied on practical and contextual knowledge when teaching modes of heat transfer and quantity of heat energy. In physics, the application of contextual knowledge is importance. One teacher failed to demonstrate the use of practical and contextual knowledge when teaching thermal physics processes, mechanisms, and calculations involving quantity of heat, due to misinterpretation of the physics syllabus. This teacher saw no need to teach the processes and mechanisms of some thermal physics concepts since the physics syllabus did not specify the requirement of such details.

- In terms of teaching strategies in the PCK framework, all six teachers introduced thermal physics topics using everyday examples and familiar contexts that resonated well with their students. This approach aimed to engage students, increase the relevance of instruction, and improve overall learning outcomes. When needed, teachers supplemented the use of familiar contexts with visual teaching and learning materials to help students visualise processes and understand abstract thermal physics concepts. A teacher named Ben employed additional teaching strategies such as: asking the learners to do advance reading and peer teaching, taking into account students' prior knowledge. Additional instructional techniques included diagnostic questions, classroom assignments, homework, and assignments to assess student understanding of thermal physics concepts and to identify any preconceptions and learning difficulties.

- None of the six teachers showed prior awareness of students' preconceptions and learning difficulties about certain thermal physics concepts and terminology. Absence of this awareness may be due to the fact that teachers generally were not doing reflective practice and rarely use reflective journals or journals to document their thoughts on successes, failures and potential improvements in the classroom. This paucity of reflective practice is evident in their lesson plans, which failed to show how they consider students' preconceptions and anticipated learning difficulties as a foundation for instructional approaches. Generally, students' challenges were identified through peer teaching, oral questioning, and assessment of written work. These challenges were then addressed through various means, including individual or collective teacher engagement with students. This mitigating measures, coupled with their adequate content and instructional knowledge could be accounting for their students' good performance.

- Based on the study's findings, it is assumed that the following factors contributed to individual teachers' PCK development in thermal physics teaching:
  - Formal university education programmes: Teachers acquired content knowledge through university courses focused on thermal physics and methods courses in physics teaching, which may include specific instruction on thermal physics.
  - Classroom teaching experience: The physics teachers developed their pedagogical knowledge by creating and implementing lesson plans related to thermal physics topics, aligning with their understanding of the subject's nature and effective teaching methods. They used recommended physics textbooks, as well as the physics syllabus, to enhance their content and pedagogical knowledge in teaching the subject.
  - In-service physics training workshops: Attending national workshops focused on teaching challenging topics such as thermal physics provided teachers with additional opportunities to learn relevant instructional strategies.

6.3 Contribution to Knowledge

Findings from this study are used to paint the exact picture of the physics teachers' PCK profile to reflect the situation in the classrooms so as to improve teachers' practice which will eventually influence student understanding and achievement in physics.

A limited number of previous studies in PCK were conducted to ascertain how some teachers developed their subject- specific PCK in disciplines such as mathematics (An, Kulm & Wu, 2004; Nadas, 2019; Haciomeroglu, 2006), chemistry (Shing, 2016) and biology (Lankford, 2010; Mthethwa-Kunene, 2014). No study has been found to have investigated the quality and status of PCK of physics teachers in teaching the concepts of thermal physics.

This study therefore has contributed the following to teaching and learning of physics:

Identification of Strengths and Gaps in PCK: Through the analysis of the collected data, the study revealed that the participating physics teachers possessed a solid understanding of thermal physics content knowledge and employed effective topic-specific instructional strategies. However, it also highlighted a limitation in their knowledge of learners' preconceptions and learning difficulties related to thermal physics. This finding underscored the importance of addressing this gap to further enhance teaching and learning in physics.

Factors Influencing PCK Development: The study identified a number of factors that contributed to the development of the teachers' PCK in teaching thermal physics. These factors include formal university education programmes, years of classroom teaching experience, peer support, and participation in in-service workshops. Understanding these factors can inform teacher education programmes and professional development initiatives to better support the cultivation of PCK among physics teachers.

Focus on pedagogical content knowledge (PCK): The study has highlighted the importance of teachers' knowledge base, specifically their pedagogical content knowledge, in influencing student understanding and achievement in physics. By investigating the PCK of well-performing physics teachers, the study has thrown light on the role of PCK in enhancing students' learning outcomes.

Identification of Well-Performing Physics Teachers: The study has identified six physics teachers from senior high schools in the Volta Region whose students had consistently produced good results in the West African Senior School Certificate Examination (WASSCE) over a five-year period. By studying these teachers, the research aimed to understand the factors contributing to their success and how they developed their PCK in teaching thermal physics.

In all, this study contributed to the knowledge base by highlighting the significance of PCK in physics teaching and providing insights into the PCK of well-performing physics teachers. It offered valuable implications for teacher preparation, professional development, and classroom practices, geared towards improving students' learning outcomes in physics, particularly in challenging topics such as thermal physics.

6.4 Recommendations

Based on the findings and contributions of the study on the quality and status of pedagogical content knowledge (PCK) of well-performing physics teachers, the following recommendations are being made:

1. Teacher Professional Development: Given the identified gap in teachers' knowledge of learners' preconceptions and learning difficulties related to thermal physics, it is recommended to provide targeted professional development opportunities for physics teachers. These programmes should focus on enhancing teachers' awareness and understanding of students' misconceptions,

addressing common learning difficulties, and equipping them with effective instructional strategies to address these challenges.

2. Incorporate PCK in Teacher Education Programmes: Teacher education programmes should emphasise the development of pedagogical content knowledge (PCK) among aspiring physics teachers. This can be achieved by integrating courses and experiences that specifically target the understanding of the interplay between content knowledge, pedagogy, and students' learning needs. Emphasising PCK in pre-service teacher education will better prepare future teachers to effectively teach challenging topics like thermal physics.

3. Collaborative Learning Communities: Encouraging collaborative learning communities among physics teachers can foster peer support and sharing of best practices. Establishing platforms for teachers to engage in regular discussions, lesson planning, and resource sharing can facilitate the development of PCK. This collaboration can provide opportunities for teachers to learn from each other, exchange ideas, and collectively address challenges related to teaching thermal physics.

4. Strengthening Contextual and Conditional Knowledge: Since three of the teachers relied mainly on declarative knowledge when teaching modes of heat transfer and quantity of heat energy, it is recommended to provide professional development opportunities that specifically target the development of procedural and conditional knowledge in thermal physics. Workshops, seminars, and training programmes can be organised to enhance teachers' understanding and application of procedural and conditional knowledge, especially in areas where they may have misconceptions or misinterpretations of the syllabus.

5. Mentorship Programmes: Implementing mentorship programmes where experienced physics teachers mentor novice teachers can be beneficial. Mentors can provide guidance, share their expertise, and support the development of PCK in newly trained teachers. These mentorship relationships can facilitate the transfer of effective instructional strategies, help address specific challenges, and contribute to the ongoing professional growth of early-career physics teachers.

6. Emphasising Reflective Practice: Encouraging teachers to engage in reflective practice can enhance their awareness of students' preconceptions and learning difficulties in thermal physics. Teachers should be encouraged to regularly reflect on their teaching practices, document their experiences, and consider how to address students' misconceptions and difficulties. Promoting the use of reflective journals or reflective teaching portfolios can serve as effective tools for teachers to engage in ongoing self-reflection and improve their instructional approaches.

7. Expansion of Professional Development Opportunities: In addition to formal university education programmes and in-service workshops, it is recommended to provide a variety of professional development opportunities for physics teachers if it is ongoing. These can include online courses, webinars, conferences, and subject-specific forums where teachers can deepen their content knowledge, enhance their pedagogical skills, and stay updated with the latest research and instructional practices in thermal physics. Collaboration with educational institutions and organisations can help facilitate access to these resources.

8. Longitudinal Studies: Conducting longitudinal studies that track the development of PCK among physics teachers over an extended period can provide insights into the long-term effects of professional development interventions. These studies can assess the impact of various factors such as continued education, mentoring, and collaborative practices on the growth of teachers' PCK and their students' learning outcomes.

By implementing these recommendations, educational stakeholders can promote the enhancement of pedagogical content knowledge among physics teachers, leading to improved teaching experiences, increased student engagement, and better learning outcomes in physics, particularly in challenging topics like thermal physics.

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APPENDIX A

Introductory Letter from Regional Directorate of GES

GHANA EDUCATION SERVICE

In case of reply the number and date of this letter should be quoted.

My Ref. No GES/VR./TJ/1

Your Ref No ....

REPUBLIC OF GHANA

REGIONAL EDUCATION OFFICE
P. O. BOX HP46,
HO. VOLTA REGION
TEL: 036- 2026461, 2026463/4
Email: **gesvred@gmail.com**

28nd November, 2022

RE: PERMISSION TO CONDUCT RESEARCH IN SOME SCHOOLS IN VOLTA REGION

With reference to your letter dated 17th October, 2022 requesting for permission to conduct research in some selected Second Cycle Schools, Management of the Volta Regional Education Directorate writes to inform you that your request has been granted.

Please note that all activities must be conducted within the confines of the rules and regulations of Ghana Education Service and we trust you will ensure that your activities will not disrupt the smooth and serene working environment.

The Directorate believes that, this is a valuable endeavour that will significantly help both students and Teachers improve upon teaching and learning in the region.

By a copy of this letter, all Municipal / District Directors of Education and Heads of Second Cycle Institutions are hereby encouraged to give the needed support and assistance he may need.

Thank you.

PAULINA SLYN EWORDE GOBE (MRS)
AKATSI SOUTH MUNICIPAL DIRECTOR
For: REGIONAL DIRECTOR
VOLTA

MR. GEOFFREY KLUTSE
PEKI COLLEGE OF EDUCATION
P.O. BOX 14
PEKI

Cc:

All District/Municipal Directors, Volta
All Heads of Second Cycle Institutions, Volta

C.A/PU

APPENDIX B

Letter from the Head of One of the Main Study Schools

MAWULI SCHOOL

(GHANA EDUCATION SERVICE)

P. O. Box MA 45
Ho. V/R. Ghana

Headmaster: J. G. Adomah, M. .. Agric. Adm., PGDE, B.Sc.(Hons.)
Banker: ('CB Main 1 10
4190
Phone: 020 066

6th February,

Ref. No.GES/VR/MS.99/VOL.III/259

MR. GEOFFREY KLUTSE, PEKI
COLLEGE OF EDUCATION,
P.O. BOX 14,
PEKI.

RE-PERMISSION TO CONDUCT RESEARCH STUDY IN YOUR SCHOOL

Reference to your letter to us requesting to conduct a research in Mawuli School on the topic: Quality and Status of Physics Teachers' Pedagogical Content Knowledge in Senior High Schools in Volta Region, we write to inform you that your permission has been granted.

You are expected to liase with the Head of Department (HOD) of Science for the Conduct of your research.

Thank you,

(JONATHAN GUSTAV ADOMAH)
HEADMASTER

HEADMASTER
MAWULI SCHOOL
HO. V/R

APPENDIX C

Pre-observation interview schedule for elective physics teachers about their lesson plans.

Duration: 30 minutes

1. For how long have you been teaching elective physics?

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2. What are your academic qualifications?

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3. What are your major subject areas?

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4. What factors did you consider in preparing this lesson plan?

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5. How do you intend to teach this lesson?

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APPENDIX D

Lesson observation schedule for elective physics teachers on classroom practice

Date: School: ……………………………………………………………………….

Class: ………………………………………………………………………………….

Teacher: ……………………………………………………………………………….

Observer: ………………………………………………………………………………

Role of observer: ………………………………………………………………………

Length of observation: …………………………………………………………………

Lesson Topic: ………………………………………………………………………….

Lesson objectives

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Lesson introduction

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Content presented and how it is presented

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Learners' preconception

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Learners' difficulties

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Teaching strategies and activities

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Presentation of lesson

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Lesson involvement

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Evaluation/conclusion of lesson

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Reflections (insights)

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APPENDIX E

Post-lesson interview schedule for elective physics teachers concerning how they developed their PCK in teaching the concept of thermal energy.

Duration: 45 minutes

1. What courses did you learn at university which helped you to prepare and teach your thermal physics lessons?

2. Has teaching concept of thermal physics over the years helped you teach the topic better? If yes, how?

3. How do you know your teaching is effective?

4. What learning difficulties do your learners experience in learning this concept?

5. What makes those areas difficult for learners to understand?

6. If learners have any problems in understanding the topic based on the instructional approach, what do you do to help them to understand?

7. Have you ever been to a physics workshop on teacher development?

a. If yes, what was the content, and duration of the workshop?

b. Who were the facilitators (Physics educators)?

c. As a physics teacher, how did you benefit from the workshop?

d. Would you recommend that similar workshops be held for teachers?

8. Have you ever been to a workshop, specifically on the concept of thermal energy? As a physics teacher, how did you benefit from the workshop? Would you recommend that similar workshops be held for teachers?

9. Do you collaborate with other teachers in your department about teaching? If yes, how has that helped you in your teaching?

10. What other sources of information do you use?

APPENDIX G

Criteria for validating pre-lesson observation teacher interview schedule for teachers on lesson plans and how they developed their PCK in teaching thermal physics.

Preamble

Please find attached a pre-lesson observation teacher interview schedule. Please indicate in the space provided if the attached interview questions cover what it is meant to cover. Thus, the questions are supposed to assess the physics teachers' demographic information, educational background, content knowledge, knowledge of instructional strategies and knowledge of learners' preconceptions and learning difficulties, which aided the development of their pedagogical content knowledge in teaching of thermal physics concepts.

Pre-lesson Observation Interview Schedule

A	**Background Information**	**Options**	**Response**
1	Does the schedule request for the participants' qualification(s)?	**Yes/No**	
2	Does the schedule request for major subjects?	**Yes/No**	
3	Does the schedule request for number of years teaching physics?	**Yes/No**	
B	**Content Knowledge**	**Yes/No**	
4	Does the schedule request teachers to describe their lesson plans in detail and how they would teach the lesson?	**Yes/No**	
5	Will the schedule be able to provide information on concepts to be taught in the lesson?	**Yes/No**	
6	Can the schedule elicit information on what the teacher intends leaners to know?	**Yes/No**	
7	Can the schedule elicit information on reasons why it is important for learners to know the intended information?	**Yes/No**	
8	Can the schedule elicit more information on the teacher's knowledge about the concepts that he/she is going to teach?	**Yes/No**	

C	**Instructional Strategies**		
9	Does the schedule request teachers to describe their lesson plans in detail and how they would teach the lesson?	**Yes/No**	
10	Can the schedule yield information on teaching procedures to be used and reasons for their selection?	**Yes/No**	
D	**Knowledge of Learners' Preconceptions and Learning Difficulties**	**Yes/No**	
11	Does the schedule request teachers to describe their lesson plans in detail and how they would teach the lesson?	**Yes/No**	
12	Can the schedule elicit information on learners' preconceptions and learning difficulties?	**Yes/No**	

Comments

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Name of Ratter (Validator) …………………………………. Signature
……………………..

APPENDIX H

Criteria for validating the lesson plan and observation schedule

Preamble

Please indicate on the attached observation schedule with the option provided, if the schedule contains enough information for assessing a normal classroom practice in terms of lesson planning, observation and what the teacher did while teaching the concepts.

	Description	Option	Response
	Planning		
1	Does the schedule request for lesson topic?	**Yes/No**	
2	Does the schedule request for lesson objectives?	**Yes/No**	
3	Does the schedule request for resources used during the lesson?	**Yes/No**	
	Content		
4	Does schedule request for content taught?	**Yes/No**	
5	Does schedule ask for how the content is presented?	**Yes/No**	
	Instructional strategies		
6	Does the schedule request for teaching strategies?	**Yes/No**	
7	Does the schedule request for how the lesson was introduction?	**Yes/No**	
	Does the schedule request for general handling of the class e.g.		
	i) Classroom interaction?	**Yes/No**	
	ii) Involvement of the learners?	**Yes/No**	
8	Does the schedule request for lesson presentation or development (progression)?	**Yes/No**	
9	Does the schedule request for how lesson is consolidated?	**Yes/No**	
10	Does the schedule request for the description of the lesson in terms of:	**Yes/No**	
	i) Learners' preconceptions diagnosis?	**Yes/No**	
	ii) Errors, misconceptions and difficulties?	**Yes/No**	
11	Does the schedule request learners' related activities?	**Yes/No**	
12	Does the schedule request teacher related activities?	**Yes/No**	
13	Does the schedule request for reflections?	**Yes/No**	

Comments

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Name of Ratter (Validator) ……………………………… Signature ……………………

APPENDIX I

Criteria for validating post-lesson observation teacher interview schedule for teachers on development of teachers' pedagogical content knowledge

Preamble

Please find attached a post-lesson observation teacher interview schedule. Kindly indicate in the space provided if the attached interview questions cover what it is meant to cover. Thus, the questions are supposed to assess how the physics teachers developed their pedagogical content knowledge in teaching of thermal physics concepts.

	Post-lesson Interview Schedule Validation		
	Development of Teachers' Pedagogical Content Knowledge	**Options**	**Response**
1	Does the schedule request for how the courses studied in the university helped in lesson preparation?	**Yes/No**	
2	Does the schedule request how teaching thermal physics over the years has helped teach the concepts better and how?	**Yes/No**	
3	Does the schedule request for how the teacher knows that his/her teaching is effective?	**Yes/No**	
4	Does the schedule request for learning difficulties experienced by learners?	**Yes/No**	
5	Does the schedule request for what made those areas difficult?	**Yes/No**	
6	Does the schedule request for how learners can be assisted if they experience some learning difficulties based on the instructional approach used by the teacher?	**Yes/No**	
7	If the teachers attend workshop for instance, does the schedule try finding out how effective the workshop was?	**Yes/No**	
8	Does the schedule try finding out if the facilitators of the workshop were physics teachers or not?	**Yes/No**	
9	Does the schedule request for the duration of the workshop?	**Yes/No**	
10	Does the schedule try finding out the benefits derived	**Yes/No**	

	from the workshop?	
11	Does the schedule ask the workshop participants if they would recommend similar workshop for other teachers?	**Yes/No**
12	Does the schedule ask if the teacher attended workshops specific to thermal physics teaching?	**Yes/No**
13	Does the schedule find out how the participant benefited from the thermal physics workshop?	**Yes/No**
14	Does the schedule request for teacher collaboration with other teachers?	**Yes/No**
15	Does the schedule request for other sources used in teaching thermal physics?	**Yes/No**

Comments

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Name of Ratter (Validator) ……………………………………. Signature
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APPENDIX J

Letter from the Headmaster of the Pilot Study School

AWUDOME SENIOR HIGH SCHOOL, TSITO
(GHANA EDUCATION SERVICE)

E-mail: awudomeshs@gmail.com Website: https://awudomeshs.org

P. O. Box TS 33
Tsito, VR
Ghana.

Our Ref: GES/ VR/ASHS/L.9/VOL.38

23rd January, 2023.

Your Ref:

Mr. Geoffrey Klutse
Peki College of Education
P. O. Box 14
Peki

RE- PERMISSION TO CONDUCT PILOT STUDY IN YOUR SCHOOL

Permission is hereby granted you to conduct your research topic: Quality and status of Physics Teachers' Pedagogical content knowledge in Senior High Schools in Volta Region.

I entreat you to stay by the rules and regulation governing the school and teachers who would be involved during observation and inter-views should be given prior information.

I wish you all the best during your stay and hope you get the best out of it.

Thank you.

……………………
COURAGE METEKU
(HEADMASTER)
0246633842

HEADMASTER
AWUDOME SENIOR HIGH SCHOOL
P. O. BOX TS 33
TSITO V/R

APPENDIX K

Consent Letter to Participating Teachers

Peki College of Education,

P. O. Box 14,

Peki.

5th December, 2022.

Dear Teacher,

REQUEST FOR PARTICIPATION IN RESEARCH STUDY

Research Topic: Quality and Status of Physics Teachers' Pedagogical Content Knowledge in Senior High Schools in Volta Region.

I hope this letter finds you well. I am writing to invite you to participate in a research study titled "Quality and Status of Physics Teachers' Pedagogical Content Knowledge in Senior High Schools in Volta Region". This study aims to gain valuable insights into the teaching of thermal physics in the Volta Region and to explore the pedagogical content knowledge (PCK) of outstanding Senior High School (SHS) physics teachers like yourself.

Kindly read the contents of this letter carefully before deciding on participating in the research study.

Purpose of the Research Study:

The primary objective of this research study is to enhance our understanding of the effective teaching of thermal physics in the Volta Region. I intend to achieve this by examining the pedagogical content knowledge possessed by well-performing SHS physics teachers like you who have consistently produced students with good grades over the years.

What You Will be Asked to Do:

If you choose to participate in this research study, you will be asked to engage in the following activities:

1. **Lesson Plan Presentation**: You will be asked to prepare lesson plans for selected thermal physics concepts you will be teaching.

2. **Interviews**: You will be asked to participate in a number of interviews in which we will discuss your approach to teaching thermal physics.

3. **Lesson Observations**: Your lessons will be observed while you teach your thermal physics concepts to gain insights into your pedagogical content knowledge.

These activities are designed to help us gather information about your pedagogical content knowledge and how you use it to teach thermal physics in the classroom.

Voluntary Participation and Confidentiality:

Participation in this research study is entirely voluntary, and you are under no obligation to take part. Your decision to participate or decline will not have any adverse consequences, and your anonymity and confidentiality will be strictly maintained throughout the study. Rest assured that all information collected during this study will be kept strictly confidential, and any data used for research purposes will be anonymised.

Risks:

I want to emphasise that there are no risks associated with your participation. However, it is only natural that, you may feel a bit uncomfortable to have me observe your lessons, but hopefully, you will get used to me. This is not an exercise designed to assess you in any way and the results will not be used anywhere else outside the purpose of the study.

Benefits:

Through participating in this study, you will be asked to keep a log on thermal physics lessons, which will give you an opportunity to reflect on your classroom practice in terms of content knowledge, knowledge of student preconceptions and learning difficulties, successes and difficulties and think about how you can improve the lessons in the future. The reflections may enable you to improve your teaching knowledge and modify teaching strategies in order to enhance learner performance.

Right to Withdraw from the Study

You are free to withdraw from the study at any stage should you wish not to continue.

Agreement: I have read, understood and considered the above, which indicate the researcher's intentions and request for my participation in the research study. I voluntarily agree to participate in this research study. I hereby show my willingness to participate in the study by signing below.

Teacher's Signature ……………………………… Date ……………………..

Audio and Video Recording

The researcher will wish to audio-record the interviews with you and video-record the classroom observations and hereby seek your permission to do this.

I agree to audio- recording: **Teacher's signature** ……………………………

I agree to video- recording: **Teacher's signature** …………………………..

This study is being done under the supervision of Prof. M. K. Amedeker, Department of Science Education, University of Education, Winneba. In case you need further clarification or have questions about the research study, please do not hesitate to contact me or my supervisor through the email: mawuden@yahoo.com.

Please find attached, a copy each of introductory letters from the university, GES regional office and your school headmaster.

Your valuable insights and experiences as a physics teacher are essential to the success of this study, and I sincerely hope you will consider participating.

Thank you in advance for your anticipated cooperation in this regard.

Yours faithfully,

(Geoffrey Klutse)
geoffreyklutse@yahoo.com
0244511857

APPENDIX L

Introductory Letter from the University

UNIVERSITY OF EDUCATION, WINNEBA
FACULTY OF SCIENCE EDUCATION
DEPARTMENT OF INTERGRATED SCIENCE EDUCATION
P. O. Box 25, Winneba, Ghana
+233 (020) 2041077
ise@uew.edu.gh

Our ref. No.: ISED/PG.1/Vol.1/24
Your ref. No.:

11th March, 2022

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

LETTER OF INTRODUCTION
MR KLUTSE, GEOFFREY

We write to introduce, Mr Klutse is a postgraduate student of the Department of Science Education, University of Education, Winneba, who is conducting a research titled:

Quality and status of Physics teachers' pedagogical content knowledge in Volta Region of Ghana

We would be very grateful if you could give him the assistance required.

Thank you.

Yours faithfully,

DEPT. OF INT. SCIENCE EDU.
UNIVERSITY OF EDUCATION, WINNEBA
P. O. BOX 25
WINNEBA

ALEXANDRA N. DOWUONA
PRINCIPAL ADMIN. ASSISTANT
For: HEAD OF DEPARTMENT

www.uew.edu.gh

APPENDIX M

Letter of Informed Consent for Teachers

10th December, 2022.

Dear Teacher

REQUEST TO PARTICIPATE IN A RESEARCH STUDY

Research Topic: Quality and Status of Physics Teachers' Pedagogical Content Knowledge in Senior High Schools in Volta Region.

My name is Geoffrey Klutse, I am a Ph.D student in the Department of Science Education, University of Education, Winneba and also a science tutor in Peki College of Education, Peki. I write to humbly seek your informed consent to participate in this research study. Please read this letter carefully and be convinced by the content before you decide to sign to participate in the research study.

Purpose of the Research Study

You are kindly invited to participate in a research study aimed at gaining some insight into teaching the concept of thermal energy. The study involves an exploration into the pedagogical content knowledge of some outstanding SHS physics teachers in the region. Your school, according to the WASSCE results analysis from Regional Education Office, GES, was identified as one of the best performing schools in the region in elective physics. While some senior high schools are underperforming, your school seems to be doing consistently well within the last five years. I therefore would like to engage you, the elective physics teachers who are behind the production of these good results in a voluntary research study.

What You will be Doing in the Study

The study is expected to invite six elective physics teachers, all from your school. I will be asking you to respond to some research items from the instruments including:

1. Presenting lesson plans for teaching the concept of thermal energy.
2. Be interviewed about your teaching the concept of thermal energy.
3. Be observed teaching the concept of thermal energy lessons.

4. Completing a post teaching interview on some emerging issues from the lesson taught.
5. Providing some teaching and learning documents such as PowerPoint slides used, teaching syllabus and students' workbook for analysis.
6. Drawing a storyline describing how your satisfaction with teaching this concept has developed over the years.
7. Asking information about your Pedagogical Content Knowledge (PCK) and how you use it to teach the concept of thermal energy.

Time Required

The duration for the different activities you will be involved in during the study varies from 10 minutes to an hour and is anticipated to take about six hours in total over a period of two weeks.

Risks and Benefits

Risks: Please know that there are no anticipated risks or harm to you. However, it is usually normal to feel a bit tensed and uneasy to have me observe your lesson during the first few minutes of the first observation. The good thing is that, these feelings go away within a short period. The purpose of the observation is not meant to assess or criticise you in any way and the outcomes of the research will not be used anywhere else outside the purpose of the study. If possible, I would like to come back when the study is completed to inform you of the outcome of the findings.

Benefits: The study might be beneficial to you as it will give you the opportunity to reflect on classroom practice in terms of content knowledge, knowledge of student preconceptions and learning difficulties, successes and difficulties and think about how you can improve the lessons in future.

Voluntary Participation and Confidentiality

Your participation in this study is purely voluntary. Should you agree to participate in this study, confidentiality is guaranteed. Your name or that of your school will not appear anywhere in the research report.

Right to Withdraw from the Study

In the course of the study, if you change your mind and wish to withdraw from the study at any stage, you are free to do so.

Agreement: I have been informed about the study, "Quality and Status of Physics Teachers' Pedagogical Content Knowledge in Senior High Schools in Volta Region"., by Geoffrey Klutse. I have read, understood the purpose and procedures of the study. I have been given an opportunity to answer questions about the study and have had answers to my satisfaction and I may withdraw at any time I so wish. I therefore voluntarily agree to participate in the research study. I hereby show my willingness to participate in the study by signing below.

Teacher's signature ………………………………….. Date …………………………..

Audio and Video Recording

The researcher will wish to audio-record the interviews with you and video-record the classroom observations and hereby seek your permission to do this.

Agreement: I understand that there will be audio-recordings of interviews and video-recordings of classroom observations, which will only be used for purposes of the research study without my name and picture appearing anywhere in the research report.

I agree to audio-recordings: Teacher's signature ………………Date ……………….

I agree to video-recordings: Teacher's signature ………………Date ……………….

This study is being done under the supervision of Prof. M. K. Amedeker, Department of Science Education, University of Education, Winneba. In case you need further clarification or have questions about the research study, you may contact me or my supervisor through the email: mawuden@yahoo.com.

Thank you.

Yours sincerely,

(Geoffrey Klutse)

geoffreyklutse@yahoo.com

0244511857

APPENDIX N

Request for WASSCE Physics Results Analysis

Peki College of Education,
P. O. Box 14,
Peki.
20th October, 2022.

The Regional Director,
Ghana Education Service,
Volta Regional Education Office,
P. O. Box HP 46,
Ho.

Dear Sir / Madam,

REQUEST FOR WASSCE PHYSICS RESULTS ANALYSIS FOR RESEARCH PURPOSES

Research Topic: Quality and Status of Physics Teachers' Pedagogical Content Knowledge in Senior High Schools in Volta Region.

I am a Ph.D student in the Department of Science Education, University of Education, Winneba and a science tutor in Peki College of Education, Peki. I am currently conducting a research on senior high school physics teachers' pedagogical content knowledge as part of the requirement of the programme.

Some senior high schools in your region are consistently producing impressive results in physics in West African Senior School Certificate Examination (WASSCE) in spite of the chief examiner's concern of low performance in some aspects of physics. The study seeks to locate the teachers behind these impressive performances so as to get an insight into their pedagogical content knowledge and to develop an understanding of their teacher knowledge. The findings will reveal the type of pedagogical content knowledge these outstanding teachers have and how they develop it. This will help address the challenges that some physics teachers in underperforming schools face and guide us on how we can improve our practice as science teachers.

I therefore write to humbly request for the WASSCE physics results analysis from 2017 to 2021, which will be used to identify these well-performing schools and teachers in your region. This information will be treated with strict confidence and will be solely used for research purposes.

This study is being done under the supervision of Prof. M. K. Amedeker, Department of Science Education, University of Education, Winneba. In case you need further clarification or have questions about the research project, you may contact me or my supervisor through the email: mawuden@yahoo.com.

Please find attached, a copy of an introductory letter from the university.

Thank you in advance for your anticipated cooperation in this regard.

Yours faithfully,

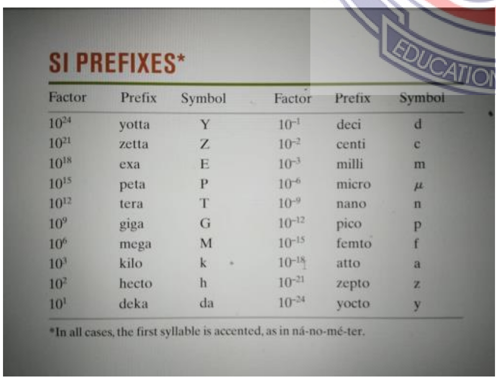
(Geoffrey Klutse)
Researcher
geoffreyklutse@yahoo.com
0244511857

APPENDIX P

Transcription of Ben's lesson observation and analysis

Description of lesson	Categorisation or themes
Classroom context Ben's physics class had 52 learners, consisting of 40 boys and 12 girls of mixed ability. His lessons were taught in a standard science laboratory. The laboratory furniture was in good shape and arranged in rows and columns with enough space for teacher and learner movement. Every student had a notebook to write in.	(a) The classroom context provided a safe learning environment for both girls and boys. (b) All students had notebooks
Lesson one topic: the definition of thermal energy', 'explanation of thermal equilibrium', 'temperature and thermometers', **Class**: SHS 2, **Time**: 60 min.	
Observation	
Lesson Introduction	
Line 1: Ben entered the classroom and greeted his class and informed them that they would be discussing heat and temperature, two very important concepts in thermal physics. He had earlier asked the students to read on the topic. *I hope you have read around the topic as I asked you to.*	**Pedagogical knowledge (PK)**: As part of his teaching strategy, Ben asked learners to read about the concept prior to the start of the lesson.
Line 2: Ben continued *Before we attempt defining thermal energy and temperature, explain this to me. What happens to a red hot stone that has been placed in a metallic plate in an open space for some time?* Learners responded in chorus *It will cool down.* Ben followed up, *What makes it get cold?* Learner 1: *It is the air.* Ben asked the learner to explain. And the learner after several attempts said the wind blew around it made it to become cold. Ben accepted that and indicated that he would explain into details when they get to heat transfer.	**PK**: Ben used questioning technique in a familiar context to arouse interest and engage learners in the discussion of the concept of thermal energy (line 2). **PK**: Ben shouldn't have encouraged chorus answers,
Line 3: Ben continued, *Can anyone tell me what thermal energy is?* (Ben wrote the topic on the board). After a short murmur and attempts, one student responded. Student 2: *Thermal energy is a form of energy that is transferred from one body to another as a result of a difference in temperature.*	**PK**: Ben used questioning technique to elicit response from learners (line 3).
Ben: *That's correct! Well done, Student 1. Heat is a form of energy that is transferred between objects due to a difference in their temperature. For example, when you hold a cup of hot tea, heat is transferred from the tea to your hand, making your hand feel warm.* *So, we can say that heat is a form of energy that is transferred between objects as a result of temperatures difference until they attain thermal equilibrium.*	**Content knowledge (CK):** Ben demonstrated mastery of content here by defining thermal energy and by giving an example.

Description of lesson	Categorisation or themes
Ben then wrote the definition on the board (in the middle of the board just below the topic)	**PK**: Good use of teaching and learning resources.
Line 4: Ben then went on to discuss the SI unit of thermal energy with the learners by asking them, *So what then is the SI unit of thermal energy?*	**PK**: Ben used questioning technique to elicit response from the students (line 4).
Students gave varied responses and one indicated that *since it is a form of energy, the SI unit must be joules.*	
Ben affirmed that answer and congratulated that student for giving that good answer. He then went to the board and took the students through the derivation of the SI unit of heat, joule (J) by doing some illustrations on the board. Students keenly observed. One student asked the following question:	**CK:** Ben demonstrated mastery of content knowledge here by indicating that SI unit of heat is joule (J) and went ahead to derive it.
Ben: *Any questions? Feel free and ask your questions*. A student raised his hand up. Ben called him to talk. Student 2: *Sir if so, when can we use kilojoules (kJ)? Because some book I read was using kJ.*	**PK**: As part of classroom management strategy, Ben created good environment for learners to ask questions.
Ben: *Good question, student 2! You see, we use kJ when the energy involved is quite large. We learnt this last year, didn't we?* The whole class said '*Yes'* though some were looking confused.	**CK**: Teacher content knowledge was used in providing the answers to the learner.
Looking at the expression on the students' faces, Ben decided to bring out a chat containing the SI prefixes as presented in the figure below.	**PK:** It takes experienced teacher to read expressions on learners faces correctly. **PK:** Teacher's teaching strategy was used to look for appropriate teaching and learning materials to support his lesson.



SI PREFIXES*

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

*In all cases, the first syllable is accented, as in ná-no-mé-ter.

Figure 4. Prefix Table

Description of lesson	Categorisation or themes
He took his time to explain to the students. Students nodded their heads in response with some openly saying they then understood.	**CK**: Using his teacher content knowledge, Ben was able to explain the content of the chat to the understanding of the students.
Line 5: Ben, *Now, let's talk about temperature. Tell me, what is your understanding of temperature?* Student 3: *Temperature is when the thing is hot*.	**PK**: Ben used questioning technique to elicit response from the students.

Description of lesson	Categorisation or themes
Ben, *Good attempt, but there's more to that. It's not complete*. Student 2: *It's the degree of hotness or coldness of an object.*	**PK**: Ben used probing question to get more response from learners to measure understanding.
Ben: *Excellent, Student 2! Temperature is a measure of the average kinetic energy of the particles in an object. In simpler terms, it tells us how hot or cold an object is. For example, we can say that boiling water has a higher temperature than ice water.*	**CK**: Teacher content knowledge was used to define temperature and supported it with practical example (line 5),
Line 6: *Now that we know what temperature is, can we discuss the SI unit of temperature?* The whole class *Yes Sir*!	
Ben continued, *What then is the SI unit of temperature*? Student 4: *The SI unit of temperature is Degree Celsius*. Ben, *good attempt though, but that isn't the SI unit. I agree it is the type of unit being used at this part of the world but it is not the SI unit. Any other attempt?* Ben posed the question again while allowing wait time. Student 5: *Is it kelvin Sir?*	**PK**: Ben directed his question to the whole class allowed wait time before calling his student to answer. This is to allow enough room for learners to think of appropriate answers.
Ben remarked: *Excellent, Student 5! The kelvin is the base unit of temperature in the International System of Units (SI) and is used to measure temperature on an absolute scale. It has a symbol of 'K'. Any questions?* Student 4 had his hand up. *Sir if the SI unit is kelvin, then, why do we keep hearing and seeing degree Celsius on television? We hardly hear kelvin when they give us weather report, Why Sir?*	**CK**: Teacher content knowledge was demonstrated here in identifying and explaining the base unit of temperature.
Ben nodding his head in agreement with question, answered; *Yes, in our country, it's degree Celsius that we use. This is what our country has adopted. Some other countries use degree Fahrenheit. I think it's a matter of convenience. Maybe it is easier and more convenient reading temperature in degree Celsius. But the SI unit remains kelvin regardless of what is being used elsewhere.*	**CK**: Teacher content knowledge was used to provide answer to student 4's question.
Ben: *Now, let me teach you how to convert from one temperature scale to the other*. Ben then got to the board and taught his students how to convert from degree celsius to kelvin and from degree celsius to degree fahrenheit while supporting it with a number of example	**CK**: Teacher content knowledge was used to teach conversion of units from ^oC to ^oF to K
Line 7: Ben, *Now, let's talk about thermometers. A thermometer is a device or instrument which is used to measure temperature. Tell me the different types of thermometers that you know of.* Ben then randomly called students to answer the question including those who did not have their hands up. Student 5: *Sir, I know of some types of thermometers like liquid-in-*	**PK**: Ben directed his question to the whole class and randomly called students including those who did not have their hands up.

Description of lesson	Categorisation or themes
glass thermometers.	
Line 8: Ben, *Excellent, Student 5! So, we have liquid-in-glass thermometers, which measure temperature by the expansion of a liquid inside a glass tube. When the temperature of the liquid changes, it expands or contracts, causing the liquid level to rise or fall, which can be read on a calibrated scale. An example of a liquid-in-glass thermometer is a mercury thermometer.*	**CK:** Teacher content knowledge was demonstrated here in explaining liquid-glass thermometers and in giving example (line 8).
Ben then brought out a number of liquid-in-glass thermometers and gave them out to students in group to observe.	**PK:** Teacher's teaching strategy taught him to support his lessons with teaching and learning materials (realia).
Ben: *Yes, any other thermometers that you know of? Student 6, yes.* Ben picked on student who did not raise her hand up.	PK: Questioning technique was used to elicit response from learners.
Student 6: *I think bimetallic thermometers, and some other ones.* This came from a student who was picked on (she did not raise her hand up in readiness to answer the question).	**PK:** Teacher's teaching strategy was employed to get a learner who was not ready to answer a question involved in the teaching process (line 8).
Ben: *Great answer student 6! Let's clap for her, wao!*	**PK:** Teacher's teaching strategy was used to motivate student 6.
Line 9: *Ben, bimetallic thermometers measure temperature by the expansion of two different metals that are joined together. When the temperature changes, the two metals expand at different rates, causing the metal to bend. The amount of bending can be used to measure the temperature. An example of a bimetallic thermometer is a kitchen thermometer.*	**CK:** Teacher content knowledge was demonstrated here in explaining bimetallic thermometers and in giving example (line 9).
Ben then displayed a chart containing pictures of a bimetallic thermometer on the board.	**PK:** Teacher's teaching strategy was used to look for appropriate teaching and learning materials to support his lesson for better understanding.

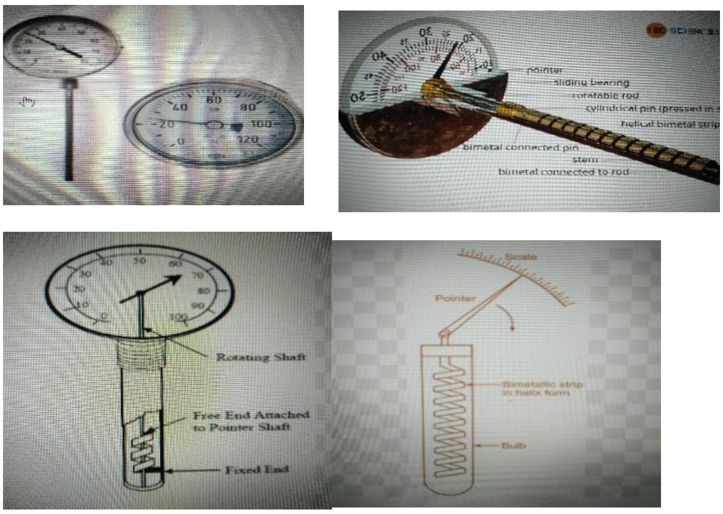
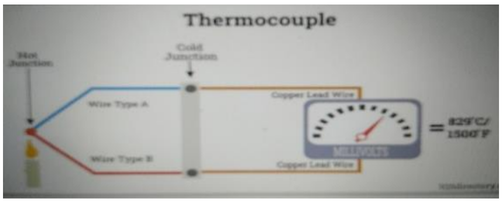
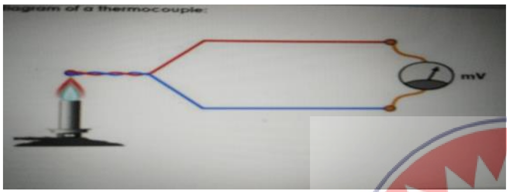


Figure 5. Bimetallic thermometers

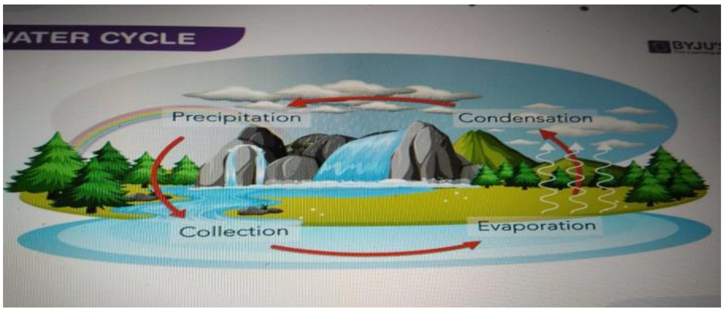
Description of lesson	Categorisation or themes
Ben then discussed the structure, the composition and function of the bimetallic thermometer.	
Line 10: Ben again indicated that there is yet another type of thermometer called thermocouples. He then discussed thermocouples with the students and supported his teaching with pictures of thermocouples.	**CK:** It takes teacher content knowledge to identify and discuss the structure, composition and functions of this device Line 10).
	**PK:** Teacher's teaching strategy was used to look for appropriate teaching and learning materials to support his lesson.
	**CK: C**ontent knowledge was used to identify and discuss the structure, composition and functions of this device.
Figure 6. Thermocouples	
Ben then discussed the structure, the composition and function of the thermocouples.	
Line 11: Ben, *Thermocouples measure temperature by the voltage generated by the junction of two different metals. The voltage generated by the junction is directly proportional to the temperature, allowing the temperature to be measured. An example of a thermocouple is a thermometer used in industry to measure high temperatures.*	**CK:** Teacher content knowledge was demonstrated here in explaining thermocouples and in giving example (line 11).
Ben: *Do you understand the different types of thermometers we have discussed?* Class: *Yes, Sir!*	**PK:** The question was directed to whole class and not to individuals to ascertain understanding.
Ben: *Do you have any questions for me?*	
Class: *No, Sir!*	
Ben: Great! That's all for today's lesson on heat, temperature, and thermometers. I hope you all have a better understanding of these concepts now. Any questions before we end the class?	
Class: *No, Sir!*	
Ben: Then I have some few questions for you	
Learner assessment	

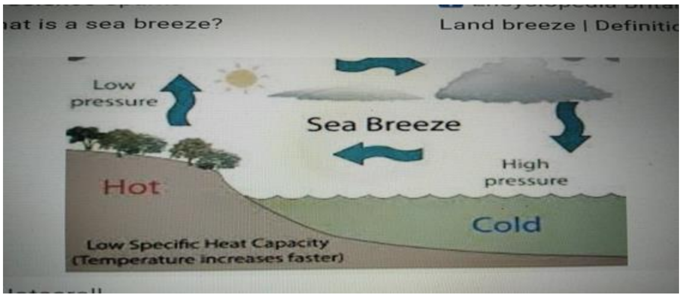
Description of lesson	Categorisation or themes
Line 12: As a way of summarising the lesson, Ben asked learners to individually define heat in their own words: Ben: *Frame your own definition of heat from the discussion we have had so far.*	**PK:** As part of teaching strategy, questioning of individual learners was used to assess how well learners had grasped the concept of heat energy (line 12).
Line 13: The learners gave varied responses ranging from *'heat is a form of energy that gets transferred from a region of higher temperature to the region of lower temperature'* which was derived from part of the teacher's definition to '. *heat is a form of energy that is transferred between two bodies as a result of temperature difference.* These definitions were the result of Ben's intervention during the first stage of definition of concept of thermal energy. He emphasised that heat only gets transferred due to temperature difference. Learners were able to identify that heat energy moves as a result of change in temperature.	**CK**: Ben used content knowledge to ascertain if the students' definitions were correct (line 13). **PK:** Probing questions were used to elicit comprehensive definition of the concept of thermal energy (line 13).
Line 14: Ben accepted both definitions as correct.	**CK:** Ben used his content knowledge of thermal physics to provide learners with feedback (line 14).
Line 15: Ben then put some figures from the reading of thermometer on the board and asked learners to convert them from one temperature scale to the other.	**CK:** Ben used his content knowledge of temperature scale to provide learners with feedback (line 15).
Line 16: learners worked individually in attempt to convert from one temperature scale to the other.	**PK:** Ben used a questioning technique involving written work to assess learners' understanding of temperature scale (line 16).
Line 17: Ben went round to supervise learners' work.	**PK:** Ben paid individual attention to learners (line 17).
Line 18: After a while, Ben then went to the board and took the learners through the calculation coupled with a lot of explanation and questioning.	**CK:** Ben used his content knowledge to provide answers to his students (line 18). **PK**: The explanation done and questioning skills displayed is part of his teaching strategies (Line 18).
Homework	
Line 19: Ben then gave students homework by writing it on the board. In this homework, learners were made to name the three types of thermometer discussed, draw and label one. Some further calculations based on temperature scales were also given. Line 20: Lastly the learners were asked to do some reading assignment on source of heat, effects of heat on substances and methods of heat transfer. He added that they should make use of the syllabus	**PK**: As part his teaching Ben used homework and assignment to give learners a chance to demonstrate their knowledge and understanding or lack of it about thermal physics (lines 19 and 20).

Description of lesson	Categorisation or themes
while doing the homework and they may be asked to present in group in the next lesson.	
Lesson two topics: 'sources of heat' and 'effects of heat on substance', **Class**: SHS 2, **Time**: 60 min.	
Line 1: Ben started his lesson by reviewing the previous lesson in which he asked them to defined heat energy, temperature and name their SI units. He further asked them to do some unit conversion and name any three temperature scales and any three types of thermometers.	**PK**: Ben used his teaching strategies to distribute questions evenly among learners in the course of review of the previous lesson (line 1).
Line 2: Learners defined heat energy, temperature and named temperature scales and types of thermometers correctly. They however needed probing and a little assistance to do unit conversion correctly. For example, one of them was asked to convert 17kJ to joules(J), the learner gave answer as 170J instead of 17,000J.	**CK**: Ben's content knowledge was used to determine learners' inadequate responses and conversion of units.
Line 3: Ben did some probing; *How did you get that answer?* Learner: *I multiplied it by 10 to get 170J*. Teacher then asked: *Why did you use 10?* No answer from learner in question.	**PK**: Probing questions directed to the whole class were again used to elicit information (line 3).
Ben then asked the class about what to do. Learner 2 answered by saying that: *since it is kilojoules, kilo stands for* 10^3 *which also means 1000, we therefore have to multiply the 17 by 1000 to get 17,000J.*	**CK:** Teacher's content knowledge was used to provide learner feedback (line 3).
Ben: *Beautiful! Exactly! Clap for him!* The teacher then asked the learner who got the answer wrong if he had understood the procedure and he responded in affirmative. Ben then concluded the review of the previous lesson on that note and began a new lesson on 'sources of heat'.	PK: Ben asked that they clap for student 2 as a way of motivating him (line 3).
Line 4: Ben: *Now let's talk about sources of heat. I asked you to read about sources of heat. What are some source of heat that you know of?* Learner 1: *Sir, the Sun*.	**PK**: Questioning technique was used to elicit response (line 4).
Ben: *Yes, that is correct but I want group 1 to present on that. Yes group 1 come forward now and do your presentation. Present all that the syllabus allows on sources of heat. Every member should be ready to talk when asked to. You may start.*	**PK:** Ben advised learners on what to focus on based on the provisions of the syllabus and the instruction attached to the home work (line 4).
Learner Group Presentation	
Line 5: Learners came forward in a group of seven with some notes and some textbooks in their hands. The group lead started while writing on the board: *Some sources of heat are;- the sun, combustion and electricity.*	**PK**: Learner activities in the form of group work or peer teaching was used by Ben to foster collaboration among learners and to assess the extent of understanding based on homework given to them. (lines 5-6).

Description of lesson	Categorisation or themes
Line 6: One group member stepped forward and started presenting*: The sun is the primary source of heat energy on Earth. The heat from the sun is transferred to the Earth's atmosphere and is responsible for many weather patterns, such as wind, rain, and hurricanes. Heat is also the source of energy for photosynthesis in plants.*	**Learners' Learning Difficulties (LLD)**: The first group presenter mentioned the sun as the primary source of heat but added that heat serves as source of energy for photosynthesis instead of light (line 6).
Ben then came in here and asked the class if the facts as presented by the first presenter was correct. The whole class responded, *Yes*! One student raised his hand up. Student 2: *I don't think it is only heat that is the source of energy for photosynthesis, I think light is equally needed.* Ben: *Sure! You have a point there! Light is definitely responsible for photosynthesis. Temperature, thus, the presence of heat or otherwise simply impact the rate of photosynthesis. The fact that light and heat are both radiated by the sun does not mean they are all involved in the process of photosynthesis. Photosynthesis makes use of light energy.*	**PK**: Questioning technique was used to draw students' attention to a misconception that since light and heat are both radiated by the sun any of them could be used for photosynthesis. **CK**: Ben's content knowledge informed him that, the information provided by the first group presenter was erroneous. **PK**: Ben later asked the learners to correct that part of the presentation.
Line 7: First Group Presenter continued*: Another source of heat energy is combustion. It's the process of burning a fuel to release heat energy. For example, we burn gas and diesel to produce heat some purpose.*	**PK**: Ben's use of group work as a teaching strategy made it easy for learners to learn through sharing in group.
Ben: Exactly! *The most common fuels used for combustion include fossil fuels such as coal, oil, and natural gas. Combustion is used to produce electricity, heat homes and buildings, and power transportation. For example, when you turn on the stove to cook your food, the heat is generated through combustion of gas or kerosene.*	**CK:** Teacher content knowledge was used to explain the concept of combustion as well as the examples given.
Line 8: Second presenter of group 1: *let's talk about how electricity can be used as a source of heat energy. This happens through a process called resistive heating. Thank you.*	**PK**: Ben's use of group work as a teaching strategy makes it easy for learners to learn through sharing is group.
Line 9: Ben to the whole class: *What is resistive heating?* One student from the class: *I think it is the use of resistance produced in a conductor to produce heat if electricity is passed.*	**PK**: Questioning technique was used to elicit detailed response from learners to foster understanding of concept (line 9).
Line 10: Ben*: Correct! Yes, it is the process by which the passage of an electric current through a conductor or high resistance produces heat. It is sometimes called joule heating or ohmic heating. Devices such as electric heaters, stoves, and ovens convert electrical energy into heat energy through resistive heating. For example, when you turn on an electric stove, the coils heat up and generate heat to cook your food.*	**CK:** Teacher content knowledge was used to explain the concept resistive heating as well as in the examples given (Line 10).

Description of lesson	Categorisation or themes
Ben then pulled out an electric water heater from his drawer, plugged it into the electric socket and switched it on without putting it into water. He asked students to come in groups to observe as he kept switching it on and off.	**PK**: As part of his teaching strategies, Ben used demonstration to support his teaching.
Line 11: Group 1 decided to recede. Ben: *You can't go back now. You left one out. What about 'friction as a source of heat?'* One student from the group guessed: *It then implies the use of friction to produce heat.* Another student from the class attempted: *When we rub our hands together, they get warm, produce heat.*	**PK**: Questioning technique was used to elicit detailed response from learners to foster understanding of concept (line 11).
Line 12: Ben: *Great example! When two surfaces rub against each other, heat is generated due to friction. This can be seen in many everyday situations, such as using a pencil eraser to generate heat or even when braking a vehicle, heat is generated due to friction between the brake pads and the rotor.*	**CK:** Teacher content knowledge was used to explain the concept heating by friction as well as in the examples given (Line 12).
Line 13: *Ben: Group one you have done well. You may take your seats. Class I hope you put your notes together from the first presentation. Let's clap for them. Let's welcome group two to present on effects of heat on substances. This is a very strong group.*	**PK**: As part of his teaching strategies, Ben motivated the first group and encourage the second (line 13).
Line 14: *Group two lead started the presentation: We are presenting the effects of heat on substance, especially water. When a certain amount of heat energy is transferred to a substance, one or more of these changes occur:* ✓ *Change of state.* ✓ *Expansion.* ✓ *Change in chemical composition*	**PK**: Learner activities in the form of group work peer teaching was used by Ben to foster collaboration among learners and to assess the extent of understanding based on homework given to them. (line 14). **PK**: Ben's use of group work as a teaching strategy made it easy for learners to learn through sharing is group.
Line 15: Ben: *Great! This is beautiful. Now, you will have to allow another member to explain point 1. Let the person be guided by the syllabus.*	**PK:** Ben advised learners on what to focus on based on the provisions of the syllabus and the instruction attached to the home work (line 15).
Line 16: Group 2, presenter 1 came forward: *We will begin with change of state. What is it? It is when a substance is heated, its particles gain heat energy and begin to move faster. This results to change of state such as from liquid state to solid state and to gas.*	**PK**: Ben's use of group work as a teaching strategy made it easy for learners to learn through sharing is group.
Line 17: *Ben: That is a good attempt, presenter 1. But to explain further, when a solid substance is heated, its particles begin to vibrate more. As the particles gain energy, they start to overcome the attractive forces holding them together in a fixed shape, and the substance's temperature rises. Eventually, the substance may reach its melting point, which is the temperature at which it changes from a solid to a liquid. At this point (liquid state), the attractive forces holding the particles in a fixed position are overcome, and the particles begin to move around more freely. Some examples of substances that melt*	**CK:** Teacher content knowledge was used to explain the concept of change of state as well as in the examples given (Line 17).

Description of lesson	Categorisation or themes
when heated include ice, which melts to become liquid water, and butter, which melts when heated to become liquid. I hope you have understood it.	
The whole class: *Yes Sir*!	**PK**: Chorus answers were encouraged here, which is not a good classroom practice.
Line 18: *Do you have any question for me?*	
The whole class: *No Sir.* Ben: *Then I have one for you. What are some examples of substances that can be affected by heat that will bring about change of state?*	**PK**: Ben used questioning techniques to elicit answers to questions posed (line 18).
Student 2: *Response: I think substances such as water, metals, plastics, and some food.* Line 19: Ben: *Great! Let's clap for him. Now, you may continue your presentation.*	**PK**: Ben motivated learners in order to encourage them to answer more questions (line 19).
Presenter 1 continued: *So when a substance is heated to a certain temperature, it can change from a solid to a liquid, or from a liquid to a gas. This change of state helps regulate the temperature of the surface of earth, brings about water cycle and produces land and sea breeze.*	
Line 20: Ben: *What is water cycle? And how does the water cycle involve changes of state?* Group 2 members and the rest of the class asked the teacher to help explain to them.	**PK**: Ben used probing questions to get the learners to produce details and important points.
Line 21: Ben then displayed a wall chat of water cycle on one side of the board and kept pointing to and making references as he gave the following explanation for about two times:	
 *Figure* 7. Water cycle	**PK**: Ben used teaching and learning resources to support his teaching activities (figure 7).
Line 22: Ben: *The water cycle involves changes of state because water changes from a liquid to a gas during evaporation and from a gas to a liquid during condensation. When water vapour in the atmosphere cools and condenses, it forms clouds. When the clouds become heavy with water droplets, the water falls to the Earth's surface as*	**CK**: Teacher content knowledge was used in explaining the concept of change of state of substance

Description of lesson	Categorisation or themes
precipitation in the form of rain, snow, or sleet.	and water cycle (line 22).
Line 23: Ben again displayed a wall chat of land and sea breeze on one side of the board and kept pointing to and making references as he gave the following explanation for about two times:	
 Figure 8. Land and sea breeze	**PK**: Ben used teaching and learning resources to support his teaching activities (figure 8).
Line 24: *Ben: How does it affect weather patterns and regulation of temperature?* The water cycle affects weather patterns because it is responsible for the formation of clouds and precipitation. When water vapour in the atmosphere condenses into clouds, it releases heat, which can affect temperature and wind patterns. Additionally, when precipitation falls, it can cause flooding, landslides, and other weather-related hazards.	**CK**: Teacher content knowledge was used in explaining the concept of effects of water cycle on weather patterns (line 24).
Line 25: Group presenter 2 then stepped forward and continued the presentation: *Expansion. Generally all substances expand when heated and contract when cooled. Heat also causes changes in a substance's physical properties. For example, when a metal is heated, it expands due to the increased movement of its particles. This property is used in applications such as thermostats and bimetallic strips. Again, the metal tracks on a railway can expand when the temperature increases, causing them to become longer. When the temperature decreases, the tracks contract, causing them to become shorter. This is why we often see gaps between the railway tracks in hot weather and the tracks touching in cold weather.*	**PK**: Ben's use of group work as a teaching strategy makes it easy for learners to learn through sharing is group.
Line 26: *Beautiful! That is very correct, You may continue.*	**CK**: Ben used teacher content knowledge to judge if the information given is correct (line 26).
Line 27: Group presenter 3 then took over and concluded: Heat can cause chemical reactions to occur in some substances. For example, when wood is heated, it turns into ash. Heat can also cause substances to decompose or break down into simpler substances.	**PK**: Ben's use of group work as a teaching strategy makes it easy for learners to learn through sharing is group (line 27).
Line 28: Ben then took the floor, congratulated the group and did the rest of the explanation by saying: *Chemical Reactions: Heat can also cause chemical reactions to occur in some substances. When a substance undergoes a chemical reaction due to heat, it is said to be thermally decomposed. For example, when wood is heated in the absence of air, it undergoes a process called pyrolysis and turns into*	**CK**: Teacher content knowledge was used to give this detailed information of chemical reaction out (line

Description of lesson	Categorisation or themes
charcoal. The heat breaks down the wood molecules into simpler molecules, which then recombine into new molecules to form the charcoal. Similarly, when limestone is heated, it decomposes into calcium oxide and carbon dioxide. The heat causes the calcium carbonate in the limestone to break down into calcium oxide and carbon dioxide gas.	28).
Line 29: Ben: *Do you all understand?* The whole class: *Yes Sir!* Ben: *Do you have any question to ask?* The whole class: *No Sir!*	**PK:** Ben sought to find out if students had grasped the concept, or if there were some doubts left in their minds.
Line 30: Ben: So, let's have a recap of our lesson today. What have we learnt today?	**PK**: Questioning of individual learners was used to assess how well learners had grasped the lesson (line 30).
Student 5: Sir, we learnt about a number of source of heat which included the sun, electricity, fossil fuel and combustion.	
Ben: *Thank you, student 5. You have done well. This shows that you were really following the lesson. Yes, student 6, continue from where she left off.* Ben picked on another student who did not have his hand up.	**CK**: Ben used teacher content knowledge to judge if the information given is correct (line 30). **PK**: Picking on students who did not have their hands up, is a teaching strategy that gets learners to be ready and pay attention all the time (line 30).
Student 6; *We continued to look at effects that he has on substances. These effects included 'change of state of substances, which brought us to water cycle and land and sea breeze as a way of regulating the earth's temperature. Eh ehmm…*	**PK:** Ben allowed the learners to do the summary as a form of teaching strategy that encourages peer teaching. **PK**: Ben motivated the learner who answered the question.
Ben: *Excellent! This is my boy! You have all these at your finger tips and you are refusing to raise your hands up. Was that all we did? Yes, let's have the last person to conclude this for us.*	**CK**: Teacher content knowledge was used to ascertain the accuracy or otherwise of the information given by learners. **PK:** used a questioning technique to arouse interest and wish to know about their level of understanding of the concept.
Student 7 who did not utter a word throughout the lesson answered: *Sir, you also said that one of the effects is 'expansion and contraction' which is seen in railways. We finished with chemical reactions.*	**PK**: Ben encourage peer teaching as a teaching strategy here.

Description of lesson	Categorisation or themes
Ben: *Beautiful! You have all done well. I am proud of you all. You were on point. Make sore when you go home, you do some further reading. Now, take your exercise books and do the following:*	**PK**: Ben motivated the learners who answered the question. **CK**: Teacher content knowledge was used to ascertain the accuracy or otherwise of the information given by learners.
Class exercise	
Line 30: Ben wrote 5 questions on the board. The first one asked learners to list and explain 3 sources of heat. Another question asked the learners to state and explain 2 effects heat has on substances. The third question requested the learners to discuss how change of state is involved in water cycle. The forth question asked the learners to explain with diagram, how change of state regulates the earth's temperature. The last question asked the learners explain how the structure of a substance affects its response to heat.	**PK**: Class exercise was used to give learners a chance to demonstrate their knowledge and understanding or lack of it about the lesson taught (Line 30).
Learners did the classwork for about 25mins after which Ben collected the class work books and marked them to end the lesson.	**CK**: Teacher content knowledge was used in marking the class exercise to determine the correctness of learners' answers.
Lesson three topics: 'methods of heat transfer' and 'measurement of heat energy', **Class**: SHS 2, **Time**: 60 min.	
Observation	**Categorisation or themes**
Lesson introduction	
Line 1: *Ben entered the lab where his students were already seated: Good morning class! I hope you are all well. Let's revisit something we discussed two weeks ago about a red hot stone placed in a metallic plate in an open space.*	**PK:** As part of his teaching strategy, Ben is introducing the lesson in a familiar context, indicating that teaching starts from known to unknown (line 1).
Ben: *What did we say would happen to that red hot stone?* Student 1: *We said it would cool till it attains thermal equilibrium with the plate.*	**PK**: Ben used the questioning technique in a familiar context to arouse interest and to introduce the lesson (line 1).
Line 2: *That's splendid! You have done well. But what makes it cool?*	**PK**: As part of his teaching strategy,Ben used motivation by praising the learner after which he asked probing question to ascertain understanding (line 2).
Student 2: *It is the transfer of the heat energy from the stone to the plate that made it to cool.*	**LLD:** The questioning technique allowed Ben to identify learn-

Description of lesson	Categorisation or themes
	ers' learning difficulties.
Ben: *Through which means or mode? Yes, answer!* The whole class was silent. Nobody seemed to have the answer. Ben then introduced the new lesson, 'methods of heat transfer'.	**PK**: Ben asked probing question to elicit further information to ascertain understanding (line 2).
Line 3: *Ben: This brings us to the new lesson for today, 'methods of heat transfer'. Heat is transferred through three methods. Thus through 'conduction', 'convection' and 'radiation'.*	**CK:** Teacher content knowledge was used to present the three methods of heat transfer (line 3).
Line 4: *So you see, the red hot stone in question lost heat through all the three modes of heat transfer, thus through; conduction, convection and through radiation.*	**CK:** Teacher content knowledge was used to present the answer to the question that learners could not answer (lines 2 & 4).
Line 5: *Now, let's discuss 'conduction'. Conduction is the transfer of heat energy between objects that are in direct contact with each other. It occurs when there is a temperature difference between two objects (usually solids) and they are in contact with each other. Heat is transferred from the object with higher temperature to the object with lower temperature until both objects reach thermal equilibrium.* *Again, conduction is the transfer of heat through a material by the vibration of particles, without any movement of the material itself. An example of conduction is a metal spoon in a hot cup of soup. The heat from the soup is conducted through the metal spoon to your hand, making the spoon feel hot. Metals (e.g aluminum) are good conductors of heat, that is why they are commonly used in cooking utensils. This is because they can quickly transfer heat from the stove to the food to cook.*	**CK:** Teacher content knowledge was used to explain the concept of heat transfer through conduction as well as the appropriateness of the examples given (line 5). **PK**: Ben used varied definitions and explanations to get students to avoid stereotype definition.
Line 6: *With this new understanding and from the example given to you, think of your own kind of example that you think depicts transfer of heat through conduction.* Student 3: *Sir, the handles of pressing irons.*	**PK**: This is one of Ben's teaching strategies that was geared towards getting the learners to internalise the knowledge being passed on (line 6).
Ben: *Any other examples?* Student 4: *Some handles of spoons and ladles are also made of plastic.*	**PK**: Questioning techniques used by Ben to elicit more response to test understanding (line 6).
Line 7: Ben: *Excellent Student 4! Other materials such as wood, plastic, and glass are poor conductors of heat, which means they transfer heat slowly. This is why wooden handles are used on cooking utensils, as they don't get hot quickly.*	**CK:** Teacher content knowledge was used to cite appropriate examples and to explain why these materials are used (line 7).
Line 8: Student 5: Sir what about the soles of our footwear, are they also made of insulators? Because, we don't feel the heat from the ground when we wear shoes when the ground is hot.	**LLD:** This question gave Ben the indication of learner understanding of the concept

Description of lesson	Categorisation or themes
	(line 8).
Ben: *Good question! Yes, it is true that the soles of our footwear is made of insulators to prevent heat transfer by conduction from the ground. That's very good of you. Thank you.*	**CK**: Teacher content knowledge was used to provide correct answers to this question.
Line 9: Ben: Let's take note of these points. *The rate of conduction depends on various factors such as the thermal conductivity of the material, the temperature difference between the two objects, and the thickness of the material. A thicker material will transfer heat more slowly than a thinner material.*	**CK**: Teacher content knowledge was used to provide further information to learners (line 9).
Line 10: *Now let's talk about convection. What do you think convection is about?* Student 3: *Convection is the transfer of heat in water or liquid.*	**PK:** Questioning techniques were used by Ben to get responses (line 10).
Line 11: *Good attempt. Convection is the transfer of heat by the movement of a fluid, such as air or water. Convection is the transfer of heat through the movement of a fluid, such as a liquid or a gas. When a fluid is heated, it expands and becomes less dense. This causes it to rise and be replaced by cooler, denser fluid. This creates a convection current, which transfers heat from one place to another.*	**CK**: Teacher content knowledge was used to provide information on concept of transfer of heat through convection to learners (line 11).
Line 12: *An example of convection is a pot of boiling water on a stove. The heat from the stove is transferred to the bottom of the pot, causing the water near the bottom to become hot and rise. The hot water is replaced by cold water, which is then heated and rises, creating a continuous cycle of heat transfer.*	**PK**: As part of his teaching strategy, Ben reinforced his lesson by giving a number of examples to buttress his explanation.
Line 13: Ben: *We came across this convection current in one of our earlier lessons. Where did we meet it and what did we say about it?*	**PK:** Ben used his teaching strategy to get the students to recall facts learnt in previous lessons and to link these facts to the new lesson for better understanding. This will also give him the opportunity to know if learners have some learning difficulties.
Learners tried recalling the lesson in question. Student 5: *Sir, we discussed this under 'effects of heat on objects'. We said convection current could be linked to water cycle and it is involved in regulating the temperature of the earth. I hope I got it right, Sir.*	
Line 14: *Ben: Sure! You are on point. Apart from the points you have made, it is also involved in ventilation of rooms, cooling system of refrigerators and car engines. Any other examples?* Student 2: *In boing water in a pot on a stove.*	**CK:** Teacher content knowledge was employed in adding some more points to what was discussed earlier (line 14).
Line 15: *That's good. Yes, in boiling water in a pot. The heat from the stove causes the water to heat up at the bottom of the pot. As the wa-*	**CK:** Teacher content knowledge was used in giv-

Description of lesson	Categorisation or themes
ter heats up, it becomes less dense and rises to the top of the pot. This is replaced by cooler, denser water, which then heats up and rises, creating a convection current.	ing further explanation (line 15).
Now, let's move forward. The third method of heat transfer is 'radiation'. Any idea? Student 7: *Radiation is the transfer of heat through space*	**PK**: Questioning technique was used to direct question to the whole class awaiting response from any learner after allowing wait time (line 15).
Ben: Line 16: *Yes, that's correct, Student 7! Radiation is the transfer of heat through electromagnetic waves. It is transfer of heat through vacuum. Unlike conduction and convection, radiation does not require a medium to transfer heat. Electromagnetic waves can travel through a vacuum, such as space.*	**CK:** Teacher content knowledge was used in giving explanation to the concept of heat transfer through radiation (line 16).
Line 17: Ben cited a number of examples to clarify his points. *An example of radiation is feeling the warmth of the sun on your skin. The sun emits electromagnetic waves, including infrared radiation, which transfer heat to your skin. Another example of radiation is the heat generated by a fire. The fire emits electromagnetic waves, including infrared radiation, which transfer heat to the surrounding objects. Any questions?*	**PK:** It takes a teacher with a good teaching strategy to know that appropriate and relevant examples aid lesson understanding. **CK**: Teacher content knowledge was used to provide relevant examples (line 17).
Line 18: Ben: *Now, we know that the three methods of heat transfer are: conduction, convection and radiation. So, if we don't want the heat to get transferred, is there a way to stop the transfer? You are free to have a short discussion with your colleagues for 3mins.*	**PK**: Questioning technique was used to direct question to the whole class awaiting response from any learner after allowing wait time (line 18)
Line 19: Learners brainstorm as they had small discussions with their colleagues closer to them.	**PK**: Ben used this teaching strategy to get his learners to brainstorm and share knowledge.
Ben: *Now, let's discuss as class. What are your views? If we don't want the heat to get transferred, is there a way to stop the transfer? Tell us your view and you think we can do this.* Learners debate each other.	
Student 4: *Yes Sir! We can stop it. For example, we can stop conduction in spoons and ladles by providing plastic or wooden handles.*	**PK**: As part of his teaching strategy, Ben allowed his learners to express themselves and to share knowledge among peers (line 19).
Student 7: *Sir, I don't think it is possible. In the long run, the substance providing the heat will get cold. The plastic and wooden handles will eventually acquire some small heat though not immediately. Is that not heat transfer?* Student 8: *Sir, me I think it is not possible. Even if we succeed in stopping transfer of heat through conduction as my colleagues are*	

Description of lesson	Categorisation or themes
saying, how can we prevent that of convection and radiation which uses vacuum?	
Line 20: *Ben then came in. I am enjoying myself as you debate one another. You all have good points and your reasons are sound. But one thing is certain, we cannot completely prevent heat transfer. It's important to note that complete prevention of heat transfer is often not possible, but these methods can help reduce the amount of heat transferred and improve energy efficiency. So you see, we can only in our best attempt minimise the transfer regardless of which method is being used.*	**PK**: Ben gave feedback and motivated learners as required in teaching strategy (line 20). **CK:** Teacher content knowledge was used in giving further explanation to minimising heat transfer (line 20).
Line 21: Ben: *Now, Let's see how we can minimise conduction. To reduce heat transfer through conduction, you can use insulating materials, such as fiberglass or foam, to create a barrier between hot and cold regions. The insulating material reduces the direct contact between the hot and cold regions, which slows down the heat transfer.*	**CK:** Teacher content knowledge was used to explain how to minimise heat transfer through conduction (line 21).
Line 22: *To reduce heat transfer through convection, you can create a barrier that prevents the fluid from circulating. This can be achieved by using a solid barrier or by reducing the temperature difference between the hot and cold regions, which reduces the driving force for convection.*	**CK:** Teacher content knowledge was used to explain how to minimise heat transfer through convection (line 22).
Line 23: Ben: *Radiation- To reduce heat transfer through radiation, you can use reflective surfaces that reflect the radiation back to the source or absorbent surfaces that absorb the radiation. For example, a shiny metal surface reflects most of the radiation that hits it, while a black matte surface absorbs most of the radiation. In addition, you can use shields or barriers that block the radiation, or you can reduce the temperature of the radiating source, which reduces the amount of radiation emitted.*	**CK:** Ben used his teacher content knowledge to explain how to minimise heat transfer through radiation (line 23).
Line 24: Ben: *These three modes of heat transfer have been taken care of (minimised) in a single device called 'the thermos flask or vacuum flask'. Thermos flask, also known as a vacuum flask or a Dewar flask, is designed to keep the temperature of the contents constant by minimising heat transfer through all three modes of heat transfer: conduction, convection, and radiation.*	**CK:** Teacher content knowledge was used in giving further explanation to minimising all three modes of heat transfer in one device (line 24).
Ben then displayed a diagram of the thermos flask on the board and led the learner to identify the parts labeled.	

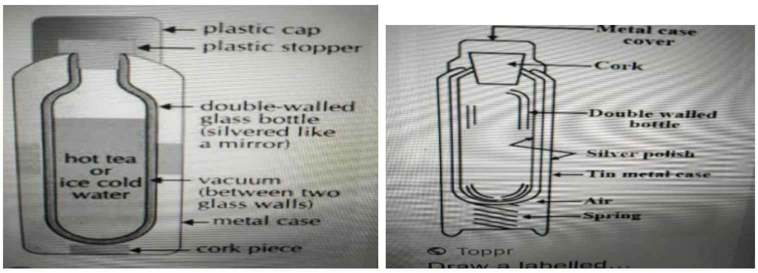


Figure 9. The Thermos Flask

Description of lesson	Categorisation or themes
	PK: Ben's experience from teaching strategy suggested to him to support his lesson with teaching and learning resource and the type to use (fig. 9).
Ben discussed the function of the thermos flask and how it was designed to minimise heat transfer through the three modes.	**CK:** Content knowledge was employed in explaining how thermos flask was designed to

Description of lesson	Categorisation or themes
	minimise heat transfer through the three modes.
Line 25: Ben: *A typical thermos flask consists of two layers of glass or plastic separated by a vacuum. The vacuum between the two layers of the flask acts as an insulating barrier, preventing heat transfer by conduction and convection. The two layers of glass or plastic also have a reflective coating to prevent radiation heat transfer.*	**CK:** Content knowledge was employed in explaining how thermos flask was designed to minimise heat transfer through conduction (line 25).
Line 26: Ben: *Convection: Heat transfer through convection is prevented in a thermos flask by the vacuum insulation and the tight-fitting stopper. The vacuum prevents the movement of air or other fluids, which eliminates convection heat transfer. The tight-fitting stopper also prevents the movement of air in and out of* the flask, which further reduces convection heat transfer.	**CK:** Content knowledge was used to explain how thermos flask was designed to minimise heat transfer through convection (line 26).
Line 27: *Ben: Radiation: Heat transfer through radiation is prevented in a thermos flask by the reflective coating on the inner surfaces of the glass or plastic layers. The reflective coating reflects the radiant heat back into the flask, preventing it from escaping to the outside environment. The vacuum insulation also reduces radiation heat transfer by minimising the number of air molecules that can absorb and re-emit radiant heat.*	**CK:** Teacher content knowledge was employed in explaining how thermos flask was designed to minimise heat transfer through radiation (line 27).
Line 28: *Ben: Overall, the combination of vacuum insulation, reflective coating, and a tight-fitting stopper makes a thermos flask an effective device for reducing heat transfer through all three modes of heat transfer. As a result, the thermos flask can keep the temperature of the contents constant for an extended period of time, whether the contents are hot or cold.*	**CK:** Teacher content knowledge was used in summarising the explanation to minimising heat transfer through the modes in a single device (line 28).
Line 29: Ben: *Did you understand?*	
The whole class: *Yes Sir!*	
Ben: *Any question so far?*	
The whole class: *No Sir!*	
Ben then summarised the key points of the lesson and closed the class.	
Lesson four topic: 'measurement of heat energy', **Class**: SHS 2, **Time**: 60 min.	
Lesson introduction	
Line 1: *Ben entered the lab where his students were already seated: Good morning class! I hope you are all well. Let's revisit something we discussed a week ago about a red hot stone placed in a metallic plate in an open space.* Students responded by providing answers to the questions asked by the teacher.	**PK:** As part of his teaching strategy, Ben is introducing the lesson in a familiar context, indicating that teaching starts from known to unknown (line 1).
Line 2: *Now, let's see how we can measure quantity of heat. This involves using a calorimeter, which is a device that measures the change in temperature of a substance as heat is transferred into or out of the system.*	**CK**: Ben tapped into his teacher content knowledge in explaining calorimetry.

Description of lesson	Categorisation or themes
Line 3: *Ben: We discussed in the early part of this lesson that some factors affect the rate and quantity of heat transferred. What are these factors?* Learners tried to recall Student 1: *The rate of conduction depends on the thermal conductivity of the material,* Student 4: *And the temperature difference between the two objects, and the thickness of the material.*	**PK**: As part of his teaching strategy, Ben tried to get the learners link the earlier lesson with this new one, indicating teaching from known to unknown (line 3).
Line 4: Ben: *Good students! You are right' So you see, thermal conductivity has to do with the nature of the material transferring or receiving the heat energy. This tells us how fast or slowly this substance acquires heat. This is called heat capacity. <u>The heat capacity</u> of an object is the amount of heat energy required to raise the temperature **of a substance** by 1 degree Celsius. The SI unit is J $^{0}C^{-1}$ or J K^{-1}.*	**CK:** Teacher content knowledge was used in explaining heat capacity (line 4).
Line 5: Ben: *We have **heat capacity** and **specific heat capacity**. The <u>specific heat capacity</u> is a measure of the amount of heat energy required to raise the temperature of **a unit mass of a substance** by 1 degree Celsius per unit mass. By referring to a unit mass, we mean 1kg of mass. The SI unit is $Jkg^{-1}\,{}^{0}C^{-1}$ or $Jkg^{-1}\,K^{-1}$.*	**CK:** Teacher content knowledge was used in explaining specific heat capacity (line 5).
Ben: *so what do you think is the difference between heat capacity and specific heat capacity of a substance?*	**PK**: Questioning technique was used to elicit response to test for understanding (line 5).
Student 2: *Heat capacity is general while specific heat capacity is specific in nature.*	**PK**: As part of his teaching strategy, Ben allowed the learners to express themselves to ascertain if there is an issue of learning difficulty.
Line 6: Ben: *This is not clear. What do you mean by 'general' and 'specific in nature'?*	**PK**: Ben asked probing question to elicit response as part of his teaching response (line 6).
Student 2: *I mean heat capacity is about any mass at all while specific heat capacity limits itself to only a unit mass (1kg),*	**PK**: Through the use of questioning technique, Ben managed to get the learner to produce clear and correct response
Ben: Great! *That is right! This is an important concept in determining the amount of heat that is required to warm a substance or to cool a substance.* Line 7: *Do you have any question for me?* The whole class: *No Sir!*	
Ben: Ok. *I have one for you. If two solids, 'A' and 'B' have heat capacities of 600JK^{-1} and 748JK^{-1} respectively. Which of these two bodies is a better conductor of heat and why?*	**PK**: As part of his teaching strategy, Ben posed a related question to test for understanding and their prepared-

Description of lesson	Categorisation or themes
	ness to move to the next stage of the lesson (line 7).
All students who attempted to answer went for body 'B' with the explanation that body 'B' acquired larger amount of heat energy.	**LLD:** The response to this question gave Ben the indication that learners' understanding of the concept is questionable (line 7).
Line 8: *Oh! I'm not happy. Let's get this right. What this means is that 'A' needs 600J of heat energy to change its temperature by 1K and solid 'B' needs 748 J of heat energy to change its temperature by 1 K. So 'A' conducts heat better (faster) than 'B', because 'A' needs lesser amount of heat to attain a 1 K rise in temperature. 'B' needs more amount of heat. Therefore, the statement that, the specific heat capacity of water is 4200 Jkg-1 K-1 means that 4200 J of heat energy is needed to change the temperature of 1kg mass of water by 1K.*	**CK:** Teacher content knowledge was used to give further explanation to the concept of heat and specific heat capacity (line 8).
Line 9: *Now let's see how we can calculate quantity of heat gained or lost. The amount of heat energy transferred can be calculated using the equation $Q = mc\Delta T$, where Q is the heat energy transferred, m is the mass of the substance, c is the specific heat capacity of the substance, and ΔT is the change in temperature.* *Therefore, $Q = mc\Delta T$, and the SI nit is joule (J).*	**CK:** Teacher content knowledge was used to explain measurement of quantity of heat (line 9).
Line 10: *Now let's try some number of examples.* Ben took his learners though three different example placing emphasis on very important areas like units of mass being in kg and working out the temperature difference well.	**PK**: As part of his teaching strategy Ben always supports his calculation lessons with a number of examples to aid understanding (line 10).
Line 11: He later gave them one of the sample questions to try in class as he went round to supervise how they were working out the answer.	**PK**: Ben, in giving trial question, tried to test for understanding as he gave individual attention (line 11). **CK**: teacher content knowledge was used to ascertain the correctness or otherwise of the trial question.
Line 12: Ben: *Now, we shall conclude today's lesson with one important concept known as latent heat. What is latent heat?*	**PK**: Questioning technique was used to elicit response (line 12).
Student 3: *Latent heat is the heat that is absorbed or released when a substance changes state, maybe from a solid to a liquid or from a liquid to a gas.*	**PK**: Ben got the learner to share knowledge with his peers (line 12).
Ben: *Excellent, Student 3! Latent heat is the heat that is absorbed or released when a substance changes state, such as when it changes from a solid to a liquid or from a liquid to a gas, without a change in temperature. At this stage all the energy being supplied is being used to change state without the temperature changing. The temperature*	**CK:** Teacher content knowledge was used to explain latent heat (line 12).

Description of lesson	Categorisation or themes
remains constant.	
Line 13: Ben: *An example is when heating water in a pot, when the water begins to boil, all the heat energy that is being supplied afterwards is just being used to change the water to vapour without any change in temperature of the water until the entire water gets finished inside the pot.*	**PK**: As part of his teaching strategy, Ben gives series of examples to aid understanding (line 13). **CK:** Teacher content knowledge was used in providing examples (line 13).
Line 14: Ben: *There are two types of latent heat: Latent heat of fusion and latent heat of vaporisation. Fusion has to do with change of state at the freezing point without change in temperature while vaporisation concerns itself with boiling points. Let's try some examples.*	**CK:** Teacher content knowledge was used in providing detailed information on latent heat (line 14).
Line 15: Ben took his learners though three different example placing emphasis on very important areas like units of mass being in kg and emphasising that there is no temperature difference.	**PK**: As part of his teaching strategy, Ben gives series of examples to aid understanding (line 15). **CK:** Teacher content knowledge was used in providing examples (line 42).
He later gave them one of the sample questions to try in class as he went round to supervise how they were working out the answer.	**PK**: Ben, in giving trial question, tried to test for understanding as he gave individual attention. **CK**: teacher content knowledge was used to ascertain the correctness or otherwise of the trial question.
Class exercise	
Line 16: Ben wrote 5 questions on the board. The first one asked learners to list and explain 3 methods of heat transfer. Another question asked the learners to explain how ventilation occurs in their classroom. The third question requested the learners to explain why air conditioners are fixed close the celling of rooms but not on the floor. The forth question asked the learners to draw a diagram of thermos flask and explain how the three modes of heat transfer are minimised. The last question asked the learners to do some calculations on quantity of heat,	**PK**: Class exercise was used to give learners a chance to demonstrate their knowledge and understanding or lack of it about the lesson taught (Line 16).
Line 17: Learners did the classwork for about 25mins after which Ben collected the class work books and marked them to end the lesson.	**CK**: Teacher content knowledge was used in marking the class exercise to determine the correctness of learners' answers (line 17).

APPENDIX Q

Kalulu's lesson observation transcription and analysis

Description of lesson	Categorisation or themes
Classroom context Kalulu's physics class had 49 learners, consisting of 35 boys and 14 girls of mixed ability. His lessons were taught in a standard science laboratory. The laboratory furniture was in good shape and arranged in rows and columns with enough space for teacher and learner movement. Every student had a notebook to write in.	(a) The classroom context provided a safe learning environment for both girls and boys. (b) All students had note-books
Lesson one topic: the definition of thermal energy', 'explanation of thermal equilibrium', 'SI units of heat energy, and thermometer and thermometry substances'. **Class**: SHS 2, **Time**: 60 min.	
Observation	
Lesson Introduction	
Line 1: Kalulu entered the classroom and greeted his class. Kalulu: *Good morning, class. Today, we're diving into the fascinating world of heat energy. Let's get started. Tell me, what happens when you heat food in the kitchen?* Student **1:** *It gets hot*! Kalulu**:** *That's correct, but let's go a bit deeper. Why does it get hot? Today, we'll explore that and understand the science behind it.* Studedent 2: *It is because the heat gets into it.*	**Pedagogical knowledge (PK)**: Kalulu used question-ing technique in a familiar context to arouse interest and to introduce the lesson. **PK**: Kalulu used question-ing technique in a familiar context to arouse interest and engage learners in the discussion of the concept of thermal energy (line 1).
Line 2: Kalulu then continued *That is a good attempt. Heat energy is a form of energy that flows from a hotter object to a cooler one. It's a bit like a flow of invisible particles.* Kalulu explained further: *When you touch an ice cube, your hand transfers heat energy to the ice, causing it to melt. This is because heat energy flows from a region of higher temperature to a region of lower temperature* Kalulu: *Is that understood?* Learners responded in chorus *Yes Sir*. Line 3: Kalulu then wrote the topic on the board. Kalulu begun by introducing foundational concepts: heat energy, thermal equilibrium, SI units of heat energy, and thermometer and thermometry substances.	**Content knowledge (CK):**Kalulu demonstrated mastery of content here by defining thermal energy and by giving a familiar exam-ple.
Kalulu: *In what unit is heat energy measured?* Student 3: *Kilojoules, Sir.*	**PK**: Kalulu used questioning technique to elicit response from learners (line 3).
Kalulu: *Heat energy is measured in joules (J). It's the amount of energy transferred when an object's temperature changes. We use*	**CK**: Kalulu demonstrated mastery of content here by

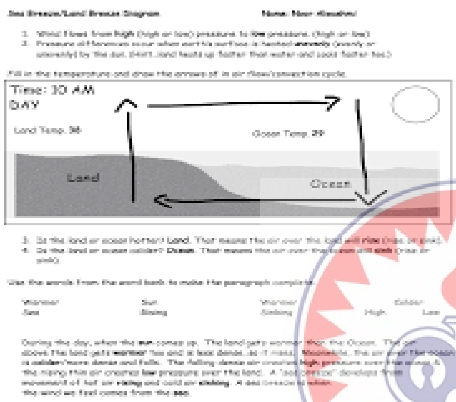
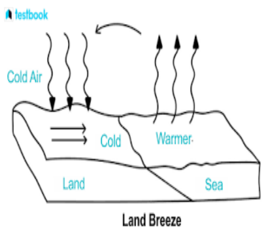
Description of lesson	Categorisation or themes
kilojoules (kJ) when quantity of the heat energy is large.	giving and explaining the SI unit of heat.
Line 4: Kalulu**:** *Think about being inside a car on a hot day. How does the air conditioning work? It's all about thermal physics. The air conditioner removes heat from the inside of the car and releases it outside, making the inside cooler. We'll uncover the science behind this.* Student 4 asked a question**:** So Sir, does it mean heat energy can be moved around? Kalulu**:** Precisely! Heat can be transferred from one object to another through various mechanisms, and we'll discuss those mechanisms today.	**PK**: Kalulu displayed pedagogical knowledge by relating the lesson to real-life examples
Line 5: Kalulu uses gestures and lighting a bunsen burner and bringing a nail close to demonstrate heat transfer, making the concept more tangible for students. After a while, the nail became red hot.	**PK**: Kalulu displayed pedagogical knowledge by using demonstration as an instructional strategy to teach.
Kalulu then explained the red hotness of the nail by attributing to the transfer of heat energy.	**PK**: Kalulu demonstrated pedagogical knowledge through his explanation of the demonstration.
Line 6: To make the lesson even more engaging and factual, Kalulu conducts a practical demonstration: Kalulu performing demonstration: *Let's see this in action. I have an electric coil heater here. Watch as I heat this water from the top and bottom of the bucket.*	**PK**: Kalulu displayed pedagogical knowledge by using demonstration as an instructional strategy to teach (line 6).
Kalulu: *What do you observe?* Student 4**:** The top water heats up faster!	**PK**: Kalulu used questioning technique to elicit response from learners (line 6).
Kalulu**:** Excellent observation! The heat energy from the heater is transferred more efficiently to the water at the top. This demonstrates the concept of heat transfer we're discussing.	**PK**: Kalulu demonstrated pedagogical knowledge through his explanation of the demonstration.
Line 7: Kalulu then asked a question: *How can we measure quantity of heat?* Student 5: *We use thermometers.* Kalulu: *Any other answer?* Students 2, 6 & 7: *Sir, it is still thermometers.*	**PK**: Kalulu used questioning technique to elicit response from learners (line 7).
Kalulu*: We use calorimeter. Not thermometer. Thermometer measures temperature (that is degree of hotness or coldness of a*	**CK**: Kalulu demonstrated mastery of content here by giving explanation.

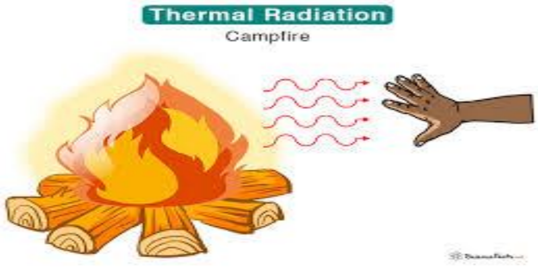
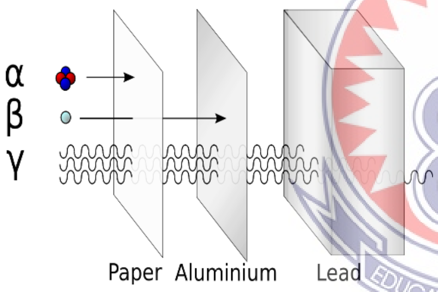
Description of lesson	Categorisation or themes
substance).	
Line 8: Kalulu introduced the concept of thermal equilibrium and its relevance.	
He asked students to imagine a cup of hot tea and its cooling process.	
Students were tasked to imagine.	**PK**: Kalulu used this approach to get the learners to brainstorm (line 8).
Kalulu explained thermal equilibrium as a state with no net heat flow. He related it to everyday experiences, such as a cup of hot tea cooling down when left on a table.	**CK**: Kalulu demonstrated mastery of content here by explaining thermal equilibrium (line 8)
Line 9: Kalulu emphasised that thermal equilibrium means there's no continuous transfer of heat between objects, resulting in a stable temperature.	
Kalulu encouraged students to discuss and ask questions about thermal equilibrium.	
Line 10: Students actively participated and asked questions, seeking to deepen their understanding of thermal equilibrium.	**PK:** Teacher used this strategy to enhance understanding.
Kalulu reinforced the idea of objects reaching thermal equilibrium by providing additional examples.	
Students shared their understanding of the concept and contributed to the discussion.	**CK:** Kalulu gave further explanation.
Line 11: Kalulu**:** *For your homework, I want you to read the chapter on thermal physics in your textbook and answer the questions. This will help us pinpoint any difficulties you might have. Remember, learning is a journey, and we're taking it together.*	**PK**: Kalulu used this technique to get the students to read ahead of the next lesson.
Students: *Yes Sir*	**Learners' Learning Difficulties (LLD)**:This is an attempt to identify learning difficulties (line 11).
Line 12: Kalulu: *If you have questions or ideas to share, please don't hesitate. We're all here to learn from each other. Your curiosity is the key to understanding thermal physics.*	
Kalulu walked around the classroom, making eye contact with students and nodding as they participated, creating a sense of inclusion and shared learning.	
As the lesson concluded:	
Kalulu opened one of the textbooks, directed where to find the relevant chapters and encourages students to ask questions if they get stuck.	

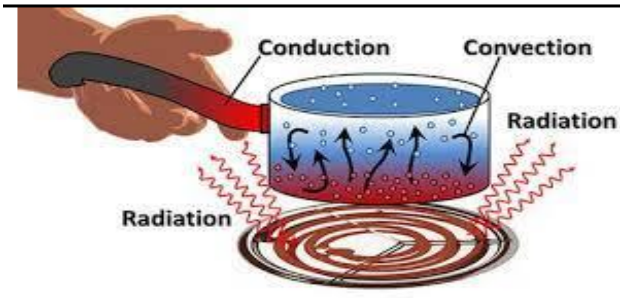
Description of lesson	Categorisation or themes
Lesson 2 topic: **'**Measurement of Heat and Heat Transfer'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: Kalulu: *Good morning, class. Today, we're building on our understanding of heat energy. Can we remember what we learned last time about heat energy and how it moves?* Student 1**:** *Heat energy flows from hot to cold.* Kalulu: *That's correct! Today, we're going to look at how we can measure heat and how it moves.* (Engaging students with a recap and providing declarative content knowledge).	**PK**: Kalulu used questioning technique to get students to recall in order to review the the previous lesson. **CK**: Kalulu demonstrated mastery of content here by explaining how heat is transferred (line 1).
Line 2: Kalulu displayed different pictures of thermometers and explained how they are used and how they work.  	**PK:** Teacher's teaching strategy was used to look for appropriate teaching and learning materials to support his lesson (line 2).
Line 3: Kalulu begun by introducing the measurement of heat and the concept of heat transfer. He used a simple demonstration with a thermometer to illustrate:	**PK**: Kalulu used demonstration to get learner to understand (line 1).
Line 4: Kalulu: *To measure temperature, we use a thermometer. It tells us how hot or cold something is. Imagine you're cooking and you use a thermometer to check the temperature of your food, let's say banku. This is how we measure heat.* (Engaging with a practical example, Thus using one real thermometer to measure the temperature of water.)	**PK**: Kalulu used demonstration as a technique to teach (line 4). **PK**: Teacher used everyday experiences and real-life examples to support his lesson for easy understanding (line 4). **CK**: Teacher used his content knowledge to explain concepts (line 4).
Line 5: Kalulu**:** *Think about when you touch a metal spoon left out in the sun. It feels hot, right? That's because the metal spoon has absorbed heat energy from the sun. We'll explore how this process happens and how materials transfer heat differently.* (Connecting concepts to everyday experiences and using real-world examples) Student 3: *So Sir, does it mean different materials can transfer heat differently?* Kalulu: *Exactly! Some materials are good at transferring heat, while others are not so great. We'll investigate this in more detail today*.	**PK**: Teacher used everyday experiences and real-life examples to support his lesson for easy understanding (line 5). **CK:** Teacher content knowledge was applied here.

Description of lesson	Categorisation or themes
Line 6: To make the lesson engaging, Kalulu conducted a practical demonstration with different materials such as metal spoons, wooden spoons, candles and nails: Kalulu**:** *I have a metal spoon and a wooden spoon here. Let's see which one heats up faster when we place them under a heat lamp.* Students eagerly watch as Kalulu placed the spoons under the heat lamp and recorded the time it took for them to warm up to a certain temperature. Line 7: Student 4**:** *The metal spoon is getting hot much faster!* Kalulu**:** *Excellent observation! Metal is a good conductor of heat, so it transfers heat quickly. This is why it gets hot faster than wood*.	**PK**: Kalulu used demonstration as a technique to teach (line 6).
Line 8: Student 5**:** *But Sir, I thought metal always feels cold*? Kalulu: *That's a great question! Metal feels cold when you touch it because it conducts heat away from your hand very effectively. We'll look at this further in the lesson.* (Addressing misconceptions with factual content)	**CK**: Teacher used his content knowledge to explain concepts (line 8). **LLD**: This is an attempt to identify learning difficulties
Line 9: As the lesson concluded: Kalulu**:** *For your homework, I want you to think about different materials that conduct heat well and those that don't. Make a list and bring it to class tomorrow. We'll discuss your findings and build on our knowledge.* Kalulu encourages students to be curious and engage with the topic outside of the classroom: Kalulu**:** *If you have questions or want to share your observations, please feel free to do so. Learning is not just about what happens in class; it's about exploring the world around us*	**PK**: Kalulu used this technique to get the students to read ahead of the next lesson (line 9). **LLD**:This is an attempt to identify learning difficulties (line 9).
Lesson 3 topic: 'Modes of Heat Transfer'**. Class:** SHS 2**, Time:** 60 min	
Line 1: Kalulu greeted the class and introduced the topic: *Today, we'll explore the different modes of heat transfer.* Kalulu: *What comes to your mind by the mention of modes of heat transfer?* Student 1: *I think it talks about ways and means of transferring heat.* Kalulu*: That is correct!* (With this, he introduced the lesson)	**PK**: Kalulu used this strategy to engage learners as they brainstorm (line 1). **PK**: Students participated.
Line 2: Kalulu posed a question: *What are these modes of heat transfer?* Students actively participated by naming conduction, convection, and radiation as the modes of heat transfer.	**PK:** Kalulu used questioning technique to elicit response from learners (line 2).

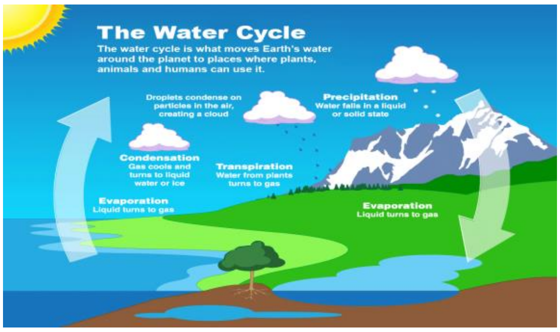
Description of lesson	Categorisation or themes
Teacher confirmed learners' answers.	**CK**: Teacher displayed content knowledge in confirming answers.
Line 3: Kalulu: *Let's discuss them now*. Kalulu: *What is conduction*? Student 1: *Conduction is when heat travels through direct contact, is this right sir*?	**PK:** Kalulu used questioning technique to elicit response from learners (line 3).
Line 4: Kalulu explained conduction as the transfer of heat through direct contact between solid objects.	**CK**: Teacher used his content knowledge to explain concepts (line 4).
He used practical examples, such as touching a metal spoon to understand how heat travels through conduction. He supported his explanation with this diagram. 	**PK**: Teacher used everyday experiences and real-life examples to support his lesson for easy understanding (line 4). **PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM **PK**: Students participated.
Students asked questions to clarify the concept, such as how fast heat travels through different materials. Student 4: *So sir, if I touch a hot pan, that's conduction, right?* Student 5: *How does conduction work in liquids like water?* Line 5: *Kalulu: Conduction mostly takes place in solids. It barely happens in liquids. Now, let's discuss convection.*	
Kalulu: *What is convection about?* Student 3: *Sir I think is has to do with converting the heat energy from one state to the other*.	**PK:** Kalulu used questioning technique to elicit response from learners (line 5).
Kalulu: *Not really. We are talking about convection as a mode of heat transfer. Not conversion. He then wrote 'convection' on the board to stress.*	**CK**: Teacher used his content knowledge to correct student (line 5).
Line 6: Student 2: *Convection is when hot air rises and cold air comes in, or Sir?* Kalulu accepted the answer and introduced convection as heat transfer through the movement of fluids (liquids or gases).	**CK**: Teacher used his content knowledge to affirm the student's answer (line 6).
He used examples like boiling water in a kettle, room ventilation, car cooling systems, refrigerators and the rising of warm air to explain convection. Students engaged in discussions and shared their experiences relat-	**PK**: Teacher used everyday experiences and real-life examples to support his

Description of lesson	Categorisation or themes
ed to convection, such as feeling hot air rising.	lesson for easy understanding (line 6).
Line 7: Student 6: *When I'm in the shower, I can feel the warm water rising around me. Is that convection?* Student 7: *What about convection in oceans and how it affects currents?* Teacher answered students' questions and introduced convection current. He explained into details citing land and sea breeze using illustrations from a textbook, supporting it with diagrams presented below:  	**CK**: Teacher used his content knowledge to answer students' questions (line 7). **PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM
Line 8: Kalulu: *So, what about radiation?* Student 3: *Radiation is like the heat we feel from the sun.* Kalulu explained radiation as the transfer of heat through electromagnetic waves, such as infrared radiation. Kalulu provided examples like feeling the warmth of the sun or from any source of fire to relate to radiation. Kalulu then displayed this image to reinforce his explanation	**PK:** Kalulu used questioning technique to elicit response from learners (line 8). **CK**: Teacher used his content knowledge to explain concepts (line 8). **PK**: Teacher used everyday experiences and real-life examples to support his lesson for easy understanding (line 8). **PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM

Description of lesson	Categorisation or themes
 	
Students asked questions to better understand radiation, including its role in warming the Earth.	
Line 9: Student 4: *How does radiation work in space where there's no air?*	**PK**: Students were encouraged to asked questions.
Student 5: *Why do some materials absorb radiation while others reflect it?*	
Kalulu answered students' questions and encouraged students to compare and contrast the three modes of heat transfer to establish connections between them (conduction, convection, and radiation).	**CK**: Teacher used his content knowledge to answer students' questions (line 9).
 	**PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM **PK**: Students participated.
Students actively participated in discussions, highlighting differences and similarities between the modes.	
Line 10: Kalulu: *Now let's discuss what you are getting from your comparisons.*	**PK:** Kalulu used questioning technique to elicit response from learners (line 10).
Student 10: *Conduction and convection need matter to transfer heat, but radiation doesn't.*	
Student 5: *All three modes involve the transfer of energy, but they do it in different ways.*	
Kalulu: *That's interesting!*	**PK:** Teacher motivated learners (line 10).
Kalulu then guided the discussion by summarising key points and addressing any remaining questions.	**PK**: Teacher used everyday experiences and real-life examples to support his lesson for easy understanding (line 8).
Kalulu discussed real-life applications of each mode of heat transfer, such as cooking methods, weather patterns, and energy-efficient designs. He backed his explanation with this image for easy understanding.	
Line 11:	**PK**: Teacher demonstrated the knowledge of selecting

Description of lesson	Categorisation or themes
 	and using appropriate TLM (line 11).
Line 12: Kalulu asked students to cite some more of heat transfer examples found around them.	**CK**: Teacher used his content knowledge to guide students to come out with responses (line 12).
Students engaged in conversations, relating the modes of heat transfer to everyday experiences and practical situations. Student 6: *When we bake bread at home, the hot air in the oven surrounds them, so that's convection!* Student 3: *Radiation from the sun heats our planet, but we also lose heat through radiation at night.*	**PK**: Teacher used everyday experiences and real-life examples to support his lesson for easy understanding (line 12).
Line 13: Kalulu accepted students' correct answers and discussed how heat transfer influences weather patterns, including the formation of wind, rain, and temperature changes. Kalulu concluded his lesson with summary of all that he taught. He then asked his learners to read about 'Effects of heat on substance' since this would be the next topic to be discussed. He added that they would be presenting groups.	
Lesson four topic: 'Effects of heat on substance'**'**Quantity of heat (measurement of heat energy)'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: Kalulu entered the lab and greeted the class and introduced the topic: 'Effects of heat on substance' He explained to them that they would be doing group presentation as discussed the last time they met. He then asked the group working on 'effect of heat on substance' to present.	**PK:** Kalulu used this strategy to get the learners to read ahead.
Line 2: Group 1 lead started the presentation*: We are presenting on the effects of heat on substance, water. When a certain substance are heated, energy is transferred to that substance and it Changes state, expand or changes chemical composition.*	**PK**: Learner activities in the form of group work peer teaching was used by Kalulu to foster collaboration among learners and to assess the extent of understanding based on homework given to them. (line 1). **PK**: Kalulu's use of group work as a teaching strategy made it easy for learners to learn through sharing is

Description of lesson	Categorisation or themes
	group.
Line 3: Kalulu: *Great! This is beautiful. Now, you will have to allow another member to explain point 1. Let the person be guided by the syllabus.*	**PK:** Kalulu advised learners on what to focus on based on the provisions of the syllabus and the instruction attached to the home work (line 3).
Line 4: Group 1, presenter 1 came forward: *We will start from definition of 'change of state'. What is it? It is when a substance is heated, its particles gain heat energy and begin to move faster. This results to change of state such as from liquid state to solid state and to gas.*	**PK**: Kalulu's use of group work as a teaching strategy made it easy for learners to learn through sharing is group.
Line 5: Kalulu*: That is a good attempt, presenter 1. But to explain further, when a solid substance is heated, its particles begin to vibrate more. As the particles gain energy, they start to overcome the attractive forces holding them together in a fixed shape, and the substance's temperature rises. Eventually, the substance may reach its melting point, which is the temperature at which it changes from a solid to a liquid. At this point (liquid state), the attractive forces holding the particles in a fixed position are overcome, and the particles begin to move around more freely. Some examples of substances that melt when heated include ice, which melts to become liquid water, and butter, which melts when heated to become liquid. I hope you have understood it.*	**CK:** Teacher content knowledge (declarative knowledge) was used to explain the concept of change of state as well as in the examples given (Line 5).
The whole class: *Yes Sir*!	**PK**: Chorus answers were encouraged here, which is not a good classroom practice.
Line 6: *Do you have any question for me?* The whole class: *No Sir.* Kalulu: *What are some examples of substances that can be affected by heat that will bring about change of state?*	**PK**: Kalulu used questioning techniques to elicit answers to questions posed (line 6).
Student 2: *Response: I think substances such as water, metals, plastics, and some food.* Line 7: Kalulu: *Great! Let's clap for him. Now, you may continue your presentation.*	**PK**: Kalulu motivated learners in order to encourage them to answer more questions (line 7).
Presenter 1 continued: *So when a substance is heated to a certain temperature, it can change from a solid to a liquid, or from a liquid to gas. This change of state helps regulate the temperature of the surface of earth, brings about water cycle and produces land and sea breeze.*	

Description of lesson	Categorisation or themes
Line 8: Kalulu: *That was a wonderful presentation. Yes, we discussed in our earlier lesson that convection current results from heating and cooling of fluids which helps regulate the temperature of the surface of earth* Kalulu then displayed picture showing water cycle on the board and explained further.	**CK**: Kalulu used his teacher content knowledge in explaining this concept.
	**PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM (line 8).
Line 9: Kalulu: *The water cycle involves changes of state because water changes from a liquid to gas during evaporation and from gas to liquid during condensation. When water vapour in the atmosphere cools and condenses, it forms clouds. When the clouds become heavy with water droplets, the water falls to the Earth's surface as precipitation in the form of rain, snow, or sleet*	**CK**: Teacher content knowledge was used in explaining the concept of change of state of substance and water cycle (line 9).
Line 10: Kalulu*: The water cycle affects weather patterns because it is responsible for the formation of clouds and precipitation. When water vapour in the atmosphere condenses into clouds, it releases heat, which can affect temperature and wind patterns. Additionally, when precipitation falls, it can cause flooding, landslides, and other weather-related hazards.*	**CK**: Teacher content knowledge was used in explaining the concept of effects of water cycle on weather patterns (line 10).
Line 11: Group presenter 2 then stepped forward and continued the presentation: *Expansion. Generally all substances expand when heated and contract when cooled. Heat also causes changes in a substance's physical properties. For example, when a metal is heated, it expands due to the increased movement of its particles. This property is used in applications such as thermostats and bimetallic strips. Again, the metal tracks on a railway can expand when the temperature increases, causing them to become longer. When the temperature decreases, the tracks contract, causing them to become shorter. This is why we often see gaps between the railway tracks in hot weather and the tracks touching in cold weather.*	**PK**: Kalulu's use of group work as a teaching strategy makes it easy for learners to learn through sharing is group
Line 12: Group presenter 3 then took over and concluded: *Heat can cause chemical reactions to occur in some substances. For example, when wood is heated, it turns into ash. Heat can also cause substances to decompose or break down into simpler substances.*	**PK:** Kalulu's use of group work as a teaching strategy makes it easy for learners to learn through sharing is group (line 12).

Description of lesson	Categorisation or themes
Line 13: Kalulu then took the floor, congratulated the group and did the rest of the explanation by saying: *Chemical Reactions: Heat can also cause chemical reactions to occur in some substances. When a substance undergoes a chemical reaction due to heat, it is said to be thermally decomposed. For example, when wood is heated in the absence of air, it undergoes a process called pyrolysis and turns into charcoal. The heat breaks down the wood molecules into simpler molecules, which then recombine into new molecules to form the charcoal. Similarly, when limestone is heated, it decomposes into calcium oxide and carbon dioxide. The heat causes the calcium carbonate in the limestone to break down into calcium oxide and carbon dioxide gas.*	**CK**: Teacher content knowledge was used to give this detailed information of chemical reaction out (line 13).
Line 14: Line 29: Kalulu: *Do you all understand?* The whole class: *Yes Sir!* Ben: *Do you have any question to ask?* The whole class: *No Sir!*	**PK:** Kalulu sought to find out if students had grasped the concept, or if there were some doubts left in their minds.
Line 15: Kalulu: *Now, let's see how we can measure quantity of heat. This involves using a calorimeter, which is a device that measures the change in temperature of a substance as heat is transferred into or out of the system.*	**CK**: Kalulu tapped into his teacher content knowledge in explaining calorimetry.
Line 16: Kalulu*: We discussed in the early part of this lesson that some factors affect the rate and quantity of heat transferred. What are these factors?* Learners tried to recall Student 2: *The rate of conduction depends on the thermal conductivity of the material,* Student 3: *And the temperature difference between the two objects, as well as the thickness of the material.*	**PK**: As part of his teaching strategy, Kalulu tried to get the learners link the earlier lesson with this new one. That is teaching from known to unknown (line 16).
Line 17: Kalulu: *Good students! You are right' So you see, thermal conductivity has to do with the nature of the material transferring or receiving the heat energy. This tells us how fast or slowly this substance acquires heat. This is called heat capacity. The heat capacity of an object is the amount of heat energy required to raise the temperature* ***of a substance*** *by 1 degree Celsius. The SI unit is* $J\,^0C^{-1}$ *or* $J\,K^{-1}$.	**CK:** Teacher content knowledge was used in explaining heat capacity (line 17).
Line 18: Kalulu: *We have* ***heat capacity*** *and* ***specific heat capacity****. The specific heat capacity is a measure of the amount of heat energy required to raise the temperature of* ***a unit mass of a substance*** *by 1 degree Celsius per unit mass. By referring to a unit mass, we*	**CK:** Teacher content knowledge was used in explaining specific heat capacity (line 18).

Description of lesson	Categorisation or themes
mean 1kg of mass. The SI unit is $Jkg^{-1}\,{}^{0}C^{-1}$ *or* $Jkg^{-1}K^{-1}$.	
Kalulu: *so what do you think is the difference between heat capacity and specific heat capacity of a substance?*	**PK**: Questioning technique was used to elicit response to test for understanding (line 18).
Student 3: *They are all talking about heat capacity, Sir.*	
Student 4: *Heat capacity is general while specific heat capacity is specific in nature.*	**PK**: As part of his teaching strategy, Kalulu allowed the learners to express themselves to ascertain if there is an issue of learning difficulty.
Line 19: Kalulu: *This is not clear. What do you mean by 'general' and 'specific in nature'?*	**PK**: kalulu asked probing question to elicit response as part of his teaching response (line 19).
Student 4: *I mean heat capacity is about any mass at all while specific heat capacity limits itself to only a unit mass (1kg),*	**PK**: Through the use of questioning technique, Kalulu managed to get the learner to produce clear and correct response
Kalulu: Excellent! *You got it. This is an important concept in determining the amount of heat that is required to warm a substance or to cool a substance.*	**CK:** Teacher content knowledge was used to ascertain correctness or otherwise of the answer (line 19).
Line 20: *Do you have any question for me?*	
The whole class: *No Sir!*	
Kalulu: Ok. *Let me ask you. If two solids, 'A' and 'B' have heat capacities of* $200JK^{-1}$ *and* $350JK^{-1}$ *respectively. Which of these two bodies is a better conductor of heat and why?*	**PK**: As part of his teaching strategy, Kalulu posed a related question to test for understanding and their preparedness to move to the next stage of the lesson (line 20).
All students who attempted to answer went for body 'B' with the explanation that body 'B' has larger amount of heat energy.	**LLD:** The response to this question gave Kalulu the indication that learners' understanding of the concept is questionable (line 20).
Line 21: Kalulu: *Oh no!. Let's get this right. What this means is that 'A' needs 200J of heat energy to change its temperature by 1K and solid 'B' needs 350 J of heat energy to change its temperature by 1 K. So 'A' conducts heat better (faster) than 'B', because 'A' needs lesser amount of heat to attain a 1 K rise in temperature. 'B' needs more amount of heat. Therefore, the statement that, the spe-*	**CK:** Teacher content knowledge was used to give further explanation to the concept of heat and specific heat capacity (line 21).

Description of lesson	Categorisation or themes
cific heat capacity of water is 4200 Jkg-1 K-1 means that 4200 J of heat energy is needed to change the temperature of 1kg mass of water by 1K.	
Line 22: Kalulu: *Now let's see how we can calculate quantity of heat gained or lost. The amount of heat energy transferred can be calculated using the equation Q = mcΔT, where Q is the heat energy transferred, m is the mass of the substance, c is the specific heat capacity of the substance, and ΔT is the change in temperature.* *Therefore, Q = mcΔT, and the SI nit is joule (J).*	**CK:** Teacher content knowledge was used to explain measurement of quantity of heat (line 22).
Line 23: *Now let's try some number of examples.* Kalulu took his learners though three different examples placing emphasis on very important areas like units of mass being in kg and working out the temperature difference well.	**PK**: As part of his teaching strategy Kalulu supported his calculation lessons with a number of examples to aid understanding (line 23).
Line 24: He later gave them one of the sample questions to try in class as he went round to supervise how they were working out the answer.	**PK**: Kalulu, in giving trial question, tried to test for understanding as he gave individual attention (line 24). **CK**: teacher content knowledge was used to ascertain the correctness or otherwise of the trial question.
Line 25: Kalulu: *Now, we shall conclude today's lesson with one important concept known as latent heat. What is latent heat?*	**PK**: Questioning technique was used to elicit response (line 25).
Student 4: *Latent heat of vaporisation means the heat is not strong.* Student 5: *Latent heat is the heat that is absorbed or released when a substance changes state, maybe from a solid to a liquid or from a liquid to a gas.*	**PK**: Kalulu got the learner to share knowledge with his peers (line 25).
Kalulu: *Excellent, Student 5! Latent heat is the heat that is absorbed or released when a substance changes state, such as when it changes from a solid to a liquid or from a liquid to a gas, without a change in temperature. At this stage all the energy being supplied is being used to change state without the temperature changing. The temperature remains constant.*	**CK:** Teacher content knowledge was used to explain latent heat (line 25).
Line 26: Kalulu: *An example is when heating water in a pot, when the water begins to boil, all the heat energy that is being supplied afterwards is just being used to change the water to vapour without any change in temperature of the water until the entire water gets finished inside the pot.*	**PK**: As part of his teaching strategy, Kalulu gave series of examples to aid understanding (line 26). **CK:** Teacher content knowledge was used in providing examples (line

Description of lesson	Categorisation or themes
	26).
Line 27: Kalulu: *There are two types of latent heat: Latent heat of fusion and latent heat of vaporisation. Fusion has to do with change of state at the freezing point without change in temperature while vaporisation concerns itself with boiling points. Let's try some examples.*	**CK:** Teacher content knowledge was used in providing detailed information on latent heat (line 27).
Line 28: Kalulu took his learners though three different example placing emphasis on very important areas like units of mass being in kg and emphasising that there is no temperature difference.	**PK**: As part of his teaching strategy, Kalulu gave series of examples to aid understanding (line 28). **CK:** Teacher content knowledge was used in providing examples (line 28).
Kalulu later gave them one of the sample questions to try in class as he went round to supervise how they were working out the answer.	**PK**: Kalulu, in giving trial question, tried to test for understanding as he gave individual attention. **CK**: teacher content knowledge was used to ascertain the correctness or otherwise of the trial question.
Line 29: *Kalulu: Is it possible to use any one means or method to minimise all these modes of heat transfer (loss/gain)?* Students provided a lot of inaccurate responses that suggesting methods to minimise heat transfer such as wrapping the objects in cloth or foam, using thick metallic or plastic materials and putting the object in water.	**PK**: Questioning technique was used to elicit response (line 29).
Kalulu then displayed this picture of a vacuum flask sourced from the internet on the board.	**PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM (line 29).

Line 30: Kalulu then explained what device could be used and how it works to minimise heat transfer. Kalulu: *A vacuum flask, also known as a thermos, is designed to keep drinks hot or cold for extended periods. It achieves this by having two bottles, an inner one for the liquid and an outer one acting as a protective layer. The space between them is a vacuum, meaning it's nearly empty with no air. This vacuum prevents heat*	**CK:** Kalulu used his content (procedural) knowledge to address the issue and guided the students towards the correct answer (line 30.

Description of lesson	Categorisation or themes
transfer through conduction and convection. Also, the inner surface of the outer bottle is coated with a reflective material to minimise radiation heat exchange. A rubber or plastic seal keeps the vacuum tight. Together, these features trap the desired temperature inside the flask, keeping your beverages hot or cold for hours, making the vacuum flask a good device for maintaining the temperature of drinks. Kalulu concluded his lesson by giving summary of what was taught and bade his students goodbye.	

APPENDIX R

Carl's lessons observation transcription and analysis

Description of lesson	Categorisation or themes
Classroom context Carl's physics class had 47 learners, consisting of 34 boys and 13 girls of mixed ability. His lessons were taught in a standard science laboratory. The laboratory furniture was in good shape and arranged in rows and columns with enough space for teacher and learner movement. Every student had a notebook to write in.	(a) The classroom context provided a safe learning environment for both girls and boys. (b) All students had notebooks
Lesson one topic: the definition of thermal energy', 'explanation of thermal equilibrium', 'SI units of heat energy, and thermometer and thermometry substances'. **Class**: SHS 2, **Time**: 60 min.	
Observation	
Lesson Introduction	
Line 1: Carl entered the lab and greeted the class and initiated the lesson by posing a question: Carl: *Have you ever seen a river flowing?* Students: *Yes Sir!* Carl: *Describe the direction of a flowing river as you had seen it relative to the topography of the land.*	**Pedagogical knowledge (PK)**: Teacher used questioning technique in a familiar context to arouse interest and engage learners in the discussion of the concept of thermal energy (line 1).
Carl encouraged students to participate actively by responding to the question.	**PK**: Carl posed question, allowed wait time as student organised themselves to respond.
Line 2: Students actively participated by attempting to describe the direction of the river flow. Carl: *That's a good attempt. Yes, anybody else?* Student 1: *The river flows downward*. Student 2: *Sir, it flows from high ground to low ground*.	**PK:** Carl got students participating.
Line 3: *Carl skilfully drew parallels between the flow of a river and the flow of heat energy*.	
Carl explained: *Heat energy, like the river, moves from regions of higher temperature to regions of lower temperature. So, it is energy that moves from a region of higher temperature to a regionof lower temperature. Not the other way round.*	**CK**: Teacher used content (declarative) knowledge to explain relating it to familiar situations (line 3).
Line 4: Students actively engaged in discussions and asked questions to clarify the concept of heat energy.	**PK**: Inquiry-Based Learning, Student participating.

Description of lesson	Categorisation or themes
Student 3: *Sir, do you mean heat energy is like a river that moves from hot things to cooler things?*	
Student 4: *So what happens when two things reach the same temperature?*	
Carl provided a concise definition of heat energy as: *The transfer of energy from regions of higher temperature to regions of lower temperature. It does not move from region of lower temperature (cold objects) to a region of higher temperature (hot objects).*	**CK:** Teacher content (declarative) knowledge was used to explain the definition (line 4).
He elaborated on the concept, emphasising the transfer of energy and the direction of flow.	**CK**: Carl explained further for emphasis.
Students asked questions to further understand heat energy.	**PK**: Inquiry-based learning, student participating
Line 5: Student 5: *Is heat energy always moving, or can it stay in one place?*	
Carl: Good question. *When the heat energy flows from a region of higher temperature (hot object) to a region of lower temperature (cold objects), there comes a time when the two objects (both hot and cold) will attain the same temperature. At this point we say they are in 'thermal equilibrium'. At this point, the heat energy will not flow anymore.*	**CK**: Carl used his content knowledge to explain.
Line 6: Student 6: *Sir, how is heat energy different from just temperature?*	
Carl: *Great! That will soon be discussed' Let's talk about the SI unit of heat energy.*	
Carl continued to explain that like other forms of energy, heat is measured in joules (J). He added that when the quantity of energy is large, bigger unit of kilojoule is used. But the SI unit remains as joule (J).	**CK:** Teacher content knowledge was used to explain.
Line 7: Carl presented real-life scenarios where understanding heat energy is crucial, such as heating a cup of koko or feeling warm in the sun. Students actively engaged in discussions about how these scenarios relate to the concept of heat energy.	**PK**: Carl used a familiar context to arouse interest and engage learners in the discussion of the concept of thermal energy (line 7).
Line 8: *Student 5: So, when the koko gets cold, does that mean that heat energy is leaving the koko?*	**PK**: Carl used a familiar context to arouse interest and engage learners in the discussion of the concept of thermal energy (line 8).
Student 8: *It's like the sun is sending us heat energy when we feel warm.*	
Carl facilitated a class discussion, asking students to reflect on the importance of understanding heat energy in everyday life.	**CK:** Teacher content knowledge was used to explain (line 8).

Description of lesson	Categorisation or themes
Line 9: *Carl: Now let's discuss temperature. Now student 6, you were asking about temperature. The whole class, any idea about temperature?* Student 7: *Sir is it not about how hot or cold something is?*	**PK**: Carl used questioning technique to elicit response from learners (line 9).
Carl: *You're right. Temperature is the degree of hotness or coldness of a body. It is used to measure how hot or cold an object is and it gives indication of quantity of heat energy a body possesses.*	**CK:** Teacher content knowledge was used to explain (line 9).
Line 10: Carl asked students shared their insights, including the practical applications of understanding heat energy and temperature.	**PK**: Student Participation
Carl then asked the students to mention the SI unit of temperature. Students mentioned a number of them including 'degree Celsius, kelvin etc.	**CK:** Teacher content knowledge was used to explain (line 10).
Line 11: Carl then had further discussions with the students. He then displayed a picture showing types of thermometers on the board. He discussed the different types of thermometers, their thermometric properties and how they are used.	**CK:** Teacher content knowledge was used to explain (line 10).
	**PK:** Teacher's teaching strategy was used to look for appropriate teaching and learning materials to support his lesson (line 11).
Line 12: Carl then concluded his first lesson by summarising the key points. He then gave them homework covering the areas taught. Student 9: *Oh Sir, knowing this helps us understand why things feel hot or cold. We understand.* Student 10: *It's like heat energy is everywhere, and we encounter it all the time.*	**PK:** Teacher's teaching strategy was used to recap the lesson to reinforce understanding. **PK:** Teacher's teaching strategy was used to assess learners and to identify possible learning difficulties for redress (line 12).
Lesson 2 topic: 'Temperature Scales and Heat Effects'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: Carl entered the lab and initiated the lesson by reviewing the previous lesson on heat energy and its movement leading to gain or loss of heat energy.	**PK**: As part of Carl's teaching strategy, he reviewed the previous lesson to establish connection between the previous and new lessons for easy understanding (line 1).
Line 2: Carl continued and emphasised the importance of understanding heat energy in relation to temperature.	**PK**: Teacher did this for emphasis

Description of lesson	Categorisation or themes
Carl: *So, let's remind ourselves of key concepts discussed in the previous lesson.*	**PK**: Carl used his questioning techniques to elicit responses from his students (line 2).
Students actively engaged in recalling key concepts from the previous lesson.	**PK**: Student participated.
Line 3: Carl took over to explain further what he began in the previous lesson by defining temperature as a measure of the average kinetic energy of particles in a substance.	**CK:** Teacher content knowledge was used to explain (line 3).
Line 4: He explained how temperature relates to quantity of heat energy possessed a body.	**CK:** Teacher content knowledge was used to explain (line 4).
Students asked questions to clarify their understanding of temperature and heat.	**PK**: Inquiry-based learning, Students' participation was encouraged .
Line 5: Student 1: *So Sir, temperature is all about how fast particles are moving and how much energy is acquired. Is it right?*	**PK**; Students were allowed to ask questions for understanding (line 5).
Student 2: *How does temperature affect different materials?*	
Carl: *Yeah, temperature affects different materials differently based on some factors. We'll be looking at that in our next lesson. But student 1, the syllabus did not require of us to discuss that into details. Maybe as you move higher.*	**CK**: Teacher content knowledge was used to explain and why there would not be the need to go further in this direction (line 5).
Line 6: Carl introduced the Celsius, Fahrenheit and kelvin temperature scales, explaining their origins and applications.	**CK:** Teacher content knowledge was used to explain (line 6).
Carl provided a detailed comparison of the two scales, including freezing and boiling points.	**CK:** Teacher content knowledge was used to explain (line 6).
Line 7: Students actively engaged in discussions about the use of these temperature scales.	
Student 3: *Why do we use different scales in different countries?*	**PK**; Students were allowed to ask questions for understanding (line 7).
Student 4: *How do you convert between Celsius and Fahrenheit?*	
Carl responded to students' questions and elaborated with some examples of the conversations from one temperature scale to the other.	**CK:** Teacher content knowledge was used to explain (line 7).
Line 8: Carl discussed the effects of heat on different materials, including expansion, contraction, change of state and chemical formula. Carl then performed a demonstration on the 'change of state'	**CK:** Carl used his teacher content knowledge to explain these concepts (line 8).

Description of lesson	Categorisation or themes
using a piece of ice and heating it to show change of state from solid to gas,	PK: As a teaching strategy, Carl used demonstration (line 8).
He explained how heating and cooling substances can lead to changes in volume and density, state and chemical formula.	**CK:** Teacher content knowledge was used to explain
Students asked questions to further grasp the concept of heat effects.	
Student 5: *What happens when a metal gets really hot?*	**PK**; Students were allowed to ask questions for understanding (line 8).
Carl responded to students' questions and elaborated with some examples and asked if there were some more questions.	**CK:** Teacher content knowledge was used to explain
Line 9: Carl facilitated a class discussion on real-life applications of temperature measurement and heat effects.	**PK**: Application of knowledge included familiar context (line 9).
Students shared their insights, including instances where temperature measurement is essential.	**PK**: Application of knowledge included familiar context (line 9).
Line 10: Student 7: *In cooking, knowing the right temperature is important for food safety.*	**PK**: Students were allowed to share their thoughts on application of knowledge and included familiar context (line 10).
Student 8: *Thermometers are used everywhere, even in weather forecasting and hospitals.*	
Lesson 3: Lesson topic: **'**Quantity of Heat and Specific Heat Capacity'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: Carl entered the lab, greeted his students began the lesson by reviewing the previous lesson.	**PK**: As part of Carl's teaching strategy, he reviewed the previous lesson to establish connection between the previous and new lessons for easy understanding (line 1).
Students actively engaged in recalling salient related concepts.	**PK**: Student participated.
Line 2: Carl introduced the concept of quantity of heat and defined it as the total energy transferred between objects due to temperature differences. He explained further and added some familiar examples such as cooking rice and banku on a gas stove.	**CK:** Teacher content knowledge was used to explain
Students listened and participated in the lesson	
Line 3: *Now that we have extensively discuss this quantity of heat concept. Can we think of the SI unit that is used in measuring it?* Student 1: *kilowatts (kW)*	**CK:** Teacher content knowledge was used to explain **PK**: Carl used his questioning techniques to elicit responses

Description of lesson	Categorisation or themes
Student 2: *Sir I think it should be in kilojoule (kJ)*	from his students (line 3).
Carl: *Any other answers?*	
Student 3: *Calories (cal).*	**PK**: Student participated.
Student 3: *Sir is it in joules (J)?*	
Line 3: *Carl: student 3, you are right.*	
He mentioned joules (J) as the SI unit and explained other units for measuring heat, such as kilojoules (kJ) and calories (cal).	**CK:** Teacher content knowledge was used to explain
Line 3:Students asked questions to clarify their understanding of quantity of heat.	**PK:** Inquiry-based learning,
Student 1: *Is it possible for us to guess or calculate the quantity of heat transferred?*	**PK**: Student participated.
Student 4: *What's the difference between joules and calories?*	
Carl responded to students' questions and elaborated with some examples and asked if there were some more questions.	**CK:** Teacher content knowledge was used to explain.
Line 4: Carl introduced specific heat capacity and defined it as the amount of heat required to raise the temperature of a unit mass of a substance by 1 degree Celsius or 1 kelvin.	**CK:** Teacher content (declarative) knowledge was used to explain.
Carl again explained heat capacity and defined it as the amount of heat required to raise the temperature of mass of a substance by 1 degree Celsius or 1 kelvin.	**CK:** Teacher content (declarative) knowledge was used to explain (line 4)
Line 5: Carl later explained that different materials have different specific heat capacities.	**CK:** Teacher content knowledge was used to explain.
Students actively engaged in discussions about specific heat capacity and its applications.	**PK**: Active student participation.
Line 6: Student 3: *Why is water often used as a reference for specific heat capacity?*	**PK**; Students were allowed to ask questions for understanding (line 6).
Student 4: *How can we determine the specific heat capacity of a substance?*	
Carl responded to students' questions and elaborated with some examples and asked if there were some more questions.	**CK:** Teacher content knowledge was used to explain (line 6)
Line 7; Carl then led his students through how to calculate the quantity of heat using the formula $Q = mc\Delta T$,	**CK:** Teacher content knowledge was used to explain (line 7)

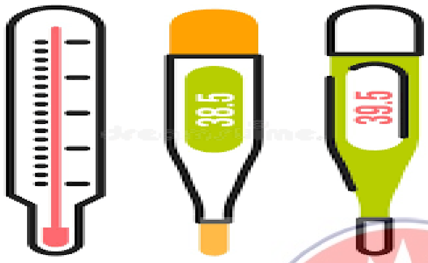
Description of lesson	Categorisation or themes
where Q is the heat energy, m is the mass, c is the specific heat capacity, and ΔT is the temperature change.	
Line 8: Carl took his students through examples of heat calculations involving different materials.	**PK:** Application of knowledge.
Students asked questions to better understand the calculation process.	**PK**: Inquiry-based learning,
Line 9: Student 5: *Sir, is it possible to calculate heat transfer in a real-world scenario?*	**PK**; Students were allowed to ask questions for understanding (line 9).
Student 6: What happens if we use the wrong units in the formula?	
Line 10: Carl responded to students' questions, elaborated with some examples and gave homework as he ended the third lesson.	**PK:** Teacher's teaching strategy was used to assess learners and to identify possible learning difficulties for redress (line 10).
Lesson 4 topic: 'Modes of Heat Transfer'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: Carl: Good morning class. Carl initiated the lesson by asking students to mention what they learnt in the last lesson. about quantity of heat,. He asked students to feel free and share their experiences related to all the concepts learnt about heat from different sources.	**PK:** Teacher used this strategy to review the previous lesson.
Students actively participated by sharing their experiences and knowledge.	**PK**: Active students' participation.
Line 2: Carl introduced the concept of conduction as one of the modes of heat transfer.	
He explained that conduction as mechanism through which heat is transferred by direct contact between two or more solids in contact with each other and gave an example using a hot ball of banku in a metal plate.	**CK:** Teacher content (declarative) knowledge was used to explain (line 2)
Line 3: Students listened to Carl and asked questions to clarify their understanding.	**PK**: Inquiry-based learning as student were made to participation
Student 1: Is conduction all about kitchen activities like cooking in pots?	
Student 2: Why are some materials hotter than others?	
Carl responded to students' questions, elaborated with some examples outside kitchen like laboratory and car engine and asked if there were some more questions.	
He later did some illustrations on the board with candles attached to nails being heated from a common source. He referred students to a page in their textbooks.	**CK:** Teacher content knowledge was used to explain (line 3)

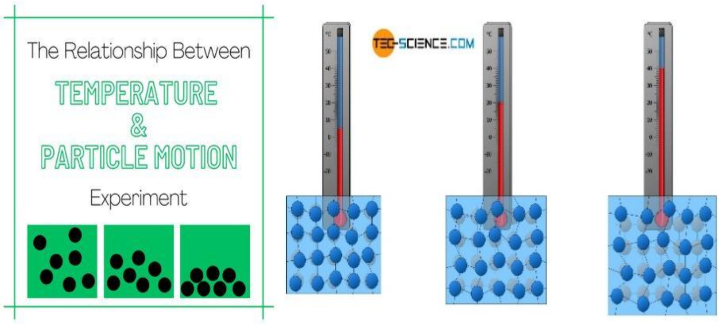
Description of lesson	Categorisation or themes
Line 4: Carl introduced convection as another mode of heat transfer, explaining that it involves the movement of fluids. He explained convection as the process responsible for heat transfer via fluid motion He stressed that if is fluid, it happens in liquids and gases.	**CK:** Teacher content (declarative) knowledge was used to explain (line 4)
He used room ventilation as an example of hot air rising and cool air sinking to illustrate convection and added refrigerator cooling systems.	**PK**: Carl used a familiar context to arouse interest and engage learners in the discussion (line 4).
Students actively engaged in discussions about convection and its real-life examples. He did some illustrations on the board and referred students to a page in their textbooks.	**PK**: Active students' participation.
Line 5: Student 3: *Does convection apply to weather patterns, like wind?*	**PK**; Students were allowed to ask questions for understanding (line 5).
Student 4: *Sir you said convection occurs in liquids and gases. Can you explain why convection occurs in liquids and gases but not in solids?*	
Line 6: Carl indicated that why this does not happen in solid was not that necessary but how convection takes place was important and he explained using illustration on the marker board.	**CK:** Teacher content knowledge was used to explain (line 6)
Line 7: Carl introduced radiation as the third mode of heat transfer, explaining that it is a mode of heat transfer which doesn't require a medium for its transfer. He cited examples like the sun's and burning fire wood's heat reaching us.	**CK:** Teacher content knowledge was used to explain (line 7)
Carl used the example of the sun's heat reaching Earth through space as an illustration on the marker board.	**PK:** Active students' participation
Line 8: Students actively participated in discussions about radiation and its applications.	
Student 5: *Is radiation only related to heat, or does it apply to other forms of energy too?*	**PK**; Students were allowed to ask questions for understanding (line 8).
Student 6: *Why does radiation feel different from conduction and convection?*	
Line 9: Carl provided detailed explanations for each mode of heat transfer, emphasising their characteristics and real-world applications.	**CK:** Teacher content knowledge was used to explain (line 9)
Line 10: He clarified students' doubts by offering clear and concise explanations, ensuring they understood the concepts and ended the class.	**CK:** Teacher content knowledge was used to explain (line 10)

APPENDIX S

John's lesson observation transcription and analysis

Description of lesson	Categorisation or themes
Classroom context John's physics class had 45 learners, consisting of 30 boys and 15 girls of mixed ability. His lessons were taught in a standard science laboratory. The laboratory furniture was in good shape and arranged in rows and columns with enough space for teacher and learner movement. Every student had a notebook to write in.	(a) The classroom context provided a safe learning environment for both girls and boys. (b) All students had notebooks
Lesson one topic: the definition of thermal energy', 'explanation of thermal equilibrium', 'SI units of heat energy, and thermometer and thermometry substances'. **Class**: SHS 2, **Time**: 60 min.	
Observation	
Lesson Introduction	
Line 1: John entered the classroom and greeted his class. John: *Good morning, everyone. Today, we're diving into the world of heat energy. But before we begin, can anyone recall what we've learned about different forms of energy in our previous lessons?* (Connecting to previous lessons)	**Pedagogical knowledge (PK)**: John used questioning technique in a familiar context to arouse interest and to introduce the lesson.
Student 1**:** *We talked about kinetic energy and potential energy'* John**:** *Excellent! Now, let's explore a new form of energy: heat energy.* (Introducing the topic)	**PK**: John used questioning technique in a familiar context to arouse interest and engage learners in the discussion as he link previous lesson to the new one (line 1).
Line 2: John**:** *Heat energy is yet another form of energy. It is a measure of how much thermal energy an object contains.* John continued: Its SI unit is the joule (J). (Providing declarative content knowledge). The kilojoule (kJ) is used when the amount of energy is large.	**Content knowledge (CK):** John demonstrated mastery of content by defining thermal energy.
Line 3: John**:** *To understand heat energy better, we need to grasp temperature and temperature scales. Temperature is the degree of hotness and coldness of a body. We have the Celsius, Fahrenheit, and Kelvin scales. Each measures temperature differently. And they are used by different countries.*	**PK:** Systematic presentation of lesson. **CK:** John demonstrated mastery of content knowledge.
Line 4: John introduced the Celsius and Kelvin temperature scales. John continued: *We use the Celsius scale for everyday temperature measurements, but in scientific work, we also use the Kelvin scale. The Kelvin scale starts from absolute zero, which is the lowest possible temperature.*	**CK:** John gave further explanation (indicating declarative knowledge) (line 4).
Line 5: Student 2: *Sir, so what is the difference between Celsius and Kelvin, and why do we need both?*	**PK**: Students were encouraged to asked questions.
Student 3 asked a question about the Kelvin scale.	**CK:** John demonstrated mas-

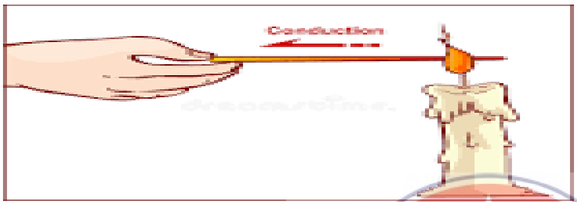
Description of lesson	Categorisation or themes
John explained, *The Kelvin scale is essential in scientific measurements because it starts at absolute zero, where there is no thermal motion. It allows us to make precise measurements for scientific research and calculations.*	tery of content knowledge.
Line 6: John**:** *Think about it this way: when you touch a hot pan on the stove, you will feel the heat energy transferring from the pan to your hand. That's what we call temperature.* John continued and mentioned that thermometer is the instrument for measurement of temperature. Line 7: John used diagrams and pictures to help students visualise different thermometers.	**PK**: Teacher used every day experiences and real-life examples to support his lesson for easy understanding (line 6).
	**PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM
Line 8: John**:** *Now, let's try to answer this question. What is the difference between the Celsius and Fahrenheit temperature scales?* Student 3**:** *Celsius is used in most counties, and Fahrenheit is mostly used in the United States.*	**PK**: John used questioning technique to engage and elicit response from learners (line 8).
Line 9: John: *Good start! But what about the freezing and boiling points of water on each scale?* Student 4**:** *In Celsius, water freezes at 0 degrees and boils at 100 degrees. In Fahrenheit, it freezes at 32 degrees and boils at 212 degrees.* John**:** Perfect! You've got it.	**PK**: Teacher motivated, engage students and guided them to do critical thinking **PK**: Reinforcing understanding.
Line 10: John discussed temperature conversion between Celsius and Kelvin scales. John explained the conversion formula, which involves adding 273.15 to the Celsius temperature to obtain the Kelvin temperature. In the other hand subtracting 273.15 from the Kelvin temperature to obtain the Celsius temperature. John then summarised the key points of the lesson and ended the lesson.	**CK:** John demonstrated mastery of content (declarative) knowledge.
Lesson 2 topic: **'**Measurement of Heat' 'quantity of heat'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: John: *Good morning, class. Today, we're building on our understanding of heat energy. Can we remember what we learned last time about heat energy and how it moves?* Student 1**:** (Raised hand up) *Heat energy is about how much thermal energy an object has, and temperature is about how hot or cold something is.*	**PK**: John used questioning technique to get students to recall in order to review the the previous lesson.

Description of lesson	Categorisation or themes
Line 2; John**:** That's right! Excellent recap. Now, we're going to look at more thermal concepts. John**:** *In thermal energy, it is a very important concept to understand how things heat up or cool down. It's like the energy stored within substances due to the motion of their particles. (Providing declarative content knowledge)* John draws diagrams on the whiteboard to illustrate how particle motion relates to thermal energy.	**PK**: john used this strategy to motivate and engage learners as he introduced the lesson. **CK**: John used his teacher content (declarative) knowledge to explain concept.
	**PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM (line 2).
Line 3: John**:** *(Pointing to the diagrams) When particles move faster, they have more thermal energy, which means they're hotter. When they move slower, they're cooler.*	**CK**: John used his teacher content (declarative) knowledge to explain concept.
Line 4: John*: (Interacting with the class) Let's discuss further. How does heat energy affects our daily lives? Give us some examples.* Student 2**:** When we cook food on the stove, the heat energy from the fire heats the pan, and that cooks the food!	**PK:** John used questioning technique to elicit response from learners (line 4). **PK;** Students were made to participate.
Line 5: **John:** Very good example! Now, let's talk about quantity of heat and specific heat capacity. John continued: *What do you think "quantity of heat" means in this context?*	**PK**: Questioning technique was used to get learners to brainstorm to elicit response (line 5).
Line 6: John: (Asking the class while moving around) *What do you think "quantity of heat" is?* Student 3**:** *Sir, is it about how much thermal energy there is in something?*	**PK;** Students were made to participate.
Line 7: John: *Exactly! (Affirming the response) Quantity of heat is all about how much heat energy an object contains. But there's more to it. Can someone explain specific heat capacity?* Student 1:Is it that the heat is specific or it's capacity is high or something ?	**PK**: Questioning technique was used to get learners to brainstorm to elicit response (line 7).
Line 8: John**:** *That's a good attempt. Specific heat capacity tells us how much heat energy 1kg (a unit mass) substance can absorb or*	**PK**: Questioning technique was used to get learners to brainstorm to elicit response

Description of lesson	Categorisation or themes
release by changing its temperature by 1^0C or 1 K.	(line 8).
Line 9: John: (Summarising) *We've covered a lot today. For homework, I want you to think about how thermal energy and specific heat capacity relate to everyday activities. Present your findings in a short essay or note. (Assigning homework)*	**PK:** Assigning homework is an instructional strategy to get student to read for easy understanding of the next lesson (line 9).
Line 10: Student 5: (Raised hand up) *What if we don't understand what you asked us to read?*	
John**:** (Supportive) *Just try your best to get some meaning out of what you read. If you have questions, we'll go over them in our next class. Goodbye.*	
Lesson three topic: 'measurement of quantity of heat'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: John**:** (At the front of the classroom) *Good day, class. Today, we're looking at some interesting areas of heat energy. But before we begin, let's quickly recap what we've learned so far about heat energy, quantity of heat, and specific heat capacity.* (Recap of previous lessons)	**PK**: John used questioning technique to get students to recall in order to review the the previous lesson.
Student 1**:** (Raised hand up) *Thermal energy is about how much energy particles have, quantity of heat is the amount of thermal energy, and specific heat capacity is how much heat energy* 1kg (a unit mass) substance can absorb or release by changing *its temperature by 1^0C or 1 K.*	**PK:** Active students' participation (line 1).
John**:** Excellent recap! You're good! Now, let's continue from where we stopped the last time.	**PK**: John used this strategy to motivate and engage learners as he introduced the new lesson.
Line 2: John: *We have **heat capacity** and **specific heat capacity**. The <u>specific heat capacity</u> is a measure of the amount of heat energy required to raise the temperature of **a unit mass of a substance** by 1 degree Celsius per unit mass. By referring to a unit mass, we mean 1kg of mass. The SI unit is $Jkg^{-1}\,{}^0C^{-1}$ or $Jkg^{-1}\,K^{-1}$.*	**CK:** Teacher content knowledge was used in explaining specific heat capacity (line 2).
Line 3: John: *On the other hand, <u>the heat capacity</u> of an object is the amount of heat energy required to raise or change the temperature **of a substance** by 1 degree Celsius. The SI unit is $J\,{}^0C^{-1}$ or $J\,K^{-1}$.*	**CK:** Teacher content knowledge was used in explaining specific heat capacity (line 3).
Line 4: John: *So what is the difference **between heat capacity** and **specific heat capacity**?*	**PK**: John used questioning technique to engage and elicit response from learners (line 4).
Student 2: *They are they all not talking about the same thing- heat capacity, Sir?*	
The whole class (confirmed in chorus): *Yes!*	

Description of lesson	Categorisation or themes
Line 5: Student 3: *Heat capacity is general while specific heat capacity is specific in nature.*	**PK**: As part of his teaching strategy, John allowed the learners to express themselves to ascertain if there is an issue of learning difficulty (line 5).
Line 5: John: *That is not clear. What do you mean by 'general' and 'specific in nature'?*	**PK**: John asked probing question to elicit response as part of his teaching response (line 5).
Student 3: *I mean heat capacity is not talking about any mass at all while specific heat capacity says only a unit mass (1kg),That's my thinking Sir.*	**PK**: Through the use of questioning technique, John managed to get the learner to produce clear and correct response (line 5).
Line 6: John: (Out of excitement) Excellent! *You are good! This is an important concept in determining the amount of heat that is required to warm a substance or to cool a substance.*	**CK:** Teacher content knowledge was used to ascertain correctness or otherwise of the answer (line 6).
Line 7: John: *Now let's see how we can calculate quantity of heat gained or lost. The amount of heat energy transferred can be calculated using the equation $Q = mc\Delta T$, where Q is the heat energy transferred, m is the mass of the substance, c is the specific heat capacity of the substance, and ΔT is the change in temperature.* *Therefore, $Q = mc\Delta T$, and the SI nit is joule (J).*	**CK:** Teacher content knowledge was used to explain measurement of quantity of heat (line 7).
Line 8: John: *Now let's try some examples for you to know how to solve them.* John took his learners though three different examples placing emphasis on very important areas like units of mass being in kg and working out the temperature difference well.	**PK**: As part of his teaching strategy John supported his calculation lessons with a number of examples to aid understanding (line 8).
Line 9: He later gave them two of the sample questions to try in class as he went round to supervise how they were working out the answers.	**PK**: John, in giving trial question, tried to test for understanding as he gave individual attention (line 9). **CK**: teacher content knowledge was used to ascertain the correctness or otherwise of the trial question.
Line 10: John: *Now, let's continue the lesson with one equally important concept known as latent heat. What is latent heat?*	**PK**: Questioning technique was used to elicit response (line 10).
Student 4: *Latent heat of vaporisation could mean there is equilibrium of temperatures between objects.*	
Student 5: *Latent heat is the heat that is gained or perhaps lost if an object is no more in that state.*	**PK**: John got the learner to share knowledge with his

Description of lesson	Categorisation or themes
	peers (line 10).
John: *Good, Student 5! Latent heat is the heat that is absorbed or released when a substance changes state, such as when it changes from a solid to a liquid or from a liquid to a gas, without a change in temperature. At this stage all the energy being supplied is being used to change state without the temperature changing. The temperature remains constant.*	**CK:** Teacher content knowledge was used to explain latent heat (line 10).
Line 11: John: *An example in boiling water in a silver, when the water starts boiling, all the heat energy that is being supplied afterwards is just being used to change the water to vapour without any change in temperature of the water until all the water inside the silver gets finished.*	**PK**: As part of his teaching strategy, John gave series of examples to aid understanding (line 11). **CK:** Teacher content knowledge was used in providing examples (line 11).
Line 12: John: *We have two types of latent heat: Latent heat of fusion and latent heat of vaporisation. Fusion talks about change of state at the freezing point without change in temperature while vaporisation is more of boiling points. Let's do some examples.*	**CK:** Teacher content knowledge was used in providing detailed information on latent heat (line 12).
Line 13: John took his learners though a number of examples placing emphasis on very important areas like units of mass being in kg and emphasising that there is no temperature difference.	**PK**: As part of his teaching strategy, John gave series of examples to aid understanding (line 13). **CK:** Teacher content knowledge was used in providing examples (line 13).
John then gave two of the sample questions to try in class as he went round to supervise how they were working out the answer. John again gave them two questions based on calculations to do as homework and ended the lesson.	**PK**: John, in giving trial question, tried to test for understanding as he gave individual attention. **CK**: teacher content knowledge was used to ascertain the correctness or otherwise of the trial question.
Lesson four topic: 'Heat Transfer'. **Class**: SHS 2, **Time**: 60 min.	
Line 1: John entered the lab, greeted his students.	
John started the lesson by asking students about their experiences with heat transfer. John: *Think about a time when you've touched something hot. What do you think happened between you and the hot object?*	PK: John used questioning technique in a familiar context to arouse interest and to elicit response to introduce the lesson.
Student 1**:** *I think heat goes from the hot thing to your cold hand.*	**PK**: Students participated.
Line 2: John**:** *You're absolutely right! Heat naturally flows from hotter objects to colder ones. Today, we'll discuss the different ways*	**CK:** Teacher content knowledge was used in

Description of lesson	Categorisation or themes
this happens.	providing explanation (line 2).
Line 3: John**:** (*Using a projector) Heat transfer is all about how heat energy moves between objects or substances. There are three main ways this happens: conduction, convection, and radiation.*	
*John**:** In conduction, heat moves through direct contact, like when you touch a hot pan. In convection, it's transferred through the movement of fluids, like air or water. And in radiation, it travels as electromagnetic waves, like the heat from the sun.*	**CK:** Teacher (declarative) content knowledge was used in providing explanation (line 3).
Line 4: John introduced the concept of conduction as the transfer of heat through solids. He demonstrated this by using a metal rod and asking students to predict what would happen when one end of the rod was heated. He supported his demonstration with this diagram.	**PK:** John used demonstration as one of his teaching strategies (line 4).
	**PK**: Teacher demonstrated the knowledge of selecting and using appropriate TLM (line 4).
Student 2**:** *I think the other end of the rod will get hot too.*	**PK**: Active students' participation.
Line 5: John**:** *That's correct! When we heat one end of the rod, heat is conducted through the solid material, making the other end hot as well. Conduction is like a game of eating hot banku with your bare hand.*	**CK:** Teacher content knowledge was used in providing explanation (line 5).
He provided other familiar examples like the roof of a building getting hot and asked students to give some more relatable examples of conduction. Student did give examples of touching a spoon that's been in hot soup and use of a fan to cool down a room.	**PK**: John used familiar and real-life examples to reinforce his lesson (line 5) **PK**: Active students' participation.
Line 6: John: *Let's make this real. Think about your father's office. When the air conditioner is on, what do you feel?*	**PK**: Questioning technique was used in familiar context to get learners to brainstorm to elicit response (line 6).
Student 2**:** (Nods) *Yes, it feels nice, comfortable and cool! But Sir, you know this yourself.*	**PK**: Active students' participation.
Line 7: John**:** (Smiling) *That's convection in action. The cool air is replacing the warm air, and that's how heat is being transferred in your room.*	**PK**: John used familiar examples to explain concept (line 7).
Line 8: John introduced the concept of convection, emphasising that it occurs in fluids like air and water. He used the example of warm air rising and asked students if they've ever felt a draft near a window.	PK: **PK**: John used real-life examples to explain concept (line 8).
He added that this happens with the help of convection current as found in boiling water and land and sea breeze. He explained more using refrigerator and car cooling systems.	

Description of lesson | **Categorisation or themes**

Line 9

PK: Teacher demonstrated the knowledge of selecting and using appropriate TLM (line 9).

John explained diagram stating the significance of this natural phenomenon and touched on climate control systems linked it to other convection (water cycle) processes like regulating the earth' temperature. Warm air rises, creating a draft near the window.

CK: Teacher content knowledge was used in providing explanation (line 9).

John: So, having discussed this, what is convection current?

Students were giving unsatisfactory answers, so John had to go over this definition until they got it right.

PK: John asked question to ascertain understanding and learners' preparedness to move to the next activity (line 9).

Line 10: John introduced radiation and explained it as heat transfer without a medium and mentioned that it can occur in a vacuum. He asked his students if anyone knew how the Sun's heat reaches the Earth.

CK: Teacher content knowledge was used in providing explanation (line 10).

Line 11: *Student 4: I think it's because of radiation, like how we get heat from a heater without feeling air.*

PK: Active students' participation.

John: *You're right! The Sun's heat travels through space to reach us, just like how you feel warmth from fire of a heater without any air in between. Radiation is interesting!*

CK: Teacher content knowledge was used in providing explanation (line 11).

Line 12: Student 3**:** *I've heard of radiation in space stuff. Is it the same thing?*

PK: Students were allowed to ask questions.

John**:** *Yeah! Radiation in space is similar to what we're discussing. It's one of the ways heat can travel through a vacuum.*

CK: Teacher content knowledge was used in providing explanation to question (line 12).

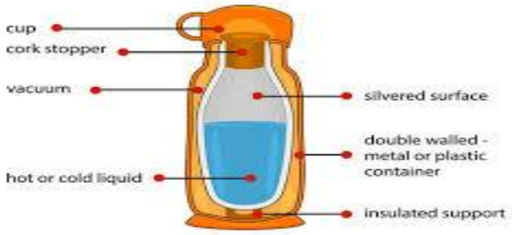
Line 13: John: Now one more thing before we end the lesson. There is one device which has been designed to minimise heat gain or loss through all these modes of heat transfer discussed. This device is the vacuum or thermos flask.

John displayed a picture of the vacuumed flask sourced from the internet.

CK: Teacher content knowledge was used in providing explanation (line 11).

PK: Teacher demonstrated the knowledge of selecting and using appropriate TLM (line 14).

Line 14

Description of lesson	Categorisation or themes
	
John explained: *A vacuum flask, which is also known as a thermos flask, is designed to minimise heat gain or loss in hot or cold drinks for extended periods. This happens through having two bottles, an inner one for the liquid and an outer one acting as a protective layer. The space between them is a vacuum, meaning it's nearly empty with no air. This vacuum prevents heat transfer through conduction and convection. Also, the inner surface of the outer bottle is coated with a reflective material to minimise radiation heat exchange. A rubber or plastic seal keeps the vacuum tight. Together, these features trap the desired temperature inside the flask, keeping your beverages hot or cold for hours, making the vacuum flask a good device for maintaining the temperature of drinks.*	**CK:** John used his (procedural) content knowledge to explain how each of these processes works (line 14).
John ended his lesson by giving summary of what was taught gave homework.	

APPENDIX T

Letter to the Head of One of the Main Study Schools

Peki College of Education,
P. O. Box 14,
Peki.
1st July, 2024.

The Headmistress,
OLA Senior High,
P. O. Box 25,
Ho.

Dear Mad,

PERMISSION TO CONDUCT RESEARCH STUDY IN YOUR SCHOOL

Research Topic: Quality and Status of Pedagogical Content Knowledge of Well-performing Physics Teachers in Senior High Schools in Volta Region.

I write to humbly seek permission from your office to conduct research study in your school as a requirement for completing a Doctoral Degree programme. I am a Ph.D candidate in the Department of Science Education, University of Education, Winneba and also a science tutor in Peki College of Education, Peki.

The Research Topic is: Quality and Status of Pedagogical Content Knowledge of Well-performing Physics Teachers in Senior High Schools in Volta Region. The study involves an exploration into the pedagogical content knowledge of some outstanding SHS physics teachers in the region. Your school, according to the WASSCE results analysis from Regional Education Office, GES, was identified as one of the best performing schools in the region in elective physics. While some senior high schools are underperforming, your school seems to be doing consistently well. I therefore would like to engage the elective physics teachers who are behind the production of these good results in a voluntary research study.

I will like to observe a few lessons of each selected physics teacher. The teachers are expected to participate in individual interviews that may last between 30-45 minutes. These activities will be carried out at the participant's convenience and will not in any way obstruct teaching and learning activities of the class. I will audio record their interviews as well as video record the observed lessons of each teacher. These recordings will be used solely for research purposes and the teachers' identity will remain anonymous. All responses from the participants will be treated with strict confidence. Participation in this study is purely voluntary and participants are free to withdraw from this study at any time they so wish.

The aim and purpose of this research is to explore the pedagogical content knowledge (PCK) of the selected physics teachers, so as to get an insight into their pedagogical actions and to develop an understanding of their teacher knowledge. It is the hope of the researcher that the findings of this study can help address the challenges that some physics teachers in underperforming schools face and can inform us on how we can improve our practice as science teachers. What is more, the participating teachers will get an opportunity to reflect on their classroom practice.

This study is being done under the supervision of Prof. M. K. Amedeker, Department of Science Education, University of Education, Winneba. In case you need further clarification or have questions about the research project, you may contact me or my supervisor through the email: mawuden@yahoo.com.

Please find attached, a copy each of introductory letters from the university and GES regional office.

Thank you in advance for your anticipated cooperation in this regard.

Yours faithfully,

(Geoffrey Klutse)

geoffreyklutse@yahoo.com

0244511857

APPENDIX U

Letter from the Head of One of the Main Study Schools

OLA Senior High School

Tel: Office : 0244536511/0208714291
E-mail: olashs@yahoo.com
GPS ADDRESS : VH00311918

P.O BOX 25
HO.

REF: NO: GES/VR/HM/OLA/189/91

12TH JULY, 2024

THE ACTING HEAD OF DEPARTMENT
DEPARTMENT OF INTEGRATED SCIENCE EDUCATION
UNIVERSITY OF EDUCATION
WINNEBA.

RE-PERMISSION TO CONDUCT RESEARCH STUDY IN YOUR SCHOOL

We acknowledge receipt of your letter with reference number ISED/PG.1/VOL.1/24 of 11th March, 2024 and write to inform you that approval has been given to Mr. Geoffrey Klutse to conduct the research in OLA Senior High School, Ho in the Volta Region.

Thank you.

BENEDICTA A.M. AGBEZUDOR (MAD)
HEADMISTRESS
OLA SENIOR HIGH SCHOOL
HO, V/R.

cc:
MR. KLUTSE GEOFFREY
UNIVERSITY OF EDUCATION
WINNEBA

Ex

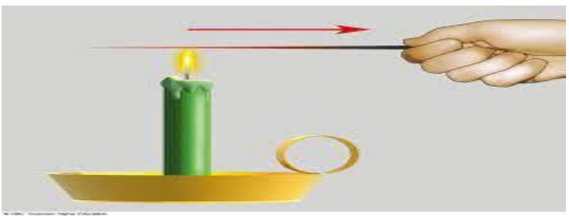
APPENDIX V

Transcription of Daniel's lesson observation and analysis

Description of Lesson	Categorisation or Themes
Classroom Context Daniel's physics class had 46 learners made up of all girls with varying levels of ability. The class was held in a well-equipped classroom with desks arranged in groups to facilitate discussion. Each student had a notebook.	(a) The classroom context created an inclusive and interactive learning environment. (b) Every student had access to a notebook.
Lesson 1 Topic: Definition of thermal energy, 'explanation of thermal equilibrium, 'SI units of heat energy, and temperature'. **Class**: SHS 2, **Time**: 60 min.	
Lesson Introduction	
Line 1: Daniel entered the class and greeted the students warmly. He introduced the lesson by relating the concept of thermal energy to something students could easily understand. *Daniel: "Imagine a hot cup of tea on a cold day. How does the warmth from the tea affect the surrounding air?" Students: "The air around it gets warmer."*	**Pedagogical Knowledge (PK):** Daniel engaged students by using a familiar context to introduce the concept of thermal energy.
Line 2: Daniel used students' responses to guide the discussion. *Daniel: "Exactly! Thermal energy moves from the hot tea to the cooler air. This is similar to how heat moves in general. Let's explore this concept further."*	**PK:** Daniel used students' input to reinforce the concept and maintain engagement.
Line 3: Teacher explained thermal energy with real-life examples. *Daniel: "Thermal energy is the energy that comes from heat. For example, when you touch a hot surface, the energy transfers from the surface to your hand."* *Student 1: "So, it's like the heat you feel from a radiator?" Daniel: "Yes, exactly. The radiator transfers heat to the air and then to you."*	**Content Knowledge (CK):** Daniel provided practical examples to clarify the concept of thermal energy.
Line 4: Daniel then introduced the SI unit of heat energy. *Daniel: "Heat energy is measured in joules (J). When the energy is substantial, we use kilojoules (kJ), but the basic unit is still joules."* *Student 2: "Why do we use kilojoules sometimes?"* *Daniel: "For larger quantities of heat, kilojoules make the numbers easier to manage."*	**CK:** Daniel used content knowledge to explain units of heat energy with relatable examples.
Line 5: Teacher addressed questions from students about thermal equilibrium. *Student 3: "What happens when two objects reach the same temperature?"* *Daniel: "When two objects reach the same temperature, they are said to be in thermal equilibrium, meaning no net heat flow occurs between them."*	**PK:** Daniel facilitated inquiry-based learning by addressing student questions about thermal equilibrium.
Line 6: Daniel elaborated on the concept of temperature, connecting it to daily life. *Daniel: "Temperature tells us how hot or cold something is. For instance, a thermometer measures temperature, helping us know if we have a fever."* *Student 4: "How is this different from heat?"* *Daniel: "Heat is the transfer of thermal energy, while temperature measures the intensity of heat."*	**CK:** Teacher used real-life contexts to explain the difference between temperature and heat.
Line 7: Teacher related the concept to everyday experiences. *Daniel: "Consider how a microwave heats food. It's an example of heat transfer through radiation."* *Student 5: "So, the microwave doesn't heat the food by touching it?"* *Daniel: "Correct, it heats through radiation."*	**PK:** Daniel used familiar scenarios to illustrate concepts and reinforce understanding.

Description of Lesson	Categorisation or Themes
Line 8: Daniel then had further discussions with the students. He then displayed a picture showing types of thermometers on the board. He discussed the different types of thermometers, their thermometric properties and how they are used. 	**PK:** Teacher's teaching strategy was used to look for appropriate teaching and learning materials to support his lesson (line 8).
Line 9: Daniel concluded the lesson by summarizing the key points and assigning homework. *Daniel: "We've discussed thermal energy, temperature, and their units. For homework, review these concepts and complete the exercises in your textbook."* *Student 6: "This makes it clear how heat affects everything around us."*	**PK:** Daniel summarised the lesson and provided homework to reinforce learning and assess understanding.

Lesson 2 topic: 'Temperature Scales and Heat Effects'. **Class**: SHS 2, **Time**: 60 min.

Line 1: Daniel started the lesson by revisiting the previous topic and linking it to the current one. *Daniel: "Last time, we discussed heat energy. Today, we will explore temperature scales and how heat affects different materials."*	**PK:** Daniel connected previous and current lessons to build a cohesive understanding (Line 1).
Line 2: Daniel reviewed key concepts from the previous lesson using student input. *Daniel: "Who remembers what we discussed about heat energy?"* *Students: "It moves from hot to cold."*	**PK:** Teacher used questioning to refresh students' memory and establish continuity (Line 2).
Line 3: Daniel defined temperature and its measurement. *Daniel: "Temperature is a measure of how hot or cold something is. It's measured using different scales like Celsius, Fahrenheit, and Kelvin."* *Student 1: "Why are there different scales?"* *Daniel: "Different countries use different scales for various reasons, such as historical reasons or convenience."*	**CK:** Daniel used content knowledge to explain temperature and temperature scales with clear definitions.
Line 4: Teacher explained the Celsius, Fahrenheit, and Kelvin scales. *Daniel: "The Celsius scale is used in most of the world, fahrenheit is used in the USA, and kelvin is often used in scientific contexts."* *Student 2: "How do you convert between these scales?"* *Daniel: "Let's practice converting temperatures between Celsius and Fahrenheit."*	**CK:** Daniel used practical examples and calculations to explain temperature scales and conversions (Line 5)..
Line 5: Teacher assisted students to do conversion of units from kelvin, Fahrenheit to Celsius scale.	
Line 6: Daniel introduced the effects of heat on materials. *Daniel: "When materials are heated, they can expand, contract, or change state. For example, when you heat a metal, it expands."* *Student 3: "Does it shrink when it cools down?"* *Daniel: "Yes, metals contract when they cool."*	**CK:** Teacher used examples to illustrate the effects of heat on different materials.
Line 7: Daniel performed a demonstration on heat effects. *Daniel: "Let's heat this metal rod and observe how it expands. We'll also look at how ice melts into water when heated."* 	**CK:** Daniel used demonstrations to visually represent the effects of heat.

Student 4: "What happens to the volume of the metal?" Daniel: "The volume increases as the metal expands."

Line 8: Students engaged in discussions and asked questions about heat effects.
Student 5: "How does heat affect the density of a substance?" Teacher: "Heating typically decreases density as substances expand. Cooling increases density as they contract."

PK: Teacher facilitated discussions and addressed students' questions to deepen understanding.

Lesson 3 Topic: 'Quantity of Heat and Specific Heat Capacity'. **Class**: SHS 2, **Time**: 60 min.

Line 1: Daniel began the lesson by connecting the previous topics to the concept of heat quantity.
Daniel: "We've learned about thermal energy and temperature. Today, we'll look at how we measure the quantity of heat and the concept of specific heat capacity."
Student 1: "What is specific heat capacity?"

PK: Daniel linked prior knowledge to new concepts, engaging students through questioning (Line 1).

Line 2: Daniel defined the quantity of heat and specific heat capacity.
Daniel: "The quantity of heat is the amount of energy transferred between objects at different temperatures. Specific heat capacity is the amount of heat required to raise the temperature of a unit mass of a substance by one degree Celsius."
Student 2: "Can you give an example?"

CK: Daniel used definitions and examples to explain key concepts clearly.

Line 3: Daniel provided a real-life example of specific heat capacity.
Daniel: "For instance, when you heat a metal spoon in hot soup, it heats up quickly because metals have low specific heat capacity. In contrast, water takes longer to heat up because it has a high specific heat capacity."
Student 3: "So, water can absorb more heat without a big temperature change?"

CK: Teacher used relatable examples to clarify specific heat capacity.

Line 4: Teacher introduced the formula for calculating the quantity of heat.
Daniel: "We use the formula Q=mcΔTQ , where Q is the heat quantity, m is the mass, c is the specific heat capacity, and ΔT\Delta is the temperature change."
Student 4: "Can we do a sample calculation?"

CK: Daniel explained the formula for calculating heat quantity.

Line 5: Teacher worked through a calculation example with the class.
Daniel: "Let's say we want to heat 500 grams of water from 20°C to 80°C. The specific heat capacity of water is 4.18 J/g°C. Using the formula, we find Q=500×4.18× (80−20)Q = 500 \times 4.18 \times (80 - 20)Q=500×4.18×(80−20). What do you get?"
Student 5: "I get 125,400 joules!"

PK: Teacher provided hands-on practice to reinforce the calculation of heat quantity.

Line 6: Daniel related the example to everyday life.
 Daniel: "Think about boiling a large pot of water for pasta. The heat energy required to bring the water to a boil is a practical example of this calculation."

PK: Daniel connected the formula to real-life situations.

Line 7: Daniel explained the concept of heat transfer and its impact.
Daniel: "The heat you add to the water increases its temperature until it reaches boiling point. This is how heat transfer works in everyday cooking."

CK: Daniel explained how heat transfer relates to the practical example of cooking.

Line 8: Daniel discussed the factors affecting specific heat capacity.
Daniel: "Different substances have different specific heat capacities. For example, sand heats up quickly on a sunny beach because it has a lower specific heat capacity compared to water."

CK: Teacher provided examples of varying specific heat capacities.

Line 9: Daniel facilitated a group activity to measure heat quantities.
Daniel: "In groups, calculate the heat required to heat different liquids, like milk and juice, using the formula provided. Compare your results."

PK: Daniel used group work to enhance learning through practical application.

Line 10: Daniel guided students through the activity, answering questions.
Student 6: "What if we don't know the specific heat capacity?" Teacher:

PK: Daniel supported students during the activity

"Good question! You might need to look it up in reference materials or textbooks."	and addressed queries (Line 10).
Line 11: Daniel used additional examples to illustrate heat capacity. *Daniel: "Consider why a hot drink cools down faster in a metal cup compared to a ceramic one. The metal's lower specific heat capacity causes it to lose heat more quickly."*	**CK:** Daniel provided practical examples to explain concepts (Line 11).
Line 12: Daniel demonstrated an experiment with different materials. *Teacher: "Here, I have metal, wood, and plastic samples. I'll heat them up and show how each material conducts and retains heat differently."*	**CK:** Daniel conducted experiments to illustrate heat transfer concepts.
Line 13: Teacher related the experiment to thermal insulation. Teacher: *"This experiment helps us understand why insulating materials like foam are used to keep heat in or out of containers."*	**PK:** Daniel connected experiments to real-life applications of thermal insulation (Line 13).
Line 14: Teacher summarised the lesson and emphasized key points. Teacher: *"Today, we covered the quantity of heat and specific heat capacity. Remember, different materials absorb and transfer heat differently, impacting everyday processes."*	**PK:** Daniel summarised the lesson effectively to reinforce learning.
Line 15: Teacher assigned homework for further practice. *Daniel: "For homework, complete the exercises on heat capacity in your textbook. Think about how these concepts apply to different household items."* *Student 7: "I'll work on it. Thank you Sir for the examples."*	**PK:** Daniel assigned relevant homework to reinforce and apply concepts learned.

Lesson 4 Topic: 'Modes of Heat Transfer'. **Class**: SHS 2, **Time**: 60 min.

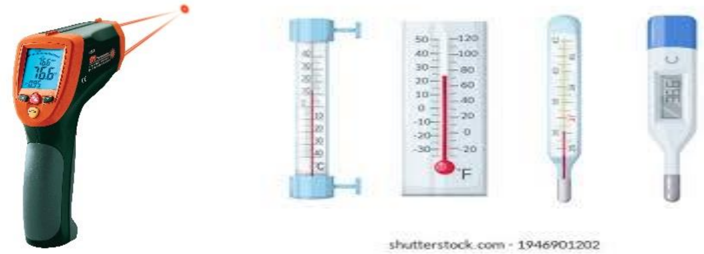
Line 1: Teacher began the lesson by relating heat transfer to everyday experiences. *Teacher: "Think about how heat travels from a hot stove to your pot. This involves different modes of heat transfer. Today, we'll explore conduction, convection, and radiation."* *Student 1: "What are these modess?"*	**PK:** Teacher used relatable examples to introduce the topic and engage students.
Line 2: Teacher defined conduction, convection, and radiation. *Teacher: "Conduction is heat transfer through direct contact, like a metal spoon in a hot cup of tea. Convection is heat transfer through fluids, like warm air rising in a room. Radiation is heat transfer through electromagnetic waves, like the warmth you feel from the sun."* *Student 2: "What's the difference between convection and radiation?"*	**CK:** Daniel provided clear definitions and comparisons of heat transfer modes.
Line 3: Teacher performed a demonstration on conduction. *Teacher: "Here's a metal rod heated at one end. Feel the other end after a few minutes. You'll notice it gets warmer."* *Student 3: "It's warm now. That's conduction?"* *Daniel: "Exactly, heat is transferred through the metal rod by direct contact."*	**CK:** Teacher used hands-on demonstrations to illustrate heat conduction.
Line 4: Daniel explained convection using a fluid example. *Daniel: "We'll heat water in this beaker and watch how the warm water rises while the cooler water sinks, creating a convection current."* *Student 4: "I see the water moving in a circular pattern!"*	**CK:** Teacher demonstrated convection currents to visualise heat transfer in fluids.
Line 5: Daniel discussed radiation with a practical example. *Daniel: "Let's use this heat lamp. You can feel the warmth on your face even though you're not touching the lamp. That's heat radiation."* *Student 5: "So, radiation doesn't need a medium like air or water?"* *Daniel: "Correct. Radiation can transfer heat through empty space."*	**CK:** Daniel used practical examples to explain heat radiation.
Line 6: Daniel related the modes of heat transfer to cooking. *Daniel: "When you cook, you use conduction in pots and pans, convection in ovens, and radiation in microwave ovens. Each mode plays a role in different cooking methods."*	**PK:** Daniel connected heat transfer modes to everyday cooking methods.

Line 7: Daniel introduced an activity to visualise conduction. *Daniel: "Let's touch different materials—metal, wood, and plastic—after heating them. Notice which one feels hot first." Student 6: "The metal gets hot the fastest."* *Daniel: "That's because metal conducts heat more efficiently than the other materials."*	**PK:** Daniel used activities to help students experience and understand conduction.
Line 8: Teacher performed a convection experiment with different liquids. *Daniel: "We'll heat oil and water and observe how they form convection currents differently."* *Student 7: "The oil doesn't mix as well as the water."*	**CK:** Daniel conducted experiments to demonstrate convection in different fluids.
Line 9: Daniel discussed real-life applications of convection. *Daniel: "Convection is used in heating systems, such as radiators and air conditioners, to circulate warm or cool air throughout a room."*	**PK:** Daniel related convection to real-life heating and cooling systems.
Line 10: Daniel explained radiation's role in daily life. *Daniel: "Radiation is essential for understanding solar energy. It's how the sun heats the Earth and provides energy for plants and weather."*	**CK:** Daniel linked radiation to broader environmental and ecological processes.
Line 11: Daniel used a teaching aid to show different modes of heat transfer. *Daniel: "Here's a diagram showing conduction, convection, and radiation. Let's discuss how each mode transfers heat in this scenario."*	**PK:** Daniel used diagrams to enhance understanding of heat transfer modes.
Line 12: Daniel conducted a group activity to explore heat transfer modes. *Daniel: "In your groups, design a simple experiment to show one of the heat transfer modes. Present your findings to the class."*	**PK:** Daniel encouraged collaborative learning through group work.
Line 13: Daniel facilitated group presentations and discussions. *Student 8: "We demonstrated convection using a balloon model." Daniel: "Great job! This example shows how convection can lift and move objects."*	**PK:** Daniel supported student presentations and discussions to reinforce learning.
Line 14: Daniel summarised the lesson and reviewed key points. *Daniel: "We've covered conduction, convection, and radiation. Remember, these modes of heat transfer explain how heat moves in different contexts."*	**PK:** Daniel summarised the lesson and reinforced key concepts.
Line 15: Daniel gave class exercise related to heat transfer. *Teacher: "For homework, find and describe three real-life examples of conduction, convection, and radiation. Be ready to share your findings."* *Student 9: "I'll look for examples around the house."*	**PK:** Daniel provided homework to apply and extend understanding of heat transfer concepts.

APPENDIX W

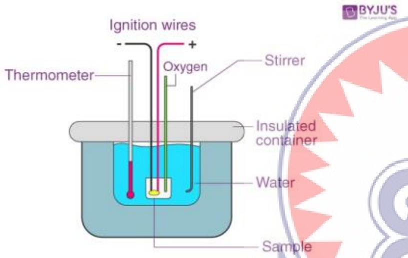
Transcription of David's lesson observation and analysis

Description of Lesson	Categorization or Themes
Classroom Context	
David's class comprised 48 learners, with a diverse range of abilities. The lesson took place in a well-organized classroom with rows and columns of tables and chairs, and sufficient space for movement	(a) The classroom context fostered a collaborative and interactive learning atmosphere. (b) All students had notebooks in front of them.
Lesson 1 Topic: Definition of Thermal Energy, Explanation of Thermal Equilibrium, Temperature and Thermometers. **Class**: SHS 2, **Time**: 60 min.	
Lesson Introduction	
Line 1: Teacher entered the classroom and greeted the students. *"Today we'll explore thermal energy, thermal equilibrium, and the concept of temperature. Who has an idea of what thermal energy is all about?"* *Student 1: "Thermal energy is the energy that keeps things warm."*	Pedagogical Knowledge (PK): Teacher used questioning to engage students and introduce new concepts.
Line 2: Teacher provided a definition. *Teacher: "Thermal energy is the total energy of all the particles in a substance due to their motion. It's related to temperature but is not the same as temperature."* *Student 2: "So, is it like the heat you feel from a fire?"*	Content Knowledge (CK): Teacher clarified the definition of thermal energy with examples.
Line 3: *Student 3 incorrectly identified thermal equilibrium.* *Student 3: "Thermal equilibrium is when things are at the same temperature and can still feel hot."* *Teacher: "Actually, thermal equilibrium means that there is no net flow of heat between objects. They are at the same temperature, and heat transfer stops."*	Learning difficulties (LD): Teacher corrected misconceptions and clarified the concept.
Line 4: Teacher introduced the concept of thermal equilibrium. *Teacher: "When two objects reach the same temperature, they are in thermal equilibrium. There's no heat transfer between them anymore."* *Student 4: "So, when I put a hot spoon in a cup of water, they will eventually have the same temperature?"* *Teacher: 'Yes, that's correct .*	CK: Teacher explained thermal equilibrium and related it to practical examples.
Line 5: Teacher moved on to discussing temperature. *Teacher: "Temperature is a measure of the average kinetic energy of the particles in a substance. It indicates how hot or cold something is."* *Student 2: "Is temperature the same as heat?"* *Teacher: 'No, that's not correct.'*	CK: Teacher differentiated between temperature and heat.
Line 6: Student 6 gave a wrong example of thermometers. *Student 6: "A thermometer measures how much heat is in a substance."* *Teacher: "Actually, a thermometer measures temperature, not heat. It indicates how hot or cold something is."*	LD: Teacher corrected the misunderstanding about thermometers.
Line 7: Teacher explained different types of thermometers. *Teacher: "There are various types of thermometers, such as mercury, alcohol, and digital thermometers, each used for different purposes."*	CK: Teacher described the types and uses of thermometers.

Description of Lesson	**Categorization or Themes**
 Teacher displayed a number of thermometers in front of the students and did some explanations about them.	
Line 8: Teacher showed practical examples of thermometers. *Teacher: "Here are some thermometers used in laboratories and daily life, like weather thermometers, laboratory thermometers and clinical thermometers."* *Student 8: "Which one is most accurate?"* Teacher discussed accuracy and application of different thermometers	CK: Teacher used his content knowledge to discuss accuracy and application of different thermometers.
Line 9: Teacher facilitated a practical activity. *Teacher: "Let's measure the temperature of various substances using different thermometers. Compare your readings."* *Student 4: "We'll use both digital and mercury thermometers for this activity."*	PK: Teacher used hands-on activities to reinforce learning.
Line 10: Teacher performed conversions between Celsius and Fahrenheit. Teacher: "*To convert between Celsius and Fahrenheit, use the formula F = (C × 9/5) + 32.*" Teacher demonstrated how to convert between Celsius and Kelvin. Line 11: *Teacher: "To convert between Celsius and Kelvin, use the formula K = C + 273.15."*	**CK:** David used his content knowledge to explain temperature conversions.
Students practiced converting temperatures using given formulas. Line 12: *Student 5: "Can we try converting some temperatures from the examples you gave?"* Teacher: "*Certainly, practice converting the temperatures and check your answers with the provided solutions.*"	**PK:** Teacher encouraged students to practice and verify their conversion skills.
Line 13: Teacher reviewed key concepts. *Teacher: "Today, we covered thermal energy, thermal equilibrium, temperature, and thermometers. Remember, thermal energy is different from temperature, and thermometers measure temperature."* *Student 10: "Can we have a quick review of thermal equilibrium?"*	PK: Teacher summarised the lesson and addressed final questions.
Line 14: Teacher provided additional examples. *Teacher: "Think of thermal equilibrium like two cups of water at different temperatures. When you mix them, they eventually reach the same temperature."* *Student 1: "That is well understood!"*	PK: Teacher used relatable examples to clarify concepts.
Line 15: Teacher assigned homework. *Teacher: "For homework, review your notes on thermal energy and temperature, and complete the problems in the textbook."* *Student 4: "We'll do that. Thanks for the lesson!"*	PK: Teacher assigned practice tasks to reinforce learning.
Line 16: Teacher addressed final questions from students. *Teacher: "Any other questions about today's topics?"* *Student 6: "What should we do if we're unsure about our thermometer readings?"* *Teacher: "Compare your answers."*	PK: Teacher provided guidance on handling uncertainties.
Line 17: Teacher wrapped up the lesson. *Teacher: "Great work today. Make sure to review and complete your homework before our next class."* *Student 4: "We'll see you next class!"*	PK: Teacher concluded the lesson and reminded students about their assignments.

Description of Lesson	Categorization or Themes
Lesson 2 Topic: Sources of Heat and Effects of Heat on Substances. Class: SHS 2, Time: 60 min.	
Lesson Introduction	
Line 1: Teacher began the lesson by asking students to provide answers gotten from the assignment given from the previous lesson. He proceeded by asking about sources of heat. *Teacher: "Can anyone list some common sources of heat?"* *Student 1: "The sun, charcoal, and a fire."*	PK: Teacher reviewed the previous lesson and used questioning to engage students and introduce the topic.
Line 2: *Teacher explained various sources of heat.* *Teacher: "Yes, those are good examples. Other sources include electrical appliances, chemical reactions, and friction."* *Student 2: "What about heat from a car engine?"* Teacher provided a comprehensive list of heat sources.	CK: Teacher provided a comprehensive list of heat sources.
Line 3: *Student 3 incorrectly identified the effect of heat.* *Student 3: "But Sir, heat always makes things either hotter or colder."* *Teacher: "Actually, heat generally makes substances warmer by increasing their temperature."*	LD: Teacher corrected misconceptions about the effects of heat.
Line 4: Teacher introduced the effects of heat on substances. *Teacher: "Heat can cause substances to expand, change state, or react chemically."* *Student 4: "So, heating ice will turn it into water?"*	CK: Teacher explained how heat affects the state of matter.
Line 5: Teacher gave a practical example of heat expansion. *Teacher: "When you heat metal, it expands. That's why railway tracks and buildings have gaps to allow for expansion."* *Student 5: "What happens if metal cools down?"*	CK: Teacher related heat effects to practical examples.
Line 6: Teacher demonstrated the effect of heat on different substances. *Teacher: "Let's observe how heating and cooling affect materials like rubber, glass, and metals."* *Student 6: "Do all materials react the same way?"* Teacher used demonstrations to show varied effects of heat on substances.	CK: Teacher used demonstrations to show varied effects of heat.
Line 7: Teacher facilitated a group discussion. *Teacher: "In your groups, discuss how heat affects substances in everyday life, such as in cooking or manufacturing."* *Student 7: "We'll discuss how heat changes food texture or appearance and even taste."*	PK: Teacher encouraged collaborative learning and application.
Line 8: Teacher corrected a misunderstanding about heat effects on objects with a lot of students emphasising chemical reaction. *Student 4: "Does heat always cause chemical reactions?* *"Teacher: "Not always. Heat can promote reactions but doesn't always cause them."*	PK: Teacher clarified the role of heat in chemical reactions.
Line 9: Teacher explained practical applications of heat effects. *Teacher: "Understanding heat effects helps in designing better cooking utensils and industrial processes."* *Student 2: "How does this work in construction?"*	CK: Teacher related heat effects to real-life
Line 10: Teacher facilitated a demonstration with different materials. *Teacher: "Here are samples of metal, plastic, and water. Observe how each reacts when heated."* *Student 8: "The metal expands more than the plastic."*	CK: Teacher used hands-on demonstrations to illustrate heat effects on various materials.
Line 11: Teacher discussed heat sources in daily life. *Teacher: "Consider how a toaster uses heat to brown bread, or how a car engine generates heat while running."* *Student 9: "Does the heat in a car engine have any safety concerns?"*	PK: Teacher connected heat sources to everyday applications and safety.

Description of Lesson	Categorization or Themes
Teacher connected heat sources to everyday applications and safety	
Line 12: Teacher corrected a student's misunderstanding about heat. *Student 10: "So, heat can only be generated by burning things?"* *Teacher: "Not necessarily. Heat can also be generated by electrical currents or friction."*	LD: Teacher clarified misconceptions about heat generation.
Line 13: Teacher explained the concept of thermal conduction. *Teacher: "Thermal conduction is the transfer of heat through a material without moving the material itself."* *Student 10: "Is that why a metal spoon gets hot when you stir a pot of soup?"* Teacher used further examples to explain thermal conduction	CK: Teacher used examples to explain thermal conduction.
Line 14: Teacher related the lesson to everyday *scenarios.* *Teacher: "Think about how heat is transferred from your hand to a hot plate of banku?'. The heat moves through the plate to your hand."* *Student 14: "So, the plate is conducting heat to my hand?"* *Techer: 'Yes, that is right."*	CK: Teacher illustrated heat transfer through practical examples.
Line 15: Teacher summarised key points *Teacher: "Today, we learnt about different sources of heat and how heat affects various substances. Remember, heat can cause expansion, state changes, and chemical reactions. Let do some short exercise"* Teacher gave class work as he went round to mark.	PK: Teacher summarised the lesson and addressed additional questions. He assessed learners' understanding.
Line 16: Teacher assigned practical tasks. *Teacher: "For homework, find examples of how heat affects materials in your home and describe these effects."* *Teacher: "We'll look into how heat changes things in our kitchen when next we meet."*	PK: Teacher provided a relevant assignment to reinforce learning.
Line 17: Teacher concluded the lesson. *Teacher: "Great work today! Make sure you complete your homework and be ready for our next class."* *Students: "Thank you Sir. See you next time!"*	PK: Teacher wrapped up the lesson and reminded students of their assignments.
Lesson 3 Topic: Methods of Heat Transfer and Measurement of Heat Energy. Class: SHS 2, Time: 60 min.	
Lesson Introduction	
Line 1: Teacher introduced the lesson by asking about methods of heat transfer. *Teacher: "Can anyone tell me how heat is transferred from one place to another?"* *Student 1: "By touching, like when you put your hand on a hot stove."*	PK: Teacher used questioning to engage students and introduce heat transfer methods.
Line 2: Teacher explained the three main methods of heat transfer. *Teacher: "Heat can be transferred by conduction, convection, and radiation. Conduction happens through direct contact, convection involves fluid movement, and radiation transfers heat through electromagnetic waves."* *Student 2: "So, the heat from a light bulb is radiation?"* *Teacher: "Great.'*	CK: Teacher defined and differentiated between the three methods of heat transfer.
Line 3: Student 3 misunderstood the method of convection. *Student 3: "Sir did you say convection is when heat moves through solids and fluids?"* *Teacher: "Actually, convection mostly occurs in fluids, like liquids and gases, where the heated parts move and transfer heat but not in*	LD: Teacher corrected misconceptions about heat transfer methods.

Description of Lesson	Categorization or Themes
solids."	
Line 4: Teacher provided practical examples of each method. *Teacher: "When you heat a metal spoon in fire, that's conduction. Boiling water involves convection, and feeling warmth from the sun is radiation.* *"Student 4: "What about a microwave? Is that conduction?"* Teacher asked students to discuss. They did and concluded that it's radiation.	CK: Teacher related methods of heat transfer to practical examples.
Line 5: Teacher explained measurement of heat energy. *Teacher: "Heat energy is measured in joules. We use instruments like calorimeters to measure heat absorbed or released during a reaction."*   *Student 5: "Sir, how does a calorimeter works?"*	CK: Teacher introduced heat measurement and provided details on calorimeters.
Line 6: Teacher demonstrated the use of a calorimeter by bringing one. *Teacher: "Here's a calorimeter in action. We'll use it to measure the heat involved in dissolving a small amount of salt in water.* *"Student 6: "Does it measure the exact amount of heat?"* *Teacher: "Yes"*	CK: Teacher used hands-on demonstrations to explain heat measurement.
Line 7: Teacher facilitated a group activity by giving the students some calorimeters to observe. Teacher asked students to try some measurements. Students did.	PK: Teacher encouraged practical application of heat measurement.
Line 8: Student 8 made some errors in attempt to use the calorimeter. *Student 8: "I think we've mixed up the units. Shouldn't it be in calories?"* *Teacher: "Actually, joules are the standard SI unit for heat energy, but calories can also be used. Just ensure consistency in your measurements."*	CK: Teacher used his content knowledge to correct errors and clarified units of measurement.
Line 9: Teacher discussed practical applications of heat measurement. *Teacher: "Understanding heat measurement is very important in fields like chemistry and engineering, where precise temperature control is necessary."*	CK: Teacher related heat measurement to real-life applications.
Line 10: Teacher reviewed the key methods of heat transfer. *Teacher: "As a way of summarising, conduction is through direct contact, convection through fluid movement, and radiation through electromagnetic waves."*	PK: Teacher summarised the lesson and addressed further questions.

Description of Lesson	Categorization or Themes
Line 11: Teacher gave homework and asked students to copy and answer.	PK: Teacher provided a relevant assignment to reinforce learning.
Line 12: Teacher addressed final questions. *Teacher: "Any final questions about heat transfer or measurement?"* *Student 4: "What should we focus on for the next class?"*	PK: Teacher addressed remaining questions and prepared students for future lessons.
Line 13: Teacher provided gave gist of what would be studied in the subsequent lesson	PK: Teacher supported learning with additional resources.
Line 14: Teacher concluded the lesson. *Teacher: "That's all for today. Make sure to complete your homework and review the methods we discussed."* *Students: "Thanks! We'll be ready for next class."*	

Lesson 4 Topic: Quantity of Heat and Specific Heat Capacity**. Class**: SHS 2, **Time**: 60 min.

Description of Lesson	Categorisation or Themes
Lesson Introduction	
Line 1: Teacher introduced the lesson by asking about the quantity of heat. *Teacher: "Can anyone explain what we mean by the quantity of heat?"* *Student 1: "Is it the amount of heat energy moved from one object to the other?"*	PK: Teacher used questioning to engage students and introduce the concept of heat quantity.
Line 2: Teacher explained the quantity of heat. *Teacher: "Exactly. The quantity of heat refers to the amount of energy transferred between objects due to a temperature difference. It's measured in joules."*	CK: Teacher made use of his content knowledge to explain quantity of heat and its measurement.
Line 3: Teacher introduced the concept of specific heat capacity. *Teacher "Let first get some understanding of specific heat capacity, Specific heat capacity is the amount of heat required to raise the temperature of one kilogram of a substance by one degree Celsius."* Teacher gave some examples of substances with high specific heat capacity	CK: Teacher used his content knowledge to explain specific heat capacity with definitions and examples.
Line 4: Student 4 made an error in understanding specific heat capacity. *Student 2: "Is specific heat capacity the same as thermal energy?"* *Teacher: "Not quite. Specific heat capacity is a property of materials, while thermal energy is the total energy of particles in a substance."*	LD: Teacher corrected misconceptions and clarified concepts.
Line 5: Teacher provided some more examples of specific heat capacities. *Teacher: "Water has a high specific heat capacity, which is why it takes longer to heat up compared to metals like iron, which have a low specific heat capacity."* *Student 3: "Does this mean water can store more heat energy?"* Teacher used examples to illustrate specific heat capacity and its effects and answered the question.	CK: Teacher used examples to illustrate specific heat capacity and its effects.
Line 6: Teacher introduced the formula for calculating heat quantity. *Teacher: "The formula for calculating the quantity of heat is $Q = mc\Delta T$, where Q is the heat quantity, m is the mass, c is the specific heat capacity, and ΔT is the temperature change."*	CK: Teacher provided the formula and invited students to see an example.

Line 7: Teacher worked through a sample calculation.
Teacher: "Let's calculate the heat required to raise the temperature of 200 grams of water from 20°C to 60°C. Using the specific heat capacity of water (4.18 J/g°C), we find $Q = 200 \times 4.18 \times (60 - 20)$*. What's the result?"*
Student 4: "I got 33,440 joules!"

PK: Teacher used his content knowledge to do calculations with hands-on examples.

Line 8: Some students made mistakes in the calculation.
Student 5: "Sir, I got 3,440 joules. Did I do something wrong?"
Teacher: "It looks like you might have used the wrong temperature difference or mass. Double-check your values and try the calculation again." Teacher went there to help student 5 out.

PK: Teacher applied his content knowledge to correct calculation errors and provided guidance.

Line 9: Teacher demonstrated a real-life application of specific heat capacity.
Teacher: "In cooking, the specific heat capacity of different ingredients affects how long they take to cook. For example, boiling indomie takes longer than heating a pan."
Student 5: "That's why indomie takes longer to cook compared to just heating the pan!"

PK: Teacher connected specific heat capacity to practical cooking scenarios.

Line 10: Teacher related specific heat capacity to real-life scenarios.
Teacher: "Consider cooking. A pan heats up quickly because it has a low specific heat capacity, while water heats slowly because of its high specific heat capacity."
Student 3: "Does that mean water can absorb a lot of heat before it gets hot?" Teacher gave explanation.

CK: Teacher connected concepts to practical applications.

Line 11: Teacher explained further practical uses of specific heat capacity and added practical problems for calculation. *Teacher: "Consider a scenario where you need to cool down a liquid quickly. How would you calculate the amount of heat to be removed, and what factors would you consider?"*
Line 12: *Student 5: "We need to know the mass, specific heat capacity, and temperature change."*
Teacher: "In engineering, materials with appropriate specific heat capacities are selected to manage thermal stress and energy efficiency."

CK: Teacher used his content knowledge to relate specific heat capacity to other fields of science.

Line 13: Teacher gave some figures out and facilitated group activities.
Teacher: "In groups, calculate the heat required for different substances using provided data. Compare your findings with other groups."
Students compare the heat required for different liquids like oil and milk.

PK: Teacher encouraged collaborative learning and application of concepts.

Line 14: Teacher addressed a common error in specific heat capacity calculations.
Student 2: "We're having problem with the units. Should we convert grams to kilograms?"
Teacher: "Yes, ensure you use consistent units. If you have mass in grams, make sure to use specific heat capacity in J/g°C."

PK: Teacher used his content knowledge to clarify unit conversions and consistency in calculations.

Line 15: Teacher reviewed key concepts.
Teacher: "Today, we focused on the quantity of heat and specific heat capacity. Remember to use the formula $Q = mc\Delta T$ *for calculations and consider the specific heat capacities of different substances."*
Student 6: "Can we get some more questions for homework?"

PK: Teacher summarised the lesson and addressed requests for additional practice.

Line 16: Teacher assigned homework.
Teacher: "For homework, solve the problems at the end of the chapter involving different substances and their specific heat capacities. Submit your answers in the next class."

PK: Teacher provided an assignment to reinforce learning.

Student 4: "We'll get to work on that."	
Line 17: Teacher concluded the lesson. *Teacher: "Review the concepts and complete your homework before our next session."* *Student 1: "See you next class!"*	PK: Teacher concluded the lesson and reminded students about their assignments.