THE EFFECT OF TRAINING IN EQUIPMENT USE ON SCIENCE TEACHERS' PCK ABOUT THE WAVE CONCEPT

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A dissertation submitted in fulfilment of the requirements for the degree of *Magister Educationis* (Masters)

In the
Faculty of Education
University of Pretoria

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Co-Supervisor: Professor Estelle Gaigher

May 2020

ETHICAL CLEARANCE CERTIFICATE

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CLEARANCE CERTIFICATE	CLEARANCE NUMBER: **SM 18/09/05**
DEGREE AND PROJECT	MEd The effect of training in equipment use on science teachers' PCK of the wave concept
INVESTIGATOR	Ms Bronia Vollebregt
DEPARTMENT	Science, Mathematics and Technology Education
APPROVAL TO COMMENCE STUDY	29 November 2018
DATE OF CLEARANCE CERTIFICATE	30 April 2020

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DECLARATION

I, Bronia Roxane Vollebregt, declare that the dissertation entitled, **The effect of training in equipment use on science teachers' PCK about the wave concept**, which I hereby submit for the degree Magister Educationis, is my own work and has not been submitted before, by me, at any other institution.

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May 2020

ACKNOWLEDGEMENTS

No researcher works in isolation. I owe a great deal to the following:

- My Supervisor and Co-supervisor: Dr. Coréne Coetzee and Professor Estelle Gaigher for their intellectual inspiration and insight, their patience, valuable guidance and encouragement throughout this research project.
- My work colleagues, manager and dear friends for their unwavering understanding and support.
- To my two Physical Sciences teacher mentors and to my trustworthy ex-colleague for their knowledge and assistance in developing the expert CoRe and for their extended advice.
- My supervisor, Dr. Coréne Coetzee for so willingly carrying out my intervention sessions and for the 'above and beyond' help and support.
- The school principals and HODs at whose schools the study was conducted. The teachers who gave their time to respond to the research instruments and interactions. Without their willingness to participate in the study, the study would not have been possible.
- My sister, who walked this path before me, my Mom for all the proofreads and my Dad for the quiet voice of reassurance as well as to my extended family. It is thanks to your encouragement and support that I did not give up during the course of this study.
- Lastly, to the Lord for giving me a clear mind when I needed it, the strength when I had none, the patience when I myself had lost it and the answers to problems and challenges when I faced them.

ABSTRACT

This study investigated the effect of training in equipment use on science teachers' Pedagogical Content Knowledge (PCK) about the wave concept. The levels of teachers' reported PCK was explored before and after in-service training through interviews and Content Representations (CoRe). Furthermore, the study extended to investigating how the teachers enacted PCK when teaching the wave concept in their classrooms after the training. This qualitative research followed a case study method with three Grade 10 Physical Sciences teachers who were selected purposefully and pragmatically. Their pedagogical reasoning was elicited through a Video Stimulated Recall (VSR) interview and their general views about the training were obtained through a post-training interview. The framework was adapted from the Refined Consensus Model (RCM) and considered PCK at a topic and concept level, with each realm of PCK being underpinned by the Topic-Specific Pedagogical Content Knowledge (TSPCK) components, namely, the learners' prior knowledge, the curricular saliency, representations, what is difficult and/or easy to teach and understand, and the conceptual teaching strategies. However, all five TSPCK components were considered. The study was centred on three key ideas in the topic of waves, namely: wavelength; frequency; and superposition. The participants' reported PCK improved and the footprint of the training was visible in the enacted PCK of all of the participants. This study suggests that training on the use of equipment improves teachers' enacted PCK and this may ultimately lead to improved learner performance.

Key term: Pedagogical Content Knowledge, Topic-Specific Pedagogical Content Knowledge, In-service Teacher Training, Topic of Waves, Refined Consensus Model.

EDITING CERTIFICATE

Exclamation Translations

To whom it may concern

The dissertation entitled, "The effect of training in equipment use on science teachers' PCK about the wave concept" has been edited and proofread as of 20 May 2020.

As a language practitioner, I have a Basic degree in Languages, an Honours degree in French and a Master's degree in Assessment and Quality Assurance. I have been translating, editing, proofreading and technically formatting documents for the past 10 years. Furthermore, I am a member of the South African Translators' Institute (SATI) and the Professional Editors' Guild (PEG).

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LIST OF ABBREVIATIONS

In the study the key abbreviations will be operationalised as follows:

BEd	Bachelor's degree in Education
CAPS	Curriculum and assessment policy Statements
CK	Content Knowledge
CoRe	Content representations
cPCK	Collective Pedagogical Content Knowledge
DOE	Department of Education
ePCK	Enacted Pedagogical Content Knowledge
FET	Further Education and Training
IEB	Independent Examinations Board
NSC	National Senior Certificate
PCK	Pedagogical Content Knowledge
PGCE	Post Graduated Certificate in Education
PhET	Physics Education Technology
pPCK	Personal Pedagogical Content Knowledge
RCM	Refined Consensus Model
SAG	Subject Assessment Guideline
TSPCK	Topic-Specific Pedagogical Content Knowledge
VSR	Video Stimulated Recall

CHAPTER 1 - INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

In this chapter, the reasons for carrying out this particular study are explained, and a brief overview of the study is given. The chapter begins with an introduction and background to the study within a South African context. The clarification of concepts and the problem statement follows. The rationale and purpose of the study are highlighted, with the research questions being stated. The chapter concludes with a summary of the research design and an overview of the chapters.

1.2 INTRODUCTION AND BACKGROUND OF STUDY

Education in South Africa has been of great concern, so much so that Spaull (2013, p. 3) remarked, "The current system is failing the majority of South Africa's youth". Out of 100 learners that begin Grade 1, only 40 reach and pass the Grade 12 NSC exam, with 12 obtaining a Bachelor’s degree (Spaull, 2013). Around the world, many countries are setting higher student learning outcomes so that the country can remain in the forefront of the global competition. This movement includes the international comparison of students' ability and performances during assessments within the field of science and is also motivated by the idea that a nation's educational success is related to its economic well-being (DeBoer, 2011). It can thus be said that the poor quality in South African education is affecting the ability of the youth to move into further education, therefore impacting the skilled work force. It is known within the South African educational system that Physical Sciences is one of the more challenging subjects amongst the 11 key subjects (Department of Basic Education, 2017a). This is also seen to be true for many other countries around the world. It is said that over time students have a tendency to lose their interest in science and that the ‘hard’ disciplines such as Physical Sciences and Chemistry are in particular the two disciples affected by this negative development (Krapp & Prenzel, 2011). Within South Africa, despite an increase in the Grade 12 Physical Sciences pass rate in public schools since 2015, there has been a decrease in the number of learners that have written the examination for Physical Sciences (Department of Basic Education, 2017b). Although the pass rate has increased, a pass is considered anything over 30%. Only 26.8% of the public school learners that wrote Physical Sciences in 2017 achieved 50% and higher, with Physical Sciences having the second worst national performance pass rate out of the 11 key subjects, mathematics being the worst (Department of Basic Education, 2017b). Both private and public schools follow the Curriculum and Assessment Policy Statement (CAPS) (Independent Examinations Board, 2015). Each subject has its own CAPS document that prescribes what content has to be taught in the respective subjects and thus, in science subjects, CAPS prescribes what practical work should be done and demonstrated. It has been said that the CAPS curriculum for Physical Sciences is extremely demanding and too prescriptive, which prevents teachers from practicing professional autonomy (Ramatlapana & Makonye, 2012; Modisaotsile, 2012). Baker (2016) further highlights the lack of laboratories within schools and the lack of equipment to carry out experiments in the South African context. In agreement with this, Modisaotsile (2012) states that the Government needs to ensure the provision of basic resources within schools and the provision of teacher training. Due to the above consensus, the Department of Basic Education, as part of the Annual Performance Plan 2017/2018, has identified the development of teachers and the provision of Learning and Teaching Support Materials as a priority (Department of Basic Education, 2017a). Although the stipulated level of qualification that a South African teacher should possess is either a four-year Bachelor of Education degree (B.Ed.) or a three- or four-year Bachelor's degree, which is followed by a Postgraduate Certificate in Education, (PGCE) (Department of Basic Education, 2018), continuous and current self-enrichment is essential. It is for this reason that an *Integrated Strategic Planning Framework for Teacher Education and Development in South Africa* 2011-2025 was proposed, allowing for training to take place for all teachers within the system. The teacher training was said to include in-service teachers and would involve quality activities with the purpose of advancing their professional skills, and improving their subject knowledge and teaching skills (The Departments of Basic Education and Higher Education and Training). A number of stakeholders have come together to provide this service. These include the national and provincial education departments, national teachers' unions and councils, the Education Training and Development Practices Sector Education and Training Authority (ETDP SETA), and the Higher Education South Africa Education Deans' Forum (HESA-EDF) (The Departments of Basic Education and Higher Education and Training, 2011).

What, therefore, is the construct that encompasses the professional skills and knowledge of a teacher? If there is such a construct, what is the essence of it? Can it be captured? It was through a seminal study carried out by Shulman (1986) that the teaching world was introduced to the idea of Pedagogical Content Knowledge (PCK). PCK is the transformation of Content Knowledge (CK) into various forms that allow and help learners to understand concepts (Shulman, 1986). According to the work of Shulman (1986), teachers are required to possess three kinds of knowledge: General Pedagogical Knowledge (GPK); Content Knowledge (CK) and Pedagogical Content Knowledge (PCK). CK is thus a pre-requisite for developing PCK (Mavhunga & Rollnick, 2013) since a teacher without the necessary knowledge of the content cannot reason about ways in which to transform the content to make it understandable for learners. Through further studies about PCK, it has become evident that PCK has a topic-specific nature (Davidowitz & Potgieter, 2016; Loughran, Mulhall & Berry, 2004; Park, Jang, Chen & Jung, 2011). Since the construct PCK is further used to refer to content specific knowledge that teachers activate when reflecting on practice (Krepf, Plöger, Scholl & Seifert, 2018), pedagogical reasoning is as much a part of teaching as is the actual performance itself (Shulman, 1986). The question arises: Can PCK be captured despite its tacit nature? Loughran et al. (2004) developed a method, and a tool, termed Content Representations (CoRe), which is used to uncover and capture a teacher's PCK about a specific topic (Magnusson, Krajcik & Borko, 1999; Mavhunga, 2014). A study by Mavhunga, Ibrahim, Qhobela and Rollnick (2016) has shown that teachers are able to transfer their knowledge to different contexts, giving evidence that teachers can transfer PCK of one topic to other topics. As such, it is worthwhile to improve teachers' PCK in even one topic. The international focus on PCK in research (Carlson & Daehler, 2019; Chan, Rollnick, & Gess-Newsome, 2018; Coetzee, 2018; Mavhunga, 2019; O'Brien, 2017) may ultimately be applied in professional development of science teachers which may lead to improved science education.

As such, the aim of the study was to investigate the development of Physical Sciences teachers' PCK about the topic of waves through in-service teacher training in the use of the ripple tank apparatus. In this study, the development of PCK in the teaching of waves was explored within the classroom environment.

1.3 PROBLEM STATEMENT

In South Africa practical work is designed, presented and implemented inadequately (Akuma & Callaghan, 2019). The importance of this is further highlighted by the statement made by Krapp and Prenzel (2011, p. 43):

Interest development in science subjects depend strongly on the perceived attractiveness of the prevalent curriculum's lesson content on the one hand, and, on the other hand, on the manner in which scientific knowledge is presented and taught.

The inadequate implementation of practical work is is not a new concern. Onwu and Stoffels (2005) highlights that despite 78% of the teachers in their study knowing that practical periods are allocated where scientific apparatus should be used, as prescribed in the curriculum, only 9% carried out laboratory exercises and 22% did not carry out any form of practical work. To further support this statistic, Randall (2008) explains that within her study of science teachers in the Mpumalanga Province, practical work being done or not done depended on the teacher's decision. However, despite the availability, or lack of equipment, teachers have expressed that science is something to be experienced through hands-on activities (Randall, 2008). In addition, Akuma and Callaghan (2019) states that professional development of a teacher is needed so that in the long run it plays a role in sustaining the youths' passion towards science. This in turn will adequately prepare the youth and the workforce of a society. Unfortunately, due to the economic status of South Africa, it is often the training programmes that are among the first areas to be removed from an action plan (Shenge, 2014).

PCK that is defined at a topic level is known as Topic-Specific Pedagogical Content Knowledge (TSPCK) (Mavhunga & Rollnick, 2016). Mavhunga and Rollnick (2013) have identified the knowledge components of TSPCK as: (i) Learners' prior knowledge; (ii) Curricular saliency; (iii) What is difficult to understand; (iv) Representations and analogies; and (v) Conceptual teaching strategies. TSPCK enables teachers to transform topic content into understandable content for learners. Previous studies have explored PCK within the topics of acid–base chemistry (Drechsler & Van Driel, 2008), chemical equilibrium (Mavhunga & Rollnick, 2013), organic chemistry (Davidowitz & Potgieter, 2016), redox and electrochemistry (O'Brien, 2017), space (Bertram, 2014), electromagnetism (Coetzee, 2018) and equations of motion (Mazibe, Coetzee & Gaigher, 2018). It is thus pertinent to say that there is a paucity of literature on studies pertaining to the development of a teacher's PCK about the topic of waves. In relation to the topic of waves, only the phenomenon of the Doppler Effect is examined in Grade 12 in public schools in South Africa. In the schools that follow the IEB curriculum, the study of waves is not a standalone knowledge area according to the Subject Assessment Guidelines (SAG) document (Independent Examinations Board, 2015). It is therefore evident that the study of waves is not a prioritised knowledge area. This is despite the fact that the phenomenon of waves is evident in our daily lives through sound and light. Moreover, learners find the properties of waves counterintuitive and difficult to comprehend (Caleon & Subramaniam, 2010). The complex nature of waves often leads to misconceptions in the understanding of waves. Consequently, this has led to the current study on teachers' TSPCK about waves.

1.4 RATIONALE AND PURPOSE OF STUDY

I taught Mathematics and Physical Sciences at a school in KwaZulu-Natal for six years. I decided to seek employment outside the classroom for a role within a company that manufactures and supplies educational science equipment for the classroom. Part of my current role is to carry out teacher in-service training on the use of equipment when purchased by a school, a Corporate Social Investment donor or by the Department of Education. During in-service training, I have witnessed that teachers have seldom had the opportunity of using ‘hands-on’ science equipment because they either lack equipment or have equipment that stands dormant. Equipment stands dormant because teachers have neither been afforded the opportunity to be shown how to use it nor have the free time to address their lack of knowledge about the equipment. It is important to me that, through the in-service training on the use of the apparatus, teachers develop better knowledge of the best way/s to transform their CK using the apparatus and gain knowledge of the learners' understanding about the topic. Mavhunga (2019) asks the valid question of what distinguishes science student teachers from other teachers, and suggests that it is their need to *learn* the *knowledge required* to teach difficult and often abstract science content so that learners understand the necessary science content. However, I believe that this could be stretched across to any science teacher who is willing to continue self-empowerment. I have established that there has been very little previous research on the development of in-service teachers' PCK about the topic of waves. Research has been done on improving pre-service teachers' PCK (Coetzee, 2018; Mavhunga & Rollnick, 2013; Savolainen, Engelbrecht, Nel & Malinen, 2012), but not much on in-service teachers' PCK specifically using Physical Sciences equipment. Therefore, through this study, I wish to add new information to the existing literature about in-service teacher training on the topic of waves and the use of related equipment. I envisage that this study may prove helpful to the public and private school administrators, teachers, the DOE and the private sector when making resource decisions about professional learning opportunities for Physical Sciences teachers.

1.5 RESEARCH QUESTION

1.5.1 Primary research question

How does in-service training in the use of Physical Sciences equipment affect teachers' PCK about the teaching of the wave concept?

1.5.2 Secondary research questions

a) What are the levels of the teachers' reported PCK about teaching the wave concept before the in-service training?
b) What are the levels of the teachers' reported PCK about teaching the wave concept after the in-service training?
c) How do the teachers enact PCK when teaching the wave concept after in-service training?

As mentioned, PCK defined at a topic level is known as TSPCK (Mavhunga & Rollnick, 2016), with five components making up TSPCK. Teachers must have an understanding of all the components of TSPCK and how to integrate them into their Conceptual Teaching Strategies (CTS). I envisage that if teachers' TSPCK is supported through in-service teacher training, then it will be evident in the conceptual teaching strategies used in their classrooms when teaching.

1.6 SUMMARY OF THE RESEARCH DESIGN AND METHODOLOGY

A qualitative research approach with a case study method was chosen for this study because it allowed the study of the Physical Sciences teachers' PCK about the topic of waves to take place within the context of the teachers' classroom. The study was embedded in an interpretative paradigm. This allowed the actions of the teachers and the way in which they interacted with the content and learners to be observed and interpreted in their natural environment (Cohen, Manion & Morrison, 2011). Three case studies involving three participating Grade 10 Physical Sciences teachers were conducted following a multiple-case study and a multi-site approach. The interest of the study was in studying the PCK held by the Grade 10 Physical Sciences teachers before and after in-service teacher training, also referred to as the intervention. PCK was explored at a topic and concept level pertaining to the topic of waves. The teachers' PCK was investigated using a multi-data collection technique in two phases, involving direct interaction with the participating teachers. Phase 1 included an interview and the completion of the CoRe (pre-CoRe), which took place before the intervention. Thereafter, the intervention was carried out. Phase 2 involved the completion of the same CoRe (post-CoRe), three classroom observations, a video stimulated recall interview, and a semi-structured interview. All of these steps were carried out after the intervention.

1.7 OVERVIEW OF CHAPTERS

This study is presented in seven chapters. Chapter 1 presents an introduction and background to the research problem. The research questions are identified and an overview of the methodology and design is presented.

Chapter 2 reviews the pertinent literature. The chapter begins with literature pertaining to Physical Sciences teachers' Pedagogical Content Knowledge (PCK), highlighting the progression of previous research regarding PCK models, PCK development, the capturing and assessment of PCK and enacted PCK. The literature review continues with a discussion of the curriculum topic of waves, practical work in the classroom, and in-service training. The chapter comprises a review relating to both previous and more recent studies about PCK in the context of the Physical Sciences classroom, and specifically about the topic of waves. The chapter concludes with the conceptual framework of the study.

Chapter 3 describes the research methodology used in this study. The chapter outlines the research paradigm and sampling process. Thereafter, the research design and instruments are explained. The data analysis strategy and the validity and credibility of the study's methodology is also described. The ethical considerations of the study and a summary conclude the chapter. Chapter 4 pertains to the intervention of the study, and explains how the intervention unfolded. The intervention plan, methodology, and the intervention findings are laid out in this chapter.

Chapter 5 comprises the pre- and post-CoRe data. Part one of Chapter 5 presents the results, analysis and interpretation of the pre-Core, together with the pre-interview for each participant.

Thereafter, part two of Chapter 5 presents the post-CoRe results, analysis, and interpretation per participant.

Chapter 6 encompasses the data collected, the analysis and interpretation of the classroom observations, VSR interview and the semi-structured post-interview. Each case study is presented separately. A chapter summary concludes the chapter.

The seventh and final chapter entails an overview of the study, and a discussion of the findings and how they answer the research questions. The chapter also highlights the emerging findings, as well as the limitations of the study. The chapter concludes with the contribution of the study to this field of research, and recommendations for future studies.

CHAPTER 2 - LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the construct of Pedagogical Content Knowledge (PCK) is discussed as applied in the teaching of the Physical Sciences topic of waves. The chapter begins with a review of the literature about PCK and the models of PCK, topic-specific PCK, the development of PCK, capturing and assessing PCK, and enacting PCK. This is followed by a review of the literature on the curriculum topic of waves, practicals in the curriculum topic of waves, practical work in the classroom, and in-service training. I hope to clarify how the theoretical gap that underpins the purpose of this study was identified. The conceptual framework for the study is also presented in this chapter. The chapter concludes with a chapter summary.

2.2 PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

Although PCK as a construct for teacher knowledge has been studied for over three decades, it has not been easy to determine exactly what it comprises or how to use this knowledge to support teacher education (Kind, 2009). A seminal study carried out by Shulman (1986) initiated the idea that teachers, when planning and teaching, use a variety of knowledge categories. Shulman (1986) suggests the existence of a knowledge base that includes Subject Matter Content Knowledge (SMCK), Pedagogical Content Knowledge (PCK), and curricular knowledge. PCK has been described as the transformation of the different knowledge types for teaching and is said to be unique to the teaching profession (Magnusson et al., 1999). Shulman (1986, p. 9) states that,

> *Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others.*

Here, Shulman (1986) highlights that learners require a teacher who is not only knowledgeable about the specific subject matter, but who also has the ability to transform the content into units that are understandable to all learners.

PCK is a construct that consists of a number of domains. Teachers need knowledge of and understanding about each of these domains. Shulman's Theory of PCK includes two key elements of knowledge, namely, the representations of subject matter and the understanding of specific learner difficulties and learner conceptions (Van Driel, Verloop & de Vos, 1998). Since then, other scholars, such as Grossman (1990), Magnusson et al. (1999), and Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) have expanded the concept of PCK by including the PCK categories of different knowledge bases for teaching. These are over and above the two key elements suggested by Shulman (Mazibe, 2017; Ndlovu, 2014; Van Driel et al., 1998). Table 2.1, adapted from Mazibe (2017), Ndlovu (2014) and Van Driel et al. (1998), shows the conceptualisation of PCK by Shulman (1986), Grossman (1990), Magnusson et al. (1999) and Rollnick et al. (2008).

Table 2.1: The conceptualisation of PCK by Shulman (1986), Grossman (1990), Magnusson et al. (1999) and Rollnick et al. (2008), adapted from Mazibe (2017), Ndlovu (2014) and Van Driel et al. (1998)

	Knowledge of Subject Matter	Representations and strategies	Student learning and conceptions	General Pedagogy	Curriculum and media	Context	Purpose
Shulman (1986)	*n*	*PCK*	*PCK*	*n*	*n*	*n*	*n*
Grossman (1990)	*n*	*PCK*	*PCK*	*n*	*PCK*	*n*	*PCK*
Magnusson et al. (1999)	*nd*	*PCK*	*PCK*	*PCK*	*PCK*	*nd*	*PCK*
Rollnick et al. (2008)	*PCK*	*M*	*nd*	*PCK*	*PCK*	*PCK*	*M*

Key: *n* - Not part of PCK; *PCK* – Part of PCK; *M* – Manifestation of teacher knowledge; *nd* – Not discussed thoroughly.

Grossman (1990) agrees with Shulman on the two key elements of PCK, but further extends the idea of PCK to include knowledge of curriculum media and materials that are available to teachers during teaching, as well as the purpose for teaching particular topics (Van Driel et al., 1998). Magnusson et al. (1999) suggest that PCK development draws on knowledge of general pedagogy over and above the suggested domains noted by Shulman (1986) and Grossman

(1990). Rollnick et al. (2008) go further to explore the influence of the Subject Matter Knowledge (SMK) of PCK, and indicate that PCK includes the knowledge of context. The knowledge of context includes factors that influence a teacher's situation while teaching, for example, the allocated teaching time, resources available to the teacher, students' socio-economic background, class size, curriculum, conditions of the classroom, curriculum and country status, and current situation (Rollnick et al., 2008).

It can be seen from the above literature that the conceptualisation of PCK differs in some aspects but overlaps in others. The similarities include an agreement on the knowledge of representations and strategies, knowledge of student learning, and conceptions and knowledge of curriculum and media being part of the key elements of PCK.

2.2.1 Models of PCK

Over the years, the construct of PCK has evolved and models showing the relationships among the domains of teacher knowledge have changed. There are a number of researchers (Carlson & Daehler, 2019; Davidowitz & Rollnick, 2011; Gess-Newsome, 2015; Grossman, 1990; Magnusson et al., 1999; Mavhunga, 2014; Rollnick et al., 2008; Tamir, 1988) who have paved the way for the development of the PCK model. The work of Magnusson et al. (1999) built on the earlier works of Grossman (1990) and Tamir (1988) and conceptualised the components of PCK for science teaching. They also defined each component by identifying the specific knowledge that is represented by each component. According to Rollnick et al. (2008), previous models included SMK as a component of PCK, but this saw the need to connect the teachers' knowledge domains to their observed classroom practice. As such, the model includes four manifestations of PCK, namely, representations, curricular saliency, assessments, and topic-specific instructional strategies. The model also includes domains of teacher knowledge, namely, knowledge of subject matter, students, context, and general pedagogical knowledge. Considering Rollnick et al.'s (2008) PCK model, Davidowitz and Rollnick (2011) recognised that teachers' knowledge domains are influenced by their beliefs about teaching and vice versa. This, in turn, plays a role in what a teacher enacts in the classroom environment. Davidowitz and Rollnick (2011) thus specify four domains from which a teacher draws to inform their PCK (Mavhunga, 2014), and have drawn up a model to include the manifestation of teacher knowledge and the domains of teacher knowledge, which include teacher beliefs. It was from the Davidowitz and Rollnick (2011) model that Mavhunga (2014) developed a topic-specific

PCK Model. The Topic-Specific PCK Model still involved the broader PCK teacher knowledge domains, but, together with the identified domains, considered the quality of PCK within a given topic (TSPCK). Mavhunga (2014) has established that teaching pre-service teachers about the transformation of a topic is a way of fast-tracking PCK development. Gess-Newsome (2015) goes further to explain a consensus model of Teacher Professional Knowledge and Skill that includes PCK and the influences on classroom practice and student outcomes (TPK&S). This model shows PCK defined as: i) A knowledge base that is used in the planning and delivery of topic-specific instruction in a specific classroom context, and ii) As a skill when involved in the act of teaching.

More recently, the Refined Consensus Model (Carlson & Daehler, 2019) (see Figure 2.1) has been developed from the models of Magnusson et al. (1999) and the Consensus Model described by Gess-Newsome (2015).

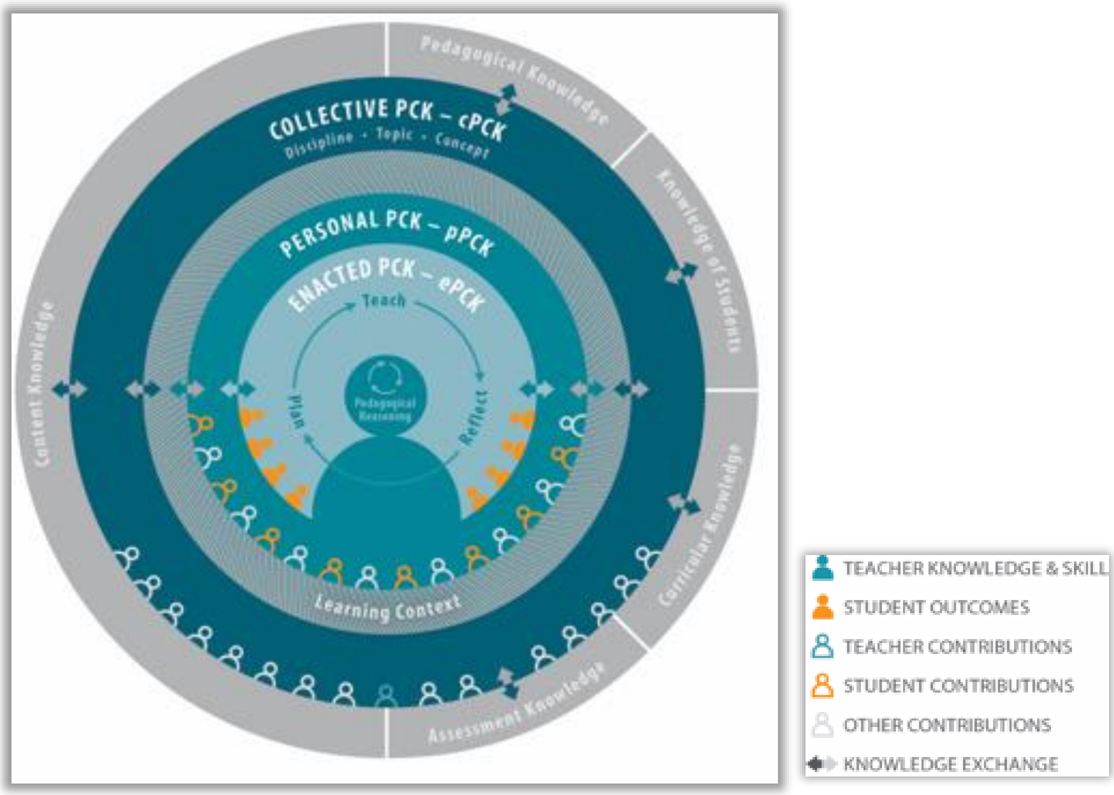


Figure 2.1: Refined Consensus Model of PCK (Carlson & Daehler, 2019)

This model, as depicted above, highlights various aspects of PCK. Although it is an updated model, it is not intended to replace the models developed by Magnusson et al. (1999) or Gess-

Newsome (2015) (Carlson & Daehler, 2019). The Refined Consensus Model (RCM) identifies three distinct realms of PCK, which are centred on the practice of teaching and consider the new idea of the role of grain sizes of PCK, thus PCK at a discipline, topic or concept level (Carlson & Daehler, 2019). The three distinct realms of PCK identified by the model are collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK) (see Figure 2.1). The model thus describes the impact that a teacher's knowledge and personal experiences has on their professional development and teaching practice (Carlson & Daehler, 2019). Collective PCK, personal PCK, classroom experience, professional contributions and enacted PCK all interconnect as a teacher applies PCK during pedagogical reasoning cycles. Pedagogical reasoning comprises the teacher's ability to justify their teaching by looking at their decision-making and actions within the context of their classroom (Chan, Rollnick & Gess-Newsome, 2018). As such, the Refined Consensus Model of PCK highlights the multidimensional nature of PCK (Mavhunga, 2019).

2.2.2 Topic-Specific PCK (TSPCK)

As mentioned previously, Shulman (1986) proposes that teachers are required to possess three kinds of knowledge: General Pedagogical Knowledge (GPK); Content Knowledge (CK) and Pedagogical Content Knowledge (PCK). Within the PCK category, Shulman (1986) suggests that, within their subject area and regularly taught topics, teachers need to know: (i) The most useful forms of representations, (ii) What makes a specific topic difficult or easy, (iii) The students' perceptions and misconceptions, and (iv) What strategies would be best to teach the content. Loughran et al. (2004) further support the idea and the construct of Topic-Specific PCK (TSPCK) and refer to it as the knowledge a teacher possesses about teaching specific content in a particular way. It is through Mavhunga and Rollnick's (2013) study that the components of TSPCK have been clearly defined. This differs from the broader idea of PCK being based at a discipline level (Mavhunga, 2014). TSPCK describes a teacher's reasoning that is used at a topic level when planning and teaching lessons (Mavhunga et al., 2016). Mavhunga and Rollnick (2013) identify five TSPCK components, namely: students' prior knowledge; curricular saliency; representations; what is difficult and/or easy relating to the topic; and teaching strategies.

The *Students' prior knowledge* component, or learners' in this case, include their common misconceptions (Mavhunga & Rollnick, 2013), learning difficulties, prior conceptions (Carlson

& Daehler, 2019), and the correct knowledge (Mavhunga, 2019) held by the learners about the topic at hand. The term 'student' is henceforth replaced by the term 'learner' in order to refer to people within the South Africa schooling system between Grades R and 12. *Knowledge of curricular saliency* includes knowledge of the big ideas within the topic and the sequencing and order followed when teaching the topic (Mavhunga, 2014) so that concepts build logically on one another (Mavhunga & Rollnick, 2013). *Curriculum Saliency* also includes knowing or identifying the topics that need to be taught before teaching, and what topics to omit during teaching (Mavhunga & Rollnick, 2013). The component of *Representations* refers to knowing the best representations (Carlson & Daehler, 2019), which could include illustrations, models and simulations (Mavhunga, 2019) that should be used to enable learners' understanding of the concept or topic being taught. *What is difficult and/or easy relating to the topic* is the identification of which concepts within the topic are difficult and/or easy to teach, this also requires an understanding of the underlying reasons. Once difficulties are identified, the teacher needs an understanding of how to develop strategies to handle such difficulties (Mavhunga, 2014). Lastly, the *Conceptual teaching strategies* category becomes evident when all four of the above-mentioned TSPCK components are integrated and interact effectively during teaching. A teacher needs to have an understanding of each of the above components so that the strategy used to teach the topic or concept allows it to reach each learner effectively, making it understood to each learner (Carlson & Daehler, 2019). Teaching strategies also involve a teacher knowing a number of ways to explain the same topic or concept and in which ways the topic or concept could be best represented (Mavhunga, 2014).

Mavhunga and Rollnick (2013) state that to improve the quality of teaching, the value of PCK lies in its topic-specific nature. Therefore, teacher professional support programmes that are structured to develop PCK could be done on one topic at a time, preventing an overwhelming emphasis on content at discipline level. Van Driel et al. (1998) suggest that PCK may be derived from two aspects: firstly, the teacher's own practice through studying learner difficulties; and secondly, from activities carried out at school, such as in-service training events concerning student conceptions.

2.2.3 Development of PCK

It is important to understand PCK and how it informs teachers' knowledge so that in the scientific teaching world it can be understood how PCK can be captured, measured, developed and improved. Williams and Lockley (2012) posit that expert teachers are not born with PCK, but it is unique to each teacher and is gained through practice (Shulman, 1986). PCK is further developed and improved on during teacher training (Kind, 2009; Mavhunga, 2014; Mavhunga & Rollnick, 2013) and through pre-service and in-service education (Barnett & Hodson, 2001). A study by Mavhunga et al. (2016) has shown that teachers are able to transfer their knowledge to different contexts, giving evidence that teachers can transfer PCK in one topic to other topics. As such, it is worthwhile to improve teachers' PCK even if it is only in one topic. The question now arises as to whether one can capture PCK. To be able to know whether a teacher's PCK improves, PCK would have to be captured and assessed.

2.2.4 Capturing and assessing PCK

As mentioned above, Loughran et al. (2004) have developed the CoRe tool to uncover, capture and portray a teacher's PCK about a specific topic (Magnusson et al., 1999; Mavhunga, 2014). In light of this, Kind (2009, p. 195) states:

> *Loughran et al.'s (2006) CoRes offers, in my opinion, the most useful technique devised to date for eliciting and recording PCK directly from teachers. The method is clearly centred in teachers' skills and knowledge, so a completed CoRe provides a powerful means of recording the work of an experienced teacher, available for sharing and exemplifying good practice.*

The CoRe tool enables the knowledge obtained to be portrayed to others (Lehane & Bertram, 2016). The tool prompts teachers to reveal their knowledge of the 'big ideas' based on the specific topic of interest. An individual's PCK is portrayed through completing a number of prompts that are related to the 'big ideas' (Loughran et al., 2004). Therefore, the CoRe is a tool that represents teachers' knowledge and understanding of teaching content to make it understandable for learners and, in essence, represents the teachers' PCK about the topic. As a result, the information gained from the CoRe tool gives a better understanding of the specialised knowledge, skills and expertise of the teacher completing the CoRe. In 2013, Mavhunga and Rollnick (2013) made the explicit link between the CoRe prompts and the five TSPCK components and continued to use the adapted CoRe for future studies (Mavhunga & Rollnick, 2017; Rollnick & Mavhunga, 2014b, 2016) (see Figure 2.2). The CoRe tool was then used to capture, uncover and portray the TSPCK of teachers.

Once captured, the teachers' PCK levels need to be assessed and measured. The PCK rubric developed by Park, Chen and Jang (2008) is an instrument that quantifies TSPCK using a four-point scale (1 = ‘Limited’ to 4 = ‘Exemplary’). Chan et al. (2018) have proposed and developed another template called the Grand Rubric (see Figure 2.3), which is "generic in nature" (Chan et al., 2018, p. 1), allowing the rubric to be customised and to be used with a variety of science topics, content and grain sizes. The Grand Rubric (see Figure 2.3) consists of five PCK components with quality indicators, with no set number of quality indicator levels for each component criterion. The Grand Rubric considers the integration between PCK components and the pedagogical reasoning of an individual. This links the Grand Rubric to the work of Carlson and Daehler (2019), which reports on a summit where a number of PCK researchers were present who developed the Refined Consensus Model. Thus, the Grand Rubric is a relevant instrument allowing for the comparison of PCK scores, as captured in the CoRe, to determine the PCK development of an individual (Chan et al., 2018).

To be developed for each Big Idea
A. Curricular Saliency
A1. What do you intend students to learn about this idea? (in original CoRe) A2. Why is it important for students to know this? (in original CoRe) A3. What concepts need to be taught before this big idea? (only in adapted CoRe) What else do you know about this idea that you don’t intend students to know yet? (in original CoRe)
B. What makes a topic easy or difficult to understand
B1. What do you consider easy or difficult about teaching this idea? (original CoRe: Difficulties/limitations connected with teaching this idea)
C. Learner Prior Knowledge
C1. What are typical students’’ misconceptions when teaching this idea? (original CoRe: Knowledge about students’ thinking that influences your teaching of this idea)
D. Conceptual Teaching Strategies
D1. What effective teaching strategies would you use to teach this big idea? D2: What questions would you consider important to ask in your teaching strategy? (original CoRE: teaching procedures)
E. Representations
E1 What representations would you use in your teaching strategy? (only in adapted CoRe)
Additional Questions not linked to a specific component
What ways would you use to assess students’ understanding (original CoRe: Specific ways of ascertaining understanding)
What aspects of teaching and planning for this big idea would you like to reflect on? (only in adapted CoRe)

Fig 2 Skeleton of Adapted CoRe

Figure.2.2: The CoRe-template adapted for Topic-Specific PCK (Rollnick & Mavhunga, 2016)

Since the unveiling of the Grand Rubric, a recent study by Coetzee (2018) suggests which of the CoRe prompts could be placed under each of the five Grand Rubric components. Coetzee (2018) proposes the amalgamation of the PCK rubric of Park et al. (2008), the adapted CoRe tool (Mavhunga & Rollnick, 2013) and the Grand Rubric (Chan et al., 2018) to assess and measure PCK. This amalgamation of rubrics is discussed further in Section 3.5.4.

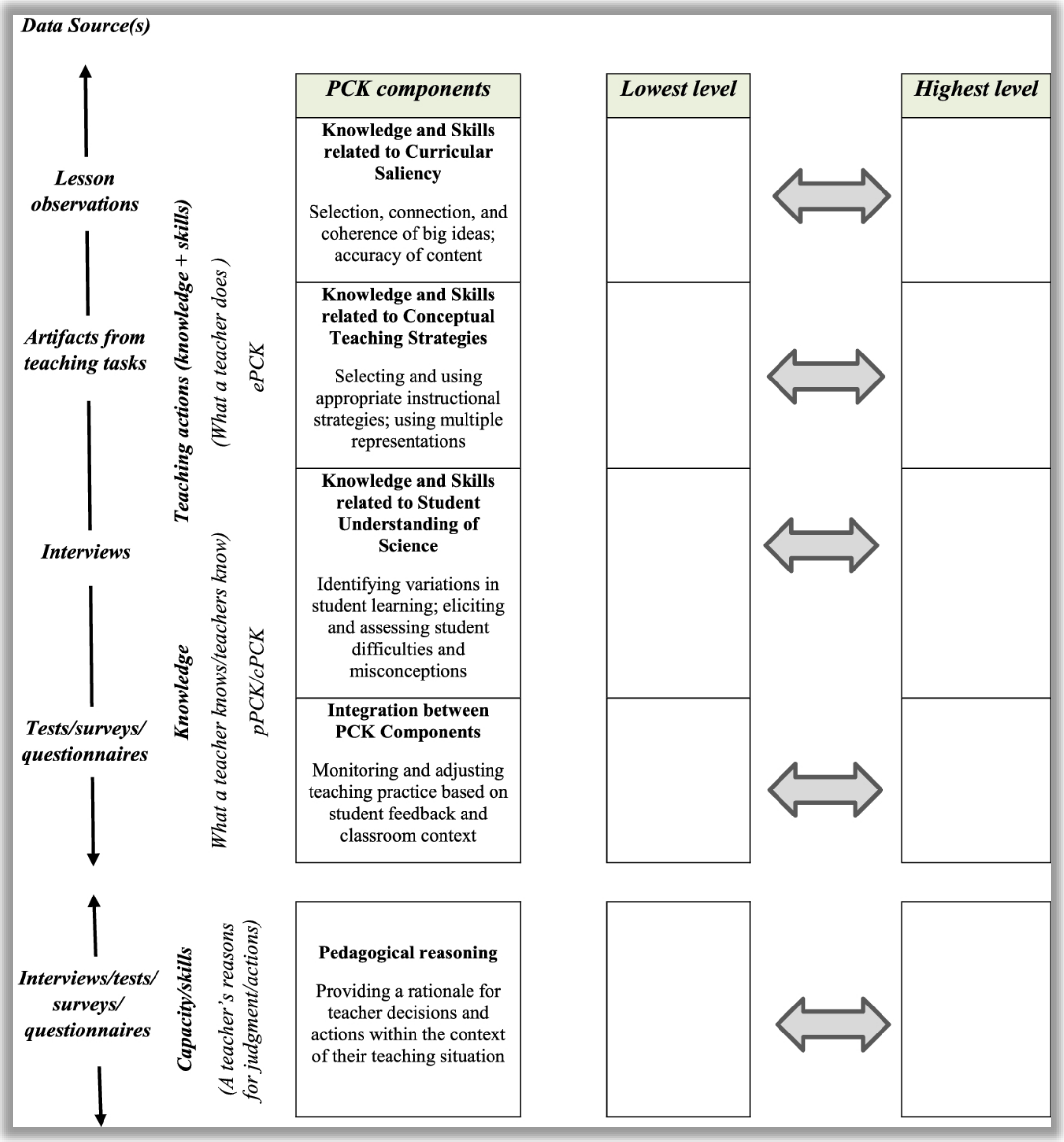


Figure 2.3: The Grand PCK Rubric Template (Chan et al., 2018)

2.2.5 Enacted PCK

The RCM places the teacher at the centre of the model, as represented by concentric circles (refer to Figure 2.1). This emphasises the significance of research related to teachers' pedagogical reasoning and the nature of PCK in action, also known as enacted PCK (Carlson & Daehler, 2019). As explained by Gess-Newsome (2015), "PCK is the knowledge of, reasoning behind, **and** enactment of the teaching of particular topics in a particular way…" (p.

36). Chan et al. (2018) describe teachers' knowledge as *static* PCK, and what teachers do within the classroom as *dynamic* PCK. Static PCK includes the planning phase of collective PCK, personal PCK or enacted PCK, while dynamic PCK involves PCK that is enacted through interactive teaching (Carlson & Daehler, 2019).

The literature explains that pedagogical reasoning cannot only be assessed through observational data, therefore it is pertinent to observe a teacher enacting PCK in the classroom environment. This way, through the use of a video stimulated recall interview, the teachers' pedagogical reasoning can be accessed (Chan et al., 2018).

2.3 THE TEACHING OF THE TOPIC OF WAVES

2.3.1 Waves as a curriculum topic

Previous research has been done within Physical Sciences education and in terms of student understanding regarding the topics of electric circuits, mechanics, heat and temperature (Wittmann, 2002), and magnetism (Caleon & Subramaniam, 2010), to name a few. Furthermore, there have also been studies in the discipline of chemistry, namely, on the concepts of kinetic nature of matter (Nakhleh, 1992), intermolecular forces (Cooper, Williams & Underwood, 2015), and on the oxidation-reduction concept (Basheer, Hugerat, Kortam & Hofstein, 2017). However, there is not an abundance of research on the teaching of the topic of waves (Caleon & Subramaniam, 2010). Classical physics considers that matter displays both particle and wave properties, whereas the modern physics of Quantum Mechanics indicates that matter and energy display a dual-wave particle nature, which includes light.

As already mentioned, in terms of the South African context, the section about waves is a small component of the CAPS curriculum (Appendix I). In addition to the CAPS curriculum, IEB schools follow the Subject Assessment Guideline (SAG) document, which does not include waves as a standalone knowledge area. However, IEB schools teach waves because it is a fundamental principle needed to understand the photoelectric effect and the dual nature of light. This marginalisation of waves exists despite the fact that wave physics is an everyday phenomenon that moulds the understanding of both classical and modern physics (Fazio, Guastella, Sperandeo-Mineo & Tarantino, 2008).

2.3.2 Learners’ misconceptions and difficulties

Duit and Treagust (2003) explain that learners possess pre-instructional knowledge and beliefs about concepts and phenomena when they begin science instruction. These pre-instructional knowledge and beliefs can often be contradictory to the scientific views of the concepts and phenomena to be taught. Martin, Sexton and Gerlovich (2002) define the term ‘misconception’ as the incorrect understanding of ideas, events and objects created due to ideas that are constructed based on personal experience. Information is naturally extrapolated from the world around us (Fazio et al., 2008), which can often lead to misconceptions.

The idea of conceptual change has been one that is more of a contemporary view when dealing with misconceptions (Van Niekerk, 2012). As Van Niekerk (2012) argues, misconceptions can be changed by modifying learners’ current concepts so that the construction of new knowledge takes place. Intended knowledge is thus understood and the acquisition of concepts is obtained by learners when their pre-instructional conceptual structures are restructured. Taslidere (2016) further explains that misconceptions are stable cognitive structures forming barriers to the restructuring of knowledge of science concepts. Learners’ understanding is affected, often negatively, which in turn affects their performance (Van Niekerk, 2012). It is therefore important that attention is given to learners’ thinking (Larkin, 2012). This will allow teachers to identify their misconceptions (Thompson & Logue, 2006) within a particular context so that learners are able to construct the correct scientific concepts (Larkin, 2012) in relation to the given context.

Teachers need to have an understanding of learners’ misconceptions so that they can assist learners in the reconstruction of their pre-instructional concepts (Van Niekerk, 2012). Sadler and Sonnert (2016) have further shown the importance of this idea, and have shown the relationship between teachers who recognise learners’ misconceptions and their learners’ classroom achievement goals. Sadler and Sonnert (2016) find that when a teacher knows the common learner misconceptions, they are more likely to increase the science knowledge of their learners as compared to teachers who do not know their learners' common misconceptions. Caleon and Subramaniam (2010) have identified the misconceptions that learners have about the topic of waves and, based on these, they state that misconceptions affect future learning of waves. These identified misconceptions include ideas about particle motion versus wave motion, the role of air in sound propagation, frequency, the distinction between source and medium, the wave speed in a medium with fixed properties, and waves at the boundary of two media. Another study by Fazio et al. (2008) indicates that sound and mechanical wave propagation are two areas that learners have difficulty understanding. Wittmann, Steinberg and Redish (2002) state that learners have fundamental difficulties with some of the basic concepts of wave physics. This is further cemented through a study by Sadler and Sonnert (2016), where they recognised that conceptual and reasoning difficulties arose due to a lack of understanding the concepts of wavelength, frequency and propagation speed. It is therefore evident that there is a broad set of concepts about the topic of waves that learners have difficulty understanding. Thus, if learners are not exposed to the use of pedagogical tools (Fazio et al., 2008) to show and explain how the phenomenon of waves exists and to explain the relationships between the basic physical quantities related to wave motion (Sadler & Sonnert, 2016), then misconceptions will arise.

To address possible misconceptions about the topic of waves, this study focused on using ripple tank apparatus to teach the fundamental concepts of waves, namely, wavelength, frequency and the subordinate idea of period, as well as the more complicated concept of superposition. It was assumed that learners would be able to develop the correct conceptual understanding of waves by observing the identified concepts, as illustrated through the apparatus and not just through other non-tangible methods, such as textbook pictures or computer simulations. Proper understanding of the foundational concepts of wavelength, frequency and period can help to introduce more complex concepts (Fazio et al., 2008). An example of a more complicated concept is that of superposition. Superposition cannot be easily portrayed using other simpler apparatus, such as a rope or a tuning fork, which is why it is suggested on page 26 of the CAPS curriculum for Physical Sciences under the "practical activities" column that a ripple tank be used (see Figure 2.4 below).

2 hours	Superposition of Pulses	• Explain that superposition is the addition of the disturbances of the two pulses that occupy the same space at the same time • Define constructive interference • Define destructive interference • Explain (using diagrams) how two pulses that reach the same point in the same medium superpose constructively and destructively and then continue in the original direction of motion • Apply the principle of superposition to pulses	**<u>Recommended experiment for informal assessment:</u>** Use a ripple tank to demonstrate constructive and destructive interference of two pulses	**Materials:** Ripple tank apparatus.

Figure 2.4: A snippet from the Grade 10-12 Physical Sciences CAPS document showing the recommended experiment for informal assessment on the concept of superposition of pulses

It has been identified that there is a gap in the literature directed at the development of teachers' PCK about the topic of waves. It has been made evident through the literature that learners have difficulties in understanding the concept of waves. The topic of waves thus necessitates a unique pedagogy and a clear understanding of the topic when teaching it. Therefore, it seems appropriate that PCK should be investigated in terms of this topic.

2.4 PRACTICAL WORK IN THE SCIENCE CLASSROOM

It is concerning that a South African-based research study has found that despite 78% of the teachers knowing that practical periods were allocated where scientific apparatus should be used, as prescribed by the curriculum statement, only 9% of the teachers carried out laboratory practicals (Onwu & Stoffels, 2005). Randall (2008) indicates that the decision made by the teacher not to do practical work is not in accordance with government policy.

Although there are dedicated teachers whose passion results in commitment and hard work, there are also many teachers who display the opposite characteristics (Kollapen, Chaane, Manthata & Chisholm, 2006). As such, these teachers have been described by Kollapen et al. (2006, p. 25) as teachers who have:

Low morale; spend too little time in the classroom; are unqualified or underqualified; are not sufficiently trained in the new curriculum; use outdated teaching methods in classes that are too big; and, who are disconnected with the communities in which they teach.

Duit and Treagust (2003) highlight another concern in terms of conceptual change in that it is difficult to change the views and classroom practice of teachers. Despite these two realisations, a study by Johnson, Scholtz, Hodges and Botha (2013) has established that some teachers acknowledge what can be achieved and are receptive to receive more materials and training. This at least opens the door to addressing the challenge faced by teachers who do not carry out scientific practical work. However, there are other forms of representing practical work. A well-known and popular representation is in the form of simulations called Physics Education Technology (PhET) simulations. These comprise representations of the actual phenomenon in an animated and interactive form to support learners' conceptual understanding of Physical Sciences topics (Perkins et al., 2006). One reason for their use is the ease with which they are made available off the internet. There is conflicting evidence on the effectiveness of these computer-generated simulations (Kotoka & Kriek, 2014). However, these authors highlight that traditional instruction used to demonstrate practical activities can be enhanced by the use of a simulation.

Basheer et al. (2017) have explored the effect of teacher demonstrations when used in the classroom environment and the effect that the demonstrations had on learners' understanding of the concept of redox reactions. The demonstrations included practical hands-on activities with the researchers observing different reactions and using different apparatus. A control group formed part of this study, which involved the learners having no exposure to the demonstrations and being taught concepts using only PowerPoint presentations. The findings of the study showed, statistically, that conceptual understanding was enhanced and thus the learners who were exposed to the teacher demonstrations achieved better.

Knowing that representations is one of the five clearly defined components of TSPCK (Mavhunga & Rollnick, 2013), and through the work of Basheer et al. (2017) explained above, it was thus necessary to look into the use of demonstrations in the classroom.

2.5 IN-SERVICE TRAINING

The post-apartheid professional development of teachers, which is often termed ‘in-service education’ or ‘staff development' has been carried out in different forms to fulfil different purposes (Ono & Ferreira, 2010). The objective of in-service training is to provide employees with the opportunity to develop their knowledge, skills and attitudes so that they become more productive on a day to day basis, being successful and happy in their positions (Aykaç & Yildirim, 2017). It is for this reason that in-service training should be seen as a continuous on-going event and an approach in developing teachers (Katman & Tutkun, 2015). However, it is often neglected due to budget constraints (Ono & Ferreira, 2010). Traditionally a ‘cascade’ training approach (Ono & Ferreira, 2010) introduced by the Department of Education would involve a selected group of teachers attending a professional development session where the teachers are trained. They would then impart their knowledge to the remaining teachers causing information to be ‘watered down’ (Ono & Ferreira, 2010). The traditional cascade approach has received criticism among teachers and researchers because it often took place in isolation from reality, resulting in it being brief, fragmented, incoherent and decontextualised (Ono & Ferreira, 2010).

An alternative approach has since been developed which considers that the human brain is constantly trying to construct knowledge by forming patterns and connections to find meaning (Ono & Ferreira, 2010). This approach assumes that training should be pertinent to a particular context as a long-term process (Ono & Ferreira, 2010), and should actively involve the teachers (Aykaç & Yildirim, 2017; Katman & Tutkun, 2015). From the work of these last-mentioned researchers, it is evident that in-service training should actively involve teachers as opposed to them passively receiving the training information, allowing relevant knowledge to be constructed correctly and with the maximum impact. In addition, a study by Nivalainen, Asikainen, Sormunen, and Hirvonen (2010, p. 406) indicates:

> *That courses in practical or laboratory work that target physics or science teachers should aim at familiarizing the participants with practical work itself, so that they are helped in understanding the purpose of experimental work at school, in learning more of the necessary content information, and also so that they are introduced to different instructional approaches.*

2.6 CONCEPTUAL FRAMEWORK

It is clear from the literature that PCK does not merely refer to the head knowledge that teachers possess, but is rather a more dynamic construct that describes the process of teaching. It is the process of teaching in a particular context, teaching a particular subject to particular learners, and it arises when teachers are faced with particular challenges within that context (Shulman, 2015).

The first sub-question of this study sought to determine the level of the teachers' reported PCK about teaching the wave concept, relating to representations and learner thinking before in-service training.

The second sub-question of the study was used in an attempt to establish the level of the teachers' reported PCK about teaching the wave concept, relating to representations and learner thinking after in-service training.

The third and last sub-question of the study investigated how the teachers enacted PCK when teaching the wave concept. This was done through investigating how they employed the equipment and enacted their knowledge, taught during the in-service training, and through their conceptual teaching strategies in the classroom.

In order to answer each sub-question, and thus the primary research question, a clear conceptual framework was developed. In this study, aspects of the models described by Mavhunga (2014), and which was discussed at the PCK summit and reported on by Carlson and Daehler (2019), were combined to formulate the conceptual framework of this study (see Figure 2.5). The framework of this study was based on the idea that the value of PCK lies in its topic-specific and possibly concept-specific nature. Although the model (Figure 2.5) refers to PCK, for this study it is PCK at a topic level with each realm of PCK: collective PCK (cPCK), personal PCK (pPCK) and enacted PCK (ePCK). These were underpinned by the TSPCK components. In addition, as discussed in the literature review, Chan et al. (2018) describe *static* PCK and *dynamic* PCK in relation to the RCM model of PCK as follows: "Static PCK corresponds to collective PCK (cPCK), personal PCK (pPCK) or enacted PCK in the planning and reflection phases (ePCKp, ePCKr) while dynamic PCK pertains to ePCK in the interactive phase of teaching" (p. 5).

In terms of the TSPCK components, Mavhunga and Rollnick (2013) identify the five TSPCK components to include students' prior knowledge, curricular saliency, representations, what is difficult and/or easy to teach, what is difficult and/or easy for learners to understand relating to the topic, and the conceptual teaching strategies used. As mentioned in the literature review, the Grand Rubric has five PCK components to assess and measure PCK. The five TSPCK components are embedded in the Grand Rubric with the effective use of representations as an important part of conceptual teaching strategies. For this study, the PCK components used and discussed are in line with the Grand Rubric (see Figure 2.3), namely, knowledge and skills related to curricular saliency; conceptual teaching strategies, which include representations; learners' understanding of science; integration between PCK components; and pedagogical reasoning.

The effect of training in **equipment use** on science teachers' PCK about the **wave concept** was the primary focus of this study because a ripple tank apparatus was used to carry out the in-service training. As indicated in the above literature review, learners possess misconceptions about the topic of waves that could be addressed using a ripple tank. It is of importance that teachers assist learners in the reconstruction of their pre-instructional concepts to better understand the topic of waves (Van Niekerk, 2012). The claim from Van Driel et al. (1998): "The more representations teachers have at their disposal and the better they recognize learning difficulties, the more effectively they can deploy their PCK" (p. 675) is the motivation for my decision to focus on the effect of training in equipment use on science teachers' PCK about the wave concept through the following statement.

It is highlighted by Park and Chen (2012) that the quality of topic-specific PCK is dependent on how the TSPCK components interact with one another. A more recent study by Mavhunga (2018) reveals the structural nature of TSPCK components, showing that the TSPCK components interact with one another. In addition, Rollnick and Mavhunga (2016) explain that when it comes to designing conceptual teaching strategies, there are indications of the integration of the other four components. As such, I consider all five TSPCK components as suggested by Mavhunga and Rollnick (2013). I observed the conceptual teaching strategies of each participant during the classroom observations and the integration of the PCK components as suggested by Park and Chen (2012) through the Grand Rubric. I am fully aware that the TSPCK components are integrated in every teaching event and that the effective interaction of the components points to well-developed PCK.

The conceptual framework (see Figure 2.5) was adapted from what was discussed at the PCK summit, as reported by Carlson and Daehler (2019) regarding the RCM. The framework was to consider PCK at a topic level with each realm of PCK: cPCK; pPCK; and ePCK. These realms were underpinned by the TSPCK components, mainly that of teachers' *knowledge about representations and analogies*, and teachers' *knowledge about learners' prior knowledge*, including misconceptions. The conceptual framework considered the knowledge interaction between cPCK and pPCK, assuming that cPCK belongs to the profession of teaching and informs the development of teachers' pPCK (Carlson & Daehler, 2019). The knowledge interaction between pPCK and ePCK was also considered, knowing that teachers' pPCK informs how they enact PCK (ePCK) in the classroom environment. Acknowledging that cPCK, pPCK and ePCK all interconnect as a teacher applies PCK during pedagogical reasoning (Chan et al., 2018), the conceptual framework of this study maintains the teacher at the centre of the model (see Figure 2.5). This is as originally shown in the Refined Consensus Model of PCK developed by several PCK researchers while at the PCK summit (Carlson & Daehler, 2019).

Thus, in addressing the research questions, three case studies were conducted. I investigated the teachers' reported PCK corresponding to their pPCK and both the teachers' reported and enacted PCK corresponding to their ePCK in relation to all the TSPCK components. I investigated the pPCK of the teachers before and after the intervention, and the ePCK of the teachers after the intervention. In doing so, I relied on the idea that the pPCK and ePCK drew on the cPCK of the profession of teaching as cPCK is said to draw from commonly shared teacher knowledge, such as coursework and textbook work (Mavhunga, 2019).

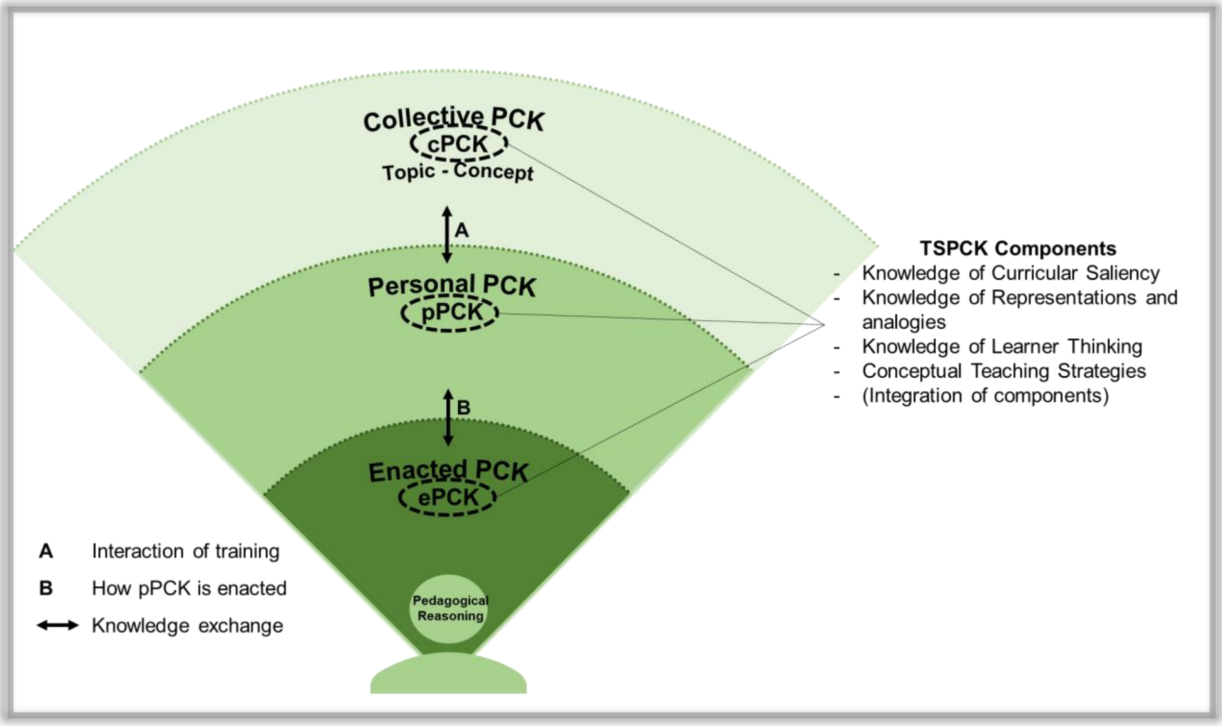


Figure 2.5: Summary of the conceptual framework adapted from Carlson and Daehler (2019) to include the TSPCK components.

2.7 CHAPTER SUMMARY

In summary, Chapter 2 covered the important literature based on the terminology and ideas of the primary research question. This concerned how in-service training in the use of Physical Sciences equipment affected teachers' PCK about the teaching of the wave concept. The conceptual framework that guided this study to answer the research questions was also explained. The next chapter will discuss the research methodology carried out in this study and how it aligned with the conceptual framework.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter, the research methodology employed to investigate how training in the use of Physical Sciences equipment affected teachers' PCK is described. The chapter includes the research paradigm and approach, the sampling procedure and the profile of the participants. The research design, instruments used, data analysis strategies and the validity and credibility of the data are also discussed. A summary of the research design and the ethical considerations conclude the chapter.

3.2 RESEARCH PARADIGM AND APPROACH

It is through the lens of post-positivism that this study was undertaken, allowing the human nature and the behaviour of the participants to be observed (Creswell, 2014). In terms of the epistemology of this research, I interacted personally with the participants to gain information through the eyes of the teachers and through their own experiences within the classroom environment.

I approached this study from an interpretative paradigm perspective, which involved getting to know the teachers in their natural environment, as suggested by Cohen et al. (2011). This method was employed because it is in line with what Rollnick et al. (2008) suggest in that PCK includes knowledge of context. I therefore saw it as essential to be engaged with the participants in their natural environment, observing their actions within their particular setting. The methodology and approach of this study was a multi-method qualitative design using a multi-data collection technique (Saunders & Tosey, 2013). This allowed the exploration of how in-service training in the use of equipment affected the teachers' PCK about the teaching of the wave concept. I gave dedicated attention to the teachers as individuals and not as a collective group (Cohen et al., 2011), therefore following a multiple-case study approach.

To carry out the study from an interpretative paradigm perspective, I designed an intervention, which is discussed in detail in Chapter 4. The intervention was in the form of in-service teacher training designed around the five TSPCK components. The study was conducted in two phases so that the respective sub-research questions could be explored. In Phase 1, the teachers completed a pre-intervention CoRe (pre-CoRe) and participated in a pre-intervention, semi-structured interview (semi-structured pre-interview). This stage of the research ascertained the teachers' level of PCK relating to representations and learners’ thinking on waves before the intervention.

In Phase 2, the teachers completed a post-intervention CoRe (post-CoRe) used to establish the teachers' level of PCK relating to representations and learners’ thinking on waves after the intervention. The teachers were given the opportunity to employ specific science equipment and enact the PCK and skills that they already possessed, as well as what they were taught during the intervention. The observations were conducted in their classrooms where they taught lessons relevant to wavelength, frequency, and superposition. After the lesson observations, I implemented a Video-Stimulated Recall (VSR) interview and a semi-structured interview (semi structured post-interview). The VSR interview was to ascertain how the teachers recalled the way in which they employed the use of the science equipment and enacted the knowledge taught during the in-service training when teaching the concepts on which this study focused. The semi-structured post-interview was to gain information about the teachers' general views on the intervention.

The informative data gathering protocol and instruments were in line with the interpretative paradigm. Collectively, the design and multiple-case study approach, the protocol followed, and the instruments used provided an opportunity to determine the answer to the primary research question. This pertained to how in-service training in the use of Physical Sciences equipment affects teachers' PCK about the teaching of the wave concept. Zainal (2007) highlights that a case study often explores a small number of subjects and therefore does not prove to be a good enough foundation for scientific generalisation. Although this is true, I envisaged that the interpretative approach would create or support theories about teacher knowledge and PCK development rather than generalise the findings to the population of all teachers in all contexts. Yin (2013) regards a small sample size as an advantage in a case study as it maintains the depth and the contextual nature of the study.

3.3 SAMPLING PROCEDURE AND PROFILE OF THE PARTICIPANTS

For this study, the participants were selected purposefully and pragmatically. The study included three participants, male and female, who were Grade 10 Physical Sciences teachers from three different private schools in Gauteng. Each participant was given a pseudonym, which was derived by the alphabetical order of the participating school's name, i.e. Participant A, for School 1. A fourth participant was approached. Considering the alphabetical order of this fourth school name, the participant from the school was given the pseudonym B. However, Participant B failed to commit and withdrew from the study after the other pseudonyms had already been put in use. The pseudonyms A, C and D remained. Participant A was then given the name Jessica, Participant C, the name Tshuma, and Participant D, the name Craig. These names will be used throughout this study. Table 3.1 shows the profiles of the participants. One of the criteria for selection was that the participants should have had no recent exposure to formal in-service teacher training on the specific ripple tank apparatus and had to be proficient in English. The selected participants and their relevant schools were provided with a ripple tank apparatus and in-service teacher training at no cost to them or to the school. These were the incentives to take part in the study.

Table 3.1: Profiles of the participating teachers

	Case Study 1 – Jessica	**Case Study 2- Tshuma**	**Case Study 3- Craig**
Age range	26-35	36-45	36 to 45
Gender	Female	Male	Male
Qualification/s	BSc degree BSc Honours degree (Geochemistry) Post Graduate Certificate in Education (PGCE)	BEd degree (Chemistry) BA degree (Psychology)	BSc degree BSc Honours degree (Agriculture and Natural Resources) Master's degree (Sustainable Agriculture)
Experience in teaching Physical Sciences (in years as of the end of 2018)	2	15	9
Current studies (if any)	None	None	None

	Case Study 1 – Jessica	Case Study 2- Tshuma	Case Study 3- Craig
English as a first Language?	Yes	No	No
Language used in the classroom to teach	English	English	English

As previously mentioned, the study was carried out in two phases. The same participants took part in Phase 1 and Phase 2. Access to the schools and to the teachers was practical, ethical and legal in all administrative ways (Cohen et al., 2011). This was ensured by obtaining permission from the school governing body or school executive body, the school principal, the participating teachers and the Grade 10 parents and learners themselves. Permission was granted to carry out the study on the school premises in the Physical Sciences classroom/laboratory, to audio record the interviews with the teachers, and to observe and video-record the classroom observations required for the study.

3.4 RESEARCH DESIGN

The methodology and approach that guided this study was one of a multi-method qualitative design using a multi-data collection technique. The case study approach allowed me to collect data from multiple sites (Baskarada, 2014) using multiple sources and techniques (Nieuwenhuis, 2007), making this approach particularly suitable for this study. Figure 3.1 shows the research design diagrammatically indicating Phase 1 and 2, the sequence of data collection, the number of interactions carried out with each participant, and the order in which the interactions occurred. Figure 3.1 also shows which research questions were addressed by each interaction.

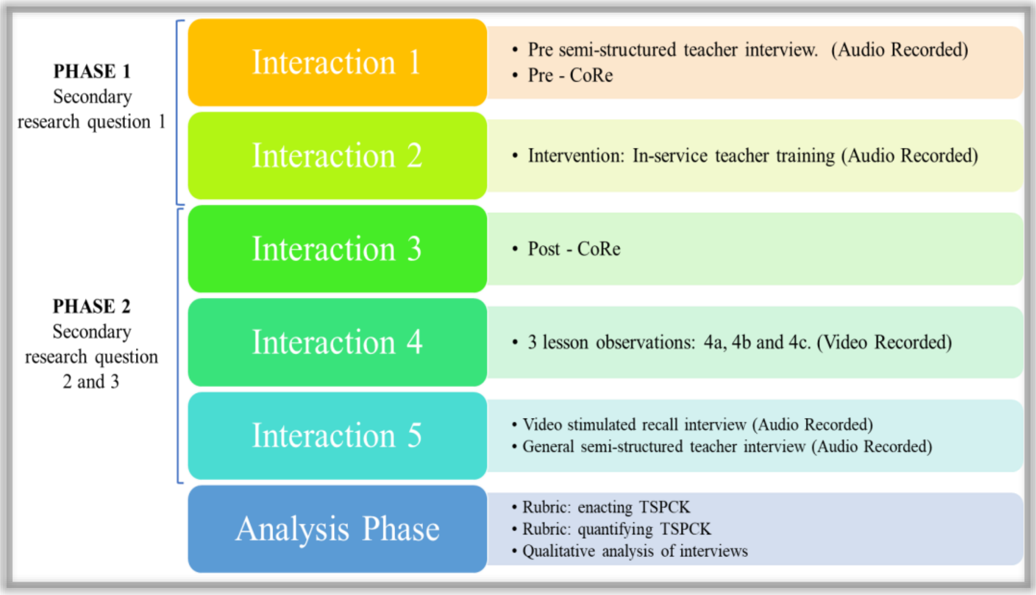


Figure 3.1: Research design shown diagrammatically indicating the sequence of data collection carried out per participant

Figure 3.2 shows how the research design corresponded with the conceptual framework of this study. I investigated the pPCK and ePCK of the teacher, focusing on all the TSPCK components. The knowledge interaction between cPCK and pPCK (see Figure 3.2, Point A) was in the form of an intervention carried out individually with each of the participants. I assumed that the intervention drew on the cPCK belonging to the profession of teaching to develop the pPCK of the participants (Carlson & Daehler, 2019). The CoRe tool was used to assess the improvement of the teachers' PCK. The interaction between pPCK and ePCK (see Figure 3.2, Point B) was established through the interviews. The teachers' pPCK and how they enacted PCK (ePCK) was accessed through classroom observations. The lesson observations and the VSR interviews gave insight into the teachers' ePCK and their pedagogical reasoning.

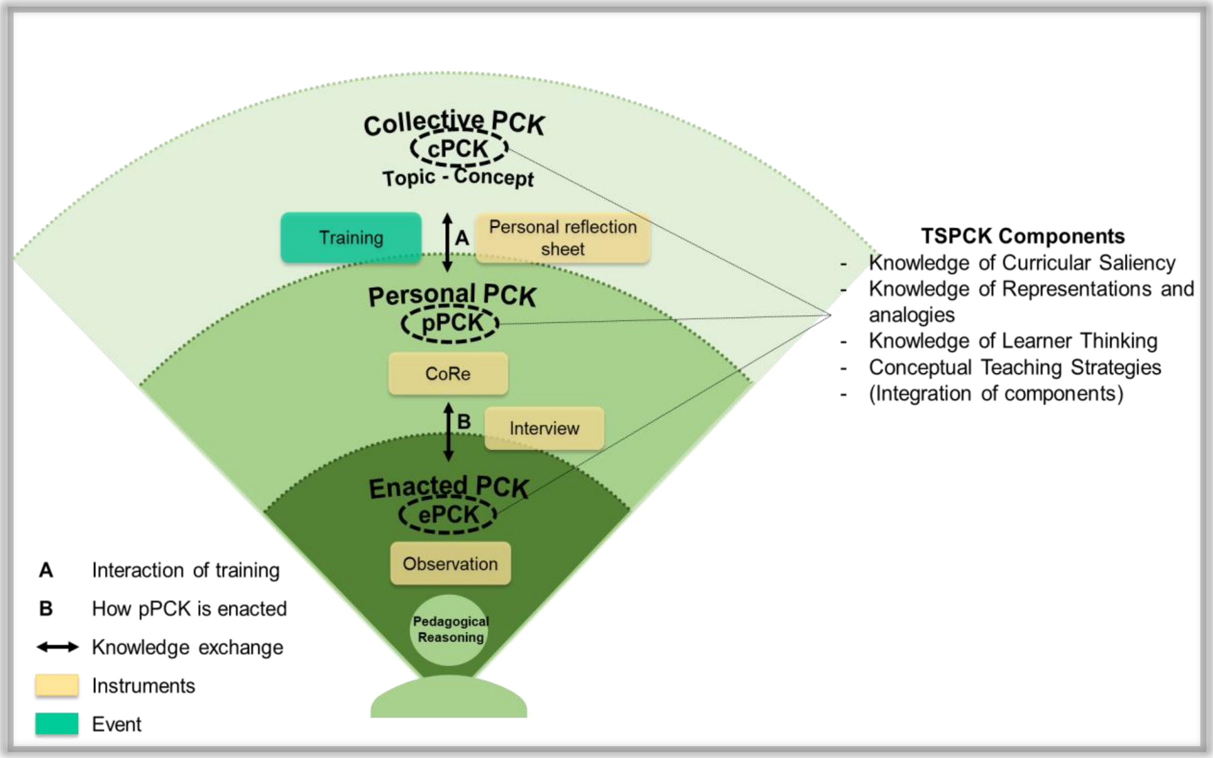


Figure 3.2: Summary of the conceptual framework, including the methodology of the events and instruments used during the study

Phase 1: Interaction 1 was to engage with each teacher in a semi-structured pre-interview (Appendix VII). I had a pre-determined list of guided questions, but would deviate and ask further relevant questions when necessary. In other words, I probed more deeply with other open-ended questions that were required to obtain additional information. This interview was used to gain knowledge about each teacher and their teaching profile. The interview unlocked the teacher's thoughts about science teaching, their ideas on the importance of 'hands-on' learning, their current resource availability, and their proposed lesson plan when teaching the fundamental concepts of waves and superposition. The semi-structured pre-interview was audio recorded and then transcribed. Interaction 1 also included the pre-CoRe (Appendix III), which took place directly after the semi-structured pre-interview. The pre-CoRe was to determine and record the level of the teachers' PCK before the intervention. The information gained concerned the teachers' knowledge related to the TSPCK components, and was explicitly linked to the key ideas of wavelength, frequency, and superposition. The CoRe prompts linked to all five TSPCK components. This is further discussed under Section 3.5. The analysis of the pre-CoRe answered the first sub-question.

Interaction 2 was the intervention, which is described in detail in Chapter 4. An experienced teacher educator was approached to conduct the intervention, who is henceforth referred to as the trainer. The trainer accompanied me to the respective schools to carry out the teacher in-service training. I was present as an observer and audio recorded each of the intervention sessions. This recording was later used to elicit the trainer's memory during a stimulated recall interview. This interview took place after all the intervention sessions had taken place. The chosen design of the training prevented the professional development opportunity from being brief and isolated (Ono & Ferreira, 2010).

Phase 2: After the in-service training, the post-CoRe was carried out to determine and record the level of the teachers' PCK relating to representations and learners' thinking on waves. The post-CoRe used the same template as the pre-CoRe. The analysis of the post-CoRe answered the second sub question. At this point, the data analysis and comparison of the pre-CoRe and post-CoRe for each participant indicated whether (if at all) the intervention had any impact on their PCK and, if so, in what ways the teachers' PCK had been affected. An assumption made in the study was that the teachers would write down what they knew. I acknowledge that the teachers may have known more than what they wrote in the CoRe as responses to the prompts. However, to assign a certain score to indicate the quality of their TSPCK, I assumed that their responses were a declaration of their knowledge. This is further discussed in Chapter 5.

Phase 2 further included three classroom observations, labelled as Interaction 4a, b and c (see Figure 3.1). When the teachers provided the dates and times of the lessons in which they were going to cover the concepts of wavelength, frequency and superposition, I ensured that I was present to observe. Each case study had three classroom observations, hence the labelling of 4a, 4b and 4c, as seen in Figure 3.1. Before each lesson began, I set up two video cameras in the classroom. Both cameras were set up as stipulated in the consent letters (Appendix X), i.e. at the back of the classroom directed at the teacher and not at the learners. It was reiterated that if any learner did not want to be present in the video, they would move to a seat behind the video recorder and remain there for the duration of the lesson. The observations were analysed to determine how the teachers employed the science equipment and enacted the knowledge taught during the in-service training in the conceptual teaching strategies used in their classrooms. The observations were a necessary data gathering process because, as seen and discussed through Figure 2.5 and Figure 3.2, a teacher's personal PCK informs how they enact their PCK in the classroom environment. This acknowledges that collective PCK, personal

PCK and enacted PCK all interconnect as a teacher applies their PCK during pedagogical reasoning (Chan et al., 2018).

The semi-structured post-interview (Appendix VIII) and VSR interview (Appendix IX) took place simultaneously during Interaction 5 (see Figure 3.1). The semi-structured post-interview (Appendix VIII) sought information about the participants' perception of the intervention. For the semi-structured post-interview, I had a pre-selected list of guided questions but would deviate and ask further questions when I needed to probe more deeply to obtain additional information. The VSR interview was guided by clips identified from the video recorded lesson observations. The recordings were used to elicit the teachers' memory on certain events pertaining to the research questions. The teachers were afforded the opportunity during the VSR interview to justify and reflect on their actions and decision-making (Nguyen, McFadden, Tangen & Beutel, 2013) while applying their PCK during pedagogical reasoning in the context of their classroom. As stipulated in the literature, the VSR interview should be done soon after the observations are carried out to reduce the time delay and thus increase recall validity (Denley & Bishop, 2010; Nguyen et al., 2013). However, due to the participants' busy teaching schedule, the VSR interviews took place during the next allocated free period as communicated to me by the participants. The semi-structured post-interviews and the VSR interviews were audio recorded and transcribed.

The intervention had to be carried out by someone other than myself. This was an ethical clearance stipulation in order to reduce bias towards the intervention because I, as the researcher, currently worked for the company that manufactures and supplies the ripple tank apparatus that was to be used during the intervention. The intervention was therefore carried out by an experienced teacher educator. With respect to the experienced teacher educator, the pre-CoRe and semi-structured pre-interviews took place during Interaction 1. This allowed for the intervention and the post-CoRe to take place during their own stipulated interactions. This ensured that the trainer was only needed for one time slot during the data collection process (see Figure 3.1).

3.5 RESEARCH INSTRUMENTS

3.5.1 The CoRe tool

Mavhunga and Rollnick (2016) adapted the CoRe tool developed by Loughran et al. (2004) and linked the prompts explicitly to Topic-Specific PCK (TSPCK) components, which is the version that I used for this study. The CoRe tool (Appendix III) was used to capture and assess the PCK of the teachers, as discussed under Section 2.2.4, about the topic of waves. The CoRe was presented in the form of a table, printed out as a template and was completed by the teachers in their own handwriting. The teachers were afforded the opportunity to indicate what they believed to be necessary ideas required for learning the key ideas of wavelength; frequency, including the subordinate idea of period; and the key idea of superposition. Previous studies, such as that of Coetzee (2018), have not indicated or stipulated key ideas to the participants and thus a blank CoRe template (Appendix III) was given. For the purpose of this study, three key ideas were identified and given to the participants in the CoRe template as definitions (see Figure 3.3). The reason for identifying key ideas was to narrow down the scope of this study to three specific key ideas and to retain the same three key ideas for all the participants of the study. Providing definitions as the key idea and not simply supplying the terms or name of the key ideas allowed me to determine if the teachers understood the definitions and thus were able to identify the key ideas via their respective definitions.

Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	

Figure 3.3: The key ideas given as definitions in the CoRe template

The version of the CoRe used in this study had prompts linking the five TSPCK components to the above-mentioned key ideas. The CoRe tool (Appendix III) was employed before (pre) and after (post) the in-service teacher training. Although a time allocation of 60 minutes was allocated, it was purely for planning purposes and therefore each teacher was given the opportunity to write until they had completed the CoRe. No time restriction was given. An expert CoRe about the topic of waves (Appendix IV) was constructed to portray an extensive but not exhaustive PCK about the three key ideas pertaining to the study. This is further discussed in Chapter 5.

3.5.2 Semi-structured interview

Audio recorded semi-structured pre- and post-interviews (Appendix VII and VIII respectively) were used in both Phase 1 and 2 of the study. The use of interviews allowed for structure to be present while also allowing flexibility so that I could probe further, and allowed for the participants to give more spontaneous responses (Brinkmann, 2014). The semi-structured pre-interview (Appendix VII) during Phase 1 enabled me to obtain information about each teacher, their ideas and beliefs about 'hands-on' learning. The interview also obtained information on how the teachers normally approached a lesson when teaching the foundational concepts of waves and the concept of superposition. The semi-structured post-interview (Appendix VIII) during Phase 2 afforded me the opportunity to obtain the teachers' general views and opinions on the in-service teacher training provided.

3.5.3 Classroom observations and recordings

According to Cohen et al. (2011), the method of observation allows the researcher to "…gather 'live' data from naturally occurring social situations. In this way, the researcher can look directly at what is taking place in situ rather than relying on second-hand accounts" (p. 396).
Three lesson observations were carried out during Phase 2, which all took place in the participants' own classroom. The purpose of the classroom observations was to assess how the teachers transferred the PCK taught during the in-service training, and recorded in the handwritten CoRes, to their conceptual teaching strategies in their classrooms. Reflection notes were taken during each observation. The reason for journaling was to explicitly document how each lesson was carried out by each respective participant and to reduce the bias of my own personal preference regarding how and in what order the topic should be taught. Each observation was video recorded to further reduce bias, allowing playbacks to elicit my memory of each observation and to allow a narrative account to be given for each lesson. Furthermore, the recordings were used for the VSR interview. The VSR interview is further discussed under Section 3.5.5.

3.5.4 TSPCK rubrics

The PCK rubric was an instrument originally developed by Park et al. (2008) to quantify TSPCK using a four-point scale (1 = 'Limited' to 4 = 'Exemplary'). In a more recent study by Chan et al. (2018) another template called the Grand Rubric (see Figure 2.3) was developed and proposed. The Grand Rubric template consists of five PCK components and no set number of quality indicator levels. In a further study, Coetzee (2018) suggests which CoRe prompts could be allocated to each of the five Grand Rubric components (see Figure 3.4), but retains the four-point scale suggested by Park et al. (2008).

PCK components	CoRe-Prompts
Knowledge and skills related to curricular saliency	• Selection of key ideas. • What do you intend the learners to know about this idea? • Why is it important for students to know this? • What concepts need to be taught before teaching this idea? • *What else do you know about this idea that learners may learn later?*
Knowledge and skills related to conceptual teaching strategies	• What representations would you use in your teaching strategy? • What questions would you consider important to ask in your teaching strategy? • *Describe the strategy you will use to establish conceptual development of the key idea.*
Knowledge and skills related to student understanding of science	• *What do learners find difficult to understand and why?* • *What are typical learners' misconceptions about pre-concepts that affect the teaching of this key-idea?* • What ways would you use to assess learners' understanding?
Integration between PCK components	There are no prompts in the CoRe tool that can be linked uniquely to this component. Assessment of this component needs careful consideration.

Figure 3.4: The suggested use of CoRe prompts together with the Grand Rubric at topic level (Coetzee, 2018)

For the purpose of this study, the TSPCK rubric for teaching waves (Appendix V) was an amalgamation of the Grand Rubric template, maintaining the five PCK components, with Coetzee's (2018) suggestion of which CoRe prompts could be allocated to each of the five Grand Rubric components. The rubric used the point scale of 1 = 'Limited', 2 = 'Adequate' and 3 = 'Rich'. The descriptors for each of the three levels were formulated to pertain to the topic of waves. The last two components of *Integration between PCK components* and *Pedagogical reasoning* of the Grand Rubric were omitted when assessing the CoRes as these two components can only be assessed fairly during classroom observations of the teachers' enacted PCK and interviews. The description of *Knowledge and Skills related to Student Understanding of Science* was adapted to read as *Knowledge and Skills related to Learner Understanding of Science* because the study was based on learners’ prior knowledge and misconceptions and not that of a student teacher. Furthermore, the prompt of *What ways should you use to assess the learners' understanding of the key ideas* was omitted because the knowledge that would be obtained through this prompt had no direct relation to or relevance in answering the research questions of this study.

The appropriateness and relevance of the information provided was analysed using the expert CoRe (Appendix IV) and the TSPCK rubric for teaching waves after which a score indicating the level of PCK was assigned. The scores for each prompt obtained in the pre- and post-CoRes were compared, with any differences between the two sets of scores used to establish whether development in the teachers’ PCK was evident. In the lesson observations, a rubric to assess enacted TSPCK (Appendix VI) using a three-point scale (1 = ‘Restricted’ to 3 = ‘Rich’) was used, which was adapted from Coetzee (2018). This rubric was based on the template of the TSPCK rubric for teaching waves using the five PCK components as suggested by Chan et al. (2018). However, the *Knowledge and Skills related to Representations* component was treated as a separate component. Moreover, I used the three-point scale suggested by Coetzee (2018). The descriptors for each of the three levels were reformulated to pertain to the topic of waves. A trusted colleague and the supervisor of this study were given the pre- and post-CoRe of each participant and were asked to score each CoRe using both the TSPCK rubric for teaching waves, and the expert CoRe. The moderation was to validate the scores that I obtained when I scored each participant’s CoRe using the TSPCK rubric for teaching waves. The moderation process is further discussed in Section 5.1.

3.5.5 Video and audio-stimulated recall interviews

PCK refers to context specific knowledge that teachers activate when reflecting on practice (Krepf et al., 2018). Thus, the technique of a Video-Stimulated Recall (VSR) interview (Appendix IX) was utilised to access the teachers' pedagogical reasoning as it cannot be accessed only through observational data (Chan et al., 2018). I elicited the teachers' thoughts about their actions by selecting certain key events that took place during the lesson observations. The selected events were rich in revealing the teachers' knowledge of the five TSPCK components and the three key ideas relevant to this study. An audio-stimulated recall interview was conducted with the trainer utilising the audio recorded content of each intervention. I had pre-selected questions that were derived from analysing each of the intervention's audio recordings. However, the interview followed a semi-structured approach to allow further questions and answers. The specific audio clips were chosen based on my diary reflections of each intervention. These clips were played to the trainer to elicit the trainer's memory. The trainer chose to recall the relevant information in the order in which the interventions took place, i.e. Craig first, followed by Jessica and then Tshuma. Her thoughts and answers pertaining to each question and each intervention were recorded and transcribed. This formed part of my formal organised field notes in order to document any significant events that the trainer felt may have had relevance and importance to the study.

3.6 DATA ANALYSIS STRATEGIES

An inductive approach was used to analyse the data. Links were identified between the objectives of the research and the findings from the data collected (Thomas, 2006), allowing themes and theories to emerge from the raw data. The pre-CoRe (Appendix III) was to provide information about the teachers' baseline understanding and knowledge of representations and learners' understanding pertaining to waves. The semi-structured pre-interview (Appendix VII) was carried out to explore the teachers' untainted thoughts about the topic of waves before being introduced to the topic during the intervention. The post-CoRe (Appendix III) was conducted to provide information about the teachers' new understanding and knowledge of the same relevant TSPCK components after the intervention. Through the analysis and comparison of the CoRes, I aimed to ascertain whether the in-service training supported the teachers' PCK about the topic of waves based on the relevant components of TSPCK. The Expert CoRe (Appendix IV) and the TSPCK rubric for teaching waves (Appendix V) were used in parallel to analyse the CoRes. The semi-structured post-interview (Appendix VIII) was carried out to explore the teachers' general perception of the intervention. The three lesson observations and VSR interview (Appendix IX) probed into what was being carried out in the classroom and how the teachers enacted their TSPCK in their classrooms. A rubric to assess the enacted TSPCK (Appendix VI) employing a three-point scale was used during the lesson observations. The analysis of data took place in three stages. The first was the interpretative and qualitative analysis of the intervention (Chapter 4). The second was the interpretative and qualitative analysis of the pre-CoRe, semi-structured pre-interview and post-CoRe (Chapter 5). The third was the interpretative and qualitative analysis of the lesson observation recordings, VSR interview and semi-structured post-interview (Chapter 6).

The comparison of the participants' TSPCK level before and after the in-service training was done to establish whether, if at all, their level of PCK had changed. The pre-interview was analysed and remarks relevant to the teachers' PCK revealed through the pre-CoRe were discussed. The post-CoRes were analysed and scored allowing the qualitative analysis of the CoRes. The method used to mark and score the CoRes is further explained in Sections 5.1.1 and 5.1.2. Narrative accounts were given for each of the classroom observations that were then coded using pre-determined codes (see Table 6.1). Sections in the videos that were rich in data, revealing information on the TSPCK components and the three keys ideas of this study were selected. Remarks given by each participant during their VSR interview that were relevant to the selected sections, and which revealed the participants' pedagogical reasoning were linked to the selected sections. Further remarks given in the semi-structured post-interview for each participant were discussed. A summary concluded the results, analysis and interpretation of the video recorded classroom observations and VSR interviews, which are detailed in Chapter 6. All events were meticulously documented as they occurred in the natural setting.

3.7 VALIDITY AND CREDIBILITY OF DATA AND THE ELIMINATION OF BIAS

This study involved the use of multiple sources, allowing the data to be triangulated to seek convergence (Creswell, 2014). This strengthened the reliability and internal validity (Cohen et al., 2011) of the study. Triangulation was obtained in this study through the following: i) Capturing the participants' PCK regarding *representations* and *learners' thinking* about the topic of waves. This was done through the pre-interview and the pre- and post-CoRe; ii) Observing the participants in their classroom teaching the topic of waves in a manner that is relevant to the key ideas of the study; iii) Interviewing each participant to establish their pedagogical thinking and the actions carried out, showing how they utilised their conceptual teaching strategies in their classrooms.

The same design, method and protocol were followed with all three participants, keeping a level of consistency throughout the study. Bias may have posed a threat to this study. It is for this reason that each interview and the intervention sessions were audio recorded and each observation was video recorded. This minimised any biased recollection and interpretation of the events (Cohen et al., 2011), and incorrect or biased interpretations of the events and responses given by the participants (Whittemore, Chase & Mandle, 2001). To further reduce bias, I did not conduct the in-service teacher training, reducing the bias regarding the apparatus, intervention and the purpose of the study. The intervention paid attention to the general setup and use of the science equipment as per the intervention plan (Appendix II). The training plan was put together considering the CAPS curriculum and SAG document pertaining to Physical Sciences. I had to remind myself to be unbiased and critical during the data interpretation so as not to allow any prior formed opinion of each participant to play a part in the data analysis and interpretation.

Connecting the existing literature on in-service teacher training, the teaching of waves, the models of PCK and components of TSPCK has allowed for this study to have a clear framework. To enhance instrument validity, colleagues within the same field of work read through each of the instruments to ensure that relevant questions and prompts were present. Over and above the former, the pre-and post-CoRe of all the participants were given to a trusted colleague and to an experienced teacher educator to score and moderate using the expert CoRe (Appendix IV) and the TSPCK rubric for teaching waves (Appendix V). The expert CoRe was developed by me, two experienced Physical Sciences teachers and a teacher educator to ensure accuracy and validity. To further ensure an accurate records of events, formal organised field notes were taken during the study, resulting in a high-quality study and report, as suggested by Yin (1992).

3.8 SUMMARY OF THE RESEARCH DESIGN AND INSTRUMENTS

Table 3.2 summarises the research design of this study, specifically, it presents the actions and instruments used during each interaction and the reasons for carrying out each interaction. Similar to Figure 3.1, Table 3.2 shows at which point each research question was addressed.

Table 3.2: Summary of the research design showing progression relative to the teacher interactions and the sequence of data collection

Progress	Action	Instrument	Reason
Interaction 1 ***Interview:30 min***	Meet for semi-structured pre-interview (after school).	Semi-structured pre-interview sheet with questions.	Establish planned PCK & obtain untainted thoughts. **Secondary research question (a)**
Pre-CoRe: 60min	Meet to explain about the CoRe prompts and to complete pre-CoRe individually (after school).	CoRe template.	Establish planned PCK and baseline understanding & knowledge of learners' understanding and of representations, including analogies. **Secondary research question (a)**
Interaction 2 ***Intervention: 60min***	In-service teacher training carried out by the trainer (after school).	Reflection sheet and interview schedule (audio stimulated recall interview).	Record any important events, comments, perceptions that took place or were evident during the training.
Interaction 3 ***Post-CoRe: 60min***	Meet to complete post-CoRe individually (after school).	CoRe template.	Establish new understanding & knowledge of learners' understanding of and representations, including analogies. **Secondary research question (b)**
Interaction 4 a, b, c ***Length of a normal school lesson.***	Three classroom observations (during school).		Access enacted PCK about the teaching of waves. **Secondary research question (c)**
Interaction 5 ***45 min***	Meet to carry out: 1. Video stimulated recall interview. 2. General semi-structured interview (after school).	Selected video clips and semi-structure post - interview schedule.	1. Access teachers' pedagogical reasoning. 2. Determine their perception of the training. **Secondary research question (c)**

Progress	Action	Instrument	Reason
Analysis Phase	1. View classroom observation videos. 2. Qualitative analysis of audio recorded interviews (Completed in personal time).	1.1 Rubric for TSPCK and expert CoRe. 1.2 Rubric for enacting TSPCK. 2. Interview Sheets. Recorded Audio.	1.1 Comparing 1st and 2nd rubric totals will indicate that the PCK, relating to the two TSPCK components, has been supported. 1.2 Determine whether teachers have a rich or restricted TSPCK while teaching the topic of waves. 2 Mentioned above. **Primary research question**

3.9 ETHICAL CONSIDERATIONS

The sensitivity of the study was low because no confidential information was revealed. Consent was given by the principal, School Executive Management (Appendix X) and the Physical Sciences teachers (Appendix X). After permission was granted by each school and teacher, I collected the relevant information through appropriately selected instruments and events. Parent consent and learner assent (Appendix X) was important because learners were present during the classroom observations, which involved video recordings. The formal letters contained information stipulating the reason for this study, what was required to complete the study, that ethical clearance had been granted, and that confidentiality would be kept throughout the study. A conscious attempt was made not to capture the learners' faces on the videos by recording from the back of the classroom. When a teacher moved to the back of the classroom to carry out a demonstration, the video camera would be angled in such a way as to remain directed on the teacher and the particular demonstration and not on the learners. All parents and learners gave consent and assent respectively, and therefore no learner had to be placed behind the camera during any of the lesson observations. The results obtained and the information recorded during the data collection process will remain confidential. Pseudonyms were used for each participant to maintain this confidentiality. Consent was given by the trainer (Appendix X) whose role in the study was to carry out the in-service teacher training. This was imperative as each training session was recorded and one semi-structure interview in the form of an audio stimulated recall interview took place with the trainer after all three of the training sessions. I applied for ethical clearance to conduct the study from the University of Pretoria.

For further transparency, the participants of this study were informed that the findings will be made available in an open repository for public and scientific use.

3.10 CHAPTER SUMMARY

In this chapter, the research methodology, the data collection process and analysis strategy used in this study were explained. The validity and credibility of the study and the ethical considerations were identified and discussed, which concluded the chapter.

Chapter 4 will comprise a detailed explanation of the intervention carried out in this study.

CHAPTER 4 - THE INTERVENTION

4.1 INTRODUCTION

Chapter 4 details the intervention that was carried out in this study. An integral part of this study was to establish how in-service training in the use of science equipment affects teachers' PCK. The in-service training served as the intervention in this study. The chapter begins with an explanation of the intervention plan (Appendix II). This is followed by a description of the intervention, which includes the diary reflections of the researcher and comments made by the trainer when asked to recall events from the interventions.

4.2 THE INTERVENTION PLAN

The participants of this study comprised three Grade 10 in-service Physical Sciences teachers from three different private schools in Gauteng (see the teacher profiles in Chapter 3, Table 3.1). The intervention was constructed in line with the CAPS document (see Figure 4.1) and the SAG document (see Figure 4.2), centred on the topic of waves. In addition, the plan and structure of the intervention considered the Ripple Tank Teacher guide that accompanied the apparatus (Electronic Appendix A).

Waves, Sound & Light	Grade 10	**Transverse pulses on a string or spring** (pulse, amplitude superposition of pulses), **Transverse waves** (wavelength, frequency, amplitude, period, wave speed, **Longitudinal waves** (on a spring, wavelength, frequency, amplitude, period, wave speed, sound waves), **Sound (**pitch, loudness, quality (tone), ultrasound), **Electromagnetic radiation** (dual (particle/ wave) nature of electromagnetic (EM) radiation, nature of EM radiation, EM spectrum, nature of EM as particle - energy of a photon related to frequency and wavelength) **16 hours**
	Grade 11	**Geometrical Optics** (Refraction, Snell's Law, Critical angles and total internal reflection), **2D & 3D Wave fronts** (Diffraction) **13 hours**
	Grade 12	**Doppler Effect (either moving source or moving observer)** (with sound and ultrasound, with light - red shifts in the universe.) **6 hours**

Figure 4.1: An overview of the topic of waves taken from page 10 of the Physical Sciences CAPS document

It is important to note that the schools following the CAPS document, as seen in Figure 4.1, cover the concept of waves in Grades 10 and 11. The concept of the Doppler Effect is taught and examined in Grade 12, which requires an understanding of wave concepts. This differs from the SAG document used by private schools, which follow the IEB curriculum. The SAG document only specifies the IEB Grade 12 examination objectives and recommends that both the Grade 11 and Grade 12 years are dedicated to preparing learners for the final Grade 12 assessment. The SAG document also states that learners are required to use principles and concepts that are within the curriculum and apply them in a logical, reasoned or deductive manner, as shown further in Figure 4.2 below.

G. **Photons and Electrons**

1. **Photoelectric Effect**

- State that the speed of light in a vacuum is constant (3×10^8 m·s^{-1})
- Solve problems using the equation $c = f\lambda$
- State that the energy of a photon is directly proportional to the frequency of the light
- Solve problems using the equation $E = hf$ or $E = \frac{hc}{\lambda}$
- Know that electron-volts (eV) and joules (J) are suitable energy units
- Convert between electron-volts and joules
  1 eV = $1{,}6 \times 10^{-19}$ J
- Describe the photoelectric effect as the process that occurs when light shines on a metal and electrons are ejected
- State the significance of the photoelectric effect: it establishes the quantum theory and it illustrates the particle nature of light
- Define threshold (cut-off) frequency (f_o) as *the minimum frequency of incident radiation at which electrons will be emitted from a particular metal*
- Define work function (W_o) as *the minimum amount of energy needed to emit an electron from the surface of a metal* and know that the work function is material specific
- Know that the threshold frequency corresponds to a maximum wavelength
- Apply the photo-electric equation:
  $E = W_0 + E_{K(max)}$
  where $E = hf = \frac{hc}{\lambda}$, $W_0 = hf_0$, and $E_{K(max)} = \frac{1}{2}mv^2_{max}$
- Explain why the number of electrons ejected per second increases with the intensity of the incident radiation provided the frequency is above the threshold frequency
- Explain why if the frequency of the incident radiation is above the threshold frequency, then increasing the frequency of the radiation will increase the maximum kinetic energy of the ejected electrons

2. **Emission spectra**

- Explain the source of atomic emission spectra (of discharge tubes) and their unique relationship to each element
- Relate the lines on the atomic spectrum to electron transitions between energy levels
- Calculate the energy associated with a transition and the corresponding wavelength or frequency using $E = hf = \frac{hc}{\lambda}$

Figure 4.2: An excerpt from the SAG document highlighting the concepts stipulated as required knowledge for the Grade 12 IEB final exam

To understand the concepts related to the topic of photons and electrons in Figure 4.2, including the photoelectric effect and the dual nature of light, the concepts of waves need to be understood by learners. Therefore the wave concept is taught at schools that follow the SAG document.

During the intervention, the intervention plan (Appendix II) was followed to ensure consistency and formality. The intervention plan was also intended to ensure the alignment of the intervention with the framework of this study. As discussed previously, the framework of this study was underpinned by the TSPCK components. A summary of the intervention plan is given below in Figure 4.3.

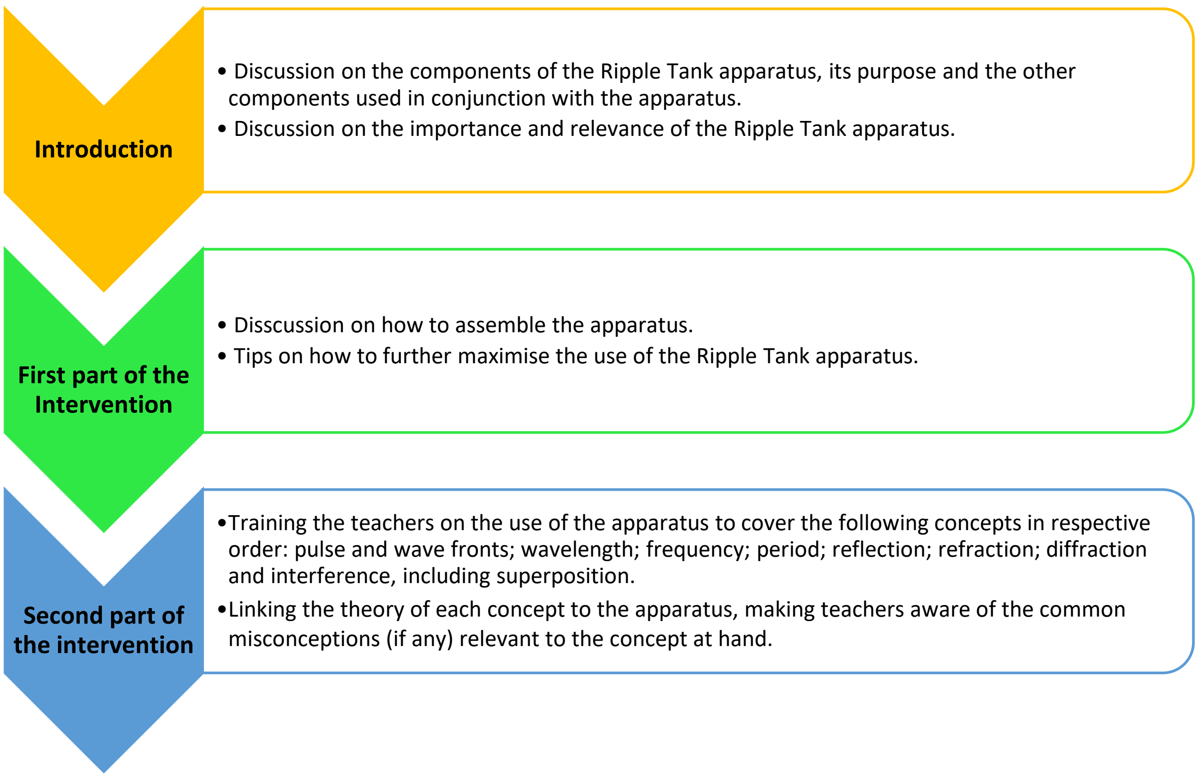


Figure 4.3: Summary of the intervention plan in respective order

Appendix II explicitly indicates where each component featured in the intervention. The concepts addressed and discussed during the intervention were as follows: a pulse; wave front; wavelength; frequency; period; reflection; refraction; diffraction and interference, including superposition. The intervention included all the above-mentioned concepts in the topic of waves to ensure that no bias was shown towards the three key ideas and their respective subordinate ideas. These were used in the CoRe to obtain the teachers' knowledge about what they believed are the necessary ideas required for learning the concepts of wavelength, frequency and superposition. The idea of following the sequence, as seen in Figure 4.3, was to allow the scaffolding of ideas, developing a new idea based on the previous idea. The intervention took place after the semi-structured pre-interview and the pre-CoRe interaction. The pre-intervention findings are discussed further in Chapter 5. The construction of a post-CoRe tool, the lesson observations, semi-structured post-interview and VSR interview were carried out after the intervention and will be presented and discussed in Chapter 6.

Researcher bias was a concern because I currently work for the company that manufactures and supplies the ripple tank apparatus that was used during the intervention. To minimise bias, I did not carry out the training myself but asked the supervisor of this study to conduct the intervention. I was present in the interventions to assist in the construction of the ripple tank before the intervention commenced, to carry out the audio recordings, and to take photographs of the important illustrations and representations used during the intervention. In addition, I was present to note the events in the form of diary entries so that accurate recall could occur after the intervention took place. Prior to the intervention, the trainer and I spent time discussing the apparatus and the intervention plan presented in Appendix II. After Interaction 1, the relevant teacher and the trainer were both consulted to find a future convenient time for the intervention to take place.

To ensure efficient recall (Cohen et al., 2011), and correct and unbiased interpretations of the events and responses given by the participants (Whittemore, Chase & Mandle, 2001), the interventions were recorded. An audio stimulated recall interview was conducted with the trainer after all three of the interventions had been conducted. I drew much of the relevant information for this chapter from my own diary reflections (Electronic appendices E, F and G) and from the audio stimulated recall interview carried out with the trainer (Electronic Appendix T and U). To support the discussion about the intervention and how it unfolded, I include photographs taken of certain explanations and illustrations that were carried out and drawn on the board by the trainer. The wave concepts that were demonstrated and observed through the use of the ripple tank apparatus are also represented as photographs.

4.3 THE INTERVENTION

During the intervention, all five of the TSPCK components were addressed (Appendix II).

In my notes, I reflect on the intervention itself and the discussions that took place between the trainer, participant, and myself during the interventions. As explained in Chapter 3, the assumption was that the in-service teacher training would draw on the cPCK belonging to the profession of teaching to develop the pPCK of the participants, which then informs ePCK (Carlson & Daehler, 2019). This is a fair assumption considering that the intervention plan was drawn up by people with experience in the use of the apparatus, and the expert CoRe was constructed by experienced Physical Sciences teachers. This study examined PCK at a topic level with each realm of PCK: cPCK, pPCK and ePCK, which were underpinned by the TSPCK components. I acknowledge that all the components are integrated in the teachers' conceptual teaching strategies and therefore, while the intervention was carried out, all five TSPCK components were addressed and incorporated. The following paragraphs discuss the ways in which the intervention considered the TSPCK components. There is specific reflection on the relevant events taken from the diary reflections and the trainer's audio-recalled interview (electronic appendices E, F, G and T and U respectively).

4.3.1 Curriculum Saliency and what is difficult or easy to understand/teach

The topic of waves is a small component of the CAPS curriculum (Appendix I). In addition, the SAG document does not include waves as a standalone knowledge area. However, wave physics is an everyday phenomenon. Knowledge of wave concepts is required to be able to understand the Doppler effect, the photoelectric effect, and the dual nature of light. Therefore, the topic is important in the school curriculum and it is assumed that all Physical Sciences teachers have an understanding of the topic of waves. During the intervention, I expected the teachers to realise, while following the sequence described in Figure 4.3, that the foundational concepts of wavelength and frequency, including the subordinate idea of period, were required to understand the more advanced principles of reflection, refraction, diffraction and superposition. Although there were only three key ideas for the study, namely, wavelength, frequency and superposition, the ripple tank apparatus can be used to support the understanding of all wave concepts. Therefore, the intervention started by addressing the foundational concepts of waves and then worked towards the more complicated phenomenon of reflection, refraction, diffraction, and interference.

The trainer recalled (Electronic Appendix U) having the impression that the teachers knew where each concept was placed in the curriculum and the order in which they should be taught. This was the same observation I had recorded in my diary reflections. I wrote the following for Jessica:

> *Although young and new to teaching Physical Sciences, the teacher had an understanding about the topic and was quite knowledgeable about the topic.*

In addition, after the intervention with Tshuma, I recorded:

> *The participant would acknowledge where in the curriculum the topic and its relevant concepts were covered i.e. Diffraction. The participant knew that the study was to focus on the Grade 10 level. During the training, we covered the concept of Diffraction. He seemed concerned that we were covering the concept and thus asked if he would have to cover [this concept] in Grade 10 instead of Grade 11. We assured him that his thinking was correct and [that] it is part of the Grade 11 curriculum.*

Furthermore, Craig was recorded saying, "The ripple tank is also very important for Grade 11 for diffraction and refraction." To further support this, the trainer remarked during her interview (Electronic Appendix U) that she believed the participant was revealing his knowledge of the Grade 11 curriculum. However, during the trainer interview, she remarked that she believed that Tshuma and Craig seemed to be reluctant to teach something in a different sequence and not allow themselves to go beyond the curriculum, even if the situation called for it.

4.3.2 Representations

Since the study investigates the effect of training on equipment use, *representations* is an important TSPCK component in the context of the study. The intervention introduced knowledge about how best to apply the ripple tank apparatus (see Figure 4.4 below) to demonstrate each of the wave concepts. Below Figure 4.4., Table 4.1 shows the demonstrations reviewed during the intervention according to the intervention plan (Appendix II).

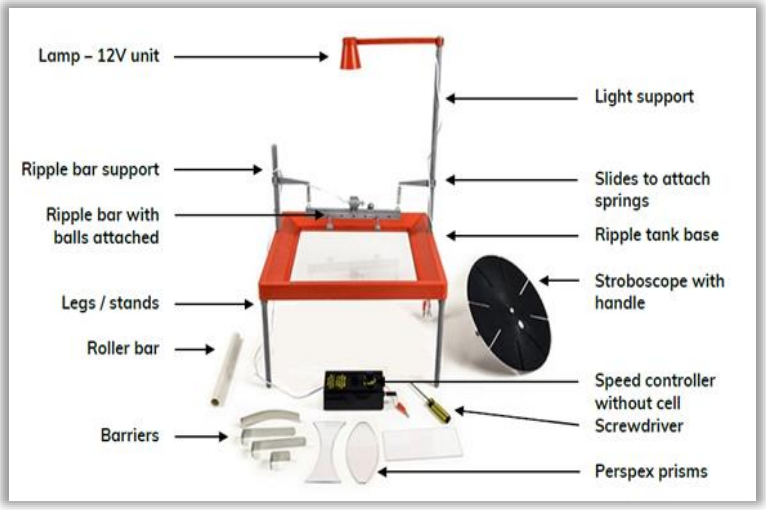
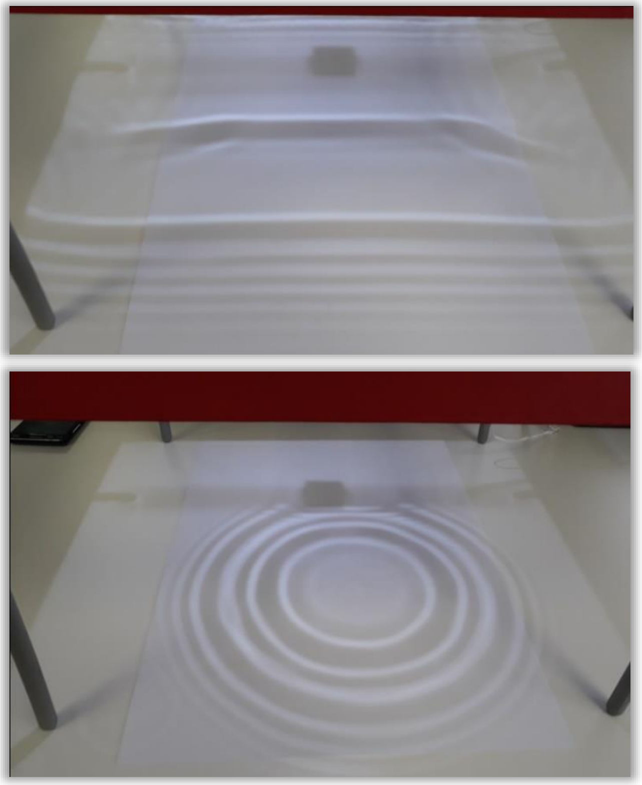
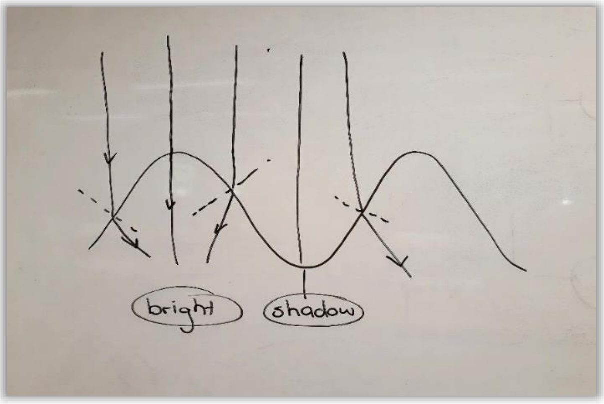


Figure 4.4: An image of the Ripple Tank apparatus provided to the school and used during the intervention

Table 4.1: The intervention activities, diagrammatic explanations and ripple tank representations

Concept	Activity
Pulse and wave front	To represent the concept of pulses, the trainer generated a series of pulses on the surface of the water. To illustrate horizontal pulses, the ripple bar was used manually by tapping it once to touch the surface of the water. To illustrate circular pulses, the trainer used her finger or a plastic pipette provided. Tapping the surface of the water with the tip of her finger or allowing droplets to fall from the dropper produced a succession of circular pulses (see Figure 4.5). Illustrating the horizontal and circular pulses (see

Concept	Activity
	Figure 4.5) allowed the trainer to then discuss the subordinate idea of wave fronts. Learners often have the misconception that the troughs are represented by the brighter lines seen in the projection on the white paper below the ripple tank, thinking that light travels through 'less' water. To address this misconception, the trainer drew a diagram on the board (see Figure 4.6). Using the principle of the refraction of light, the trainer addressed the misconception, clarifying that the darker lines seen in the projection are because of the troughs and the lighter lines in the projection are because of the crests.  *Figure 4.5: Ripple tank representation of a (top) linear and (bottom) circular pulse*

Concept	Activity
	 *Figure 4.6: A diagrammatic explanation for the crest of a wave being seen as the darker lines and the troughs of a wave being the lighter lines when observed in the projection using the ripple tank*
Wavelength, frequency, and period	To illustrate the relationship between wavelength and frequency, the ripple bar was used together with the controller to control the frequency of vibrations. The ripple bar was placed on the surface of the water and the controller was set on the minimum setting. The controller was used to slowly change the frequency by turning the controller towards the maximum point (see Figure 4.7). The change in frequency resulted in the change of the wavelength. The speed of the wave remained constant since the medium (water) was not changed.

Concept	Activity

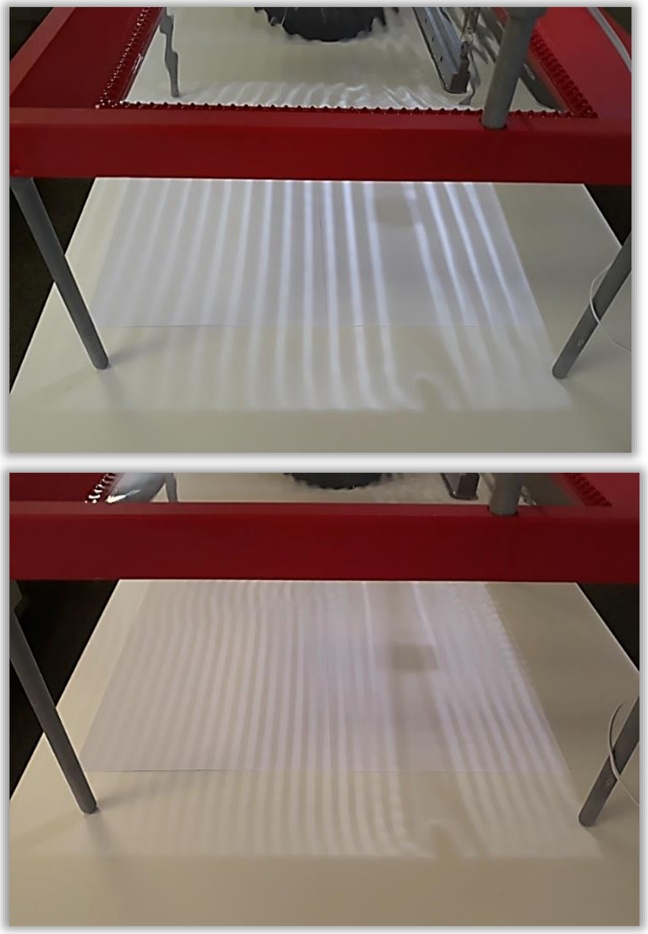


Figure 4.7: Ripple tank representation showing the relationship between (top) higher frequency, shorter wavelength and (bottom) lower frequency, longer wavelength

The revolutions of the motor caused the ripple bar to vibrate on the surface of the water to produce waves of a certain frequency. To obtain a frequency that produced clear waves, a 10Ω resistor was attached to the red terminal of the controller using a crocodile clip lead. This provided extra resistance to the controller and reduced the number of vibrations, resulting in a lower frequency and better observed wave fronts. This, in turn, demonstrated a more obvious change in the frequency and wavelength when comparing the minimum setting to the maximum setting on the controller.

Concept	Activity
	At this point, the teachers were introduced to the stroboscope (see Figure 4.8). Due to its circular design containing equally spaced single slits when spun at the correct speed, the stroboscope allows the teacher to observe the waves as if the waves were stationary by rotating it at the correct speed. This made it clearer for the teacher to observe the relationship between wavelength and frequency when the controller was adjusted. After demonstrating the relationship between wavelength and frequency, the trainer addressed the concept of period. The trainer ensured that the teachers were aware of the fact that learners often confuse the concepts of frequency and period, resulting in learners confusing their definitions, units and equations. By addressing and demonstrating wavelength, frequency and period, the first and second key ideas pertaining to this study were addressed.
	
	Figure 4.8: The stroboscope
	The misconception that the speed of a wave can change even when the medium (water) is unchanged was addressed by referring to the equation written on the board (see Figure 4.9). After demonstrating wavelength and frequency using the ripple tank and stroboscope, the trainer elaborated further that the medium in the ripple tank (water) did not change. This resulted in the speed remaining constant. It was further discussed that an increase of the frequency results in the decrease of the wavelength, keeping

Concept	Activity
	the speed of the wave the same. The formula made use of symbols, resulting in a discussion about symbols and units of the wave equation.

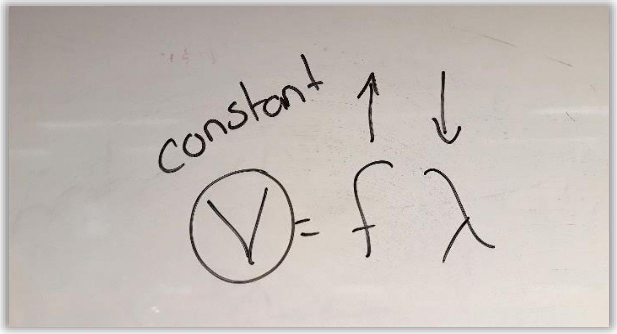


Figure 4.9: Formula showing the relationship between the speed of a wave, and frequency and wavelength

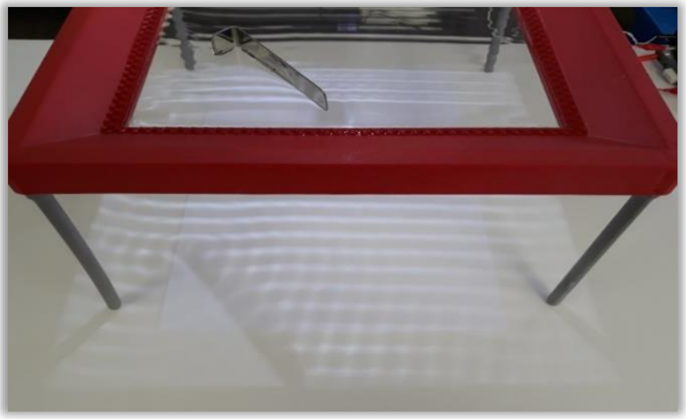
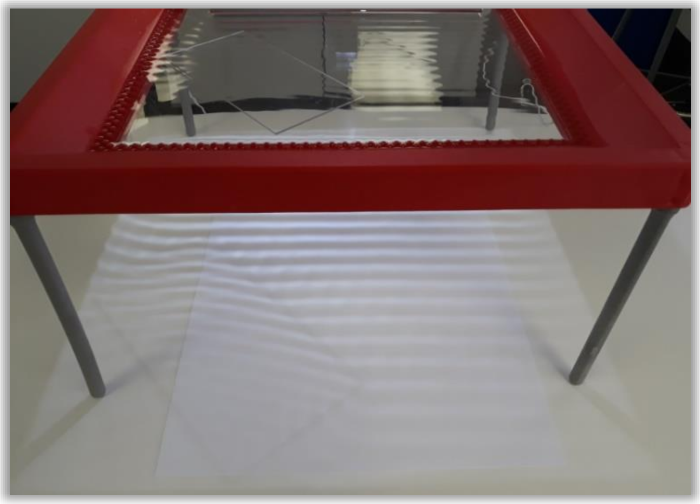


Figure 4.10: Ripple tank representation of reflection using the longer straight barrier

Concept	Activity
Reflection	To demonstrate the phenomenon of reflection, the longer, single, straight barrier was placed into the water on the ripple tank base at an angle (Figure 4.10). Reflection was observed where the wave fronts would hit the barrier and reflect at 90^{o}, causing a grid like pattern to be observed (Figure 4.10). Reflection was further demonstrated using the curved barrier (photograph not taken). The demonstration of reflection using the curved barrier visually showed both the converging of reflected waves and the diverging of reflected waves.

Concept	Activity
Refraction	To represent the concept of refraction, a rectangular Perspex prism was placed under the surface of the water. This resulted in shallow water being present directly above the prism and deeper water to be present around the prism. A small amount of sunlight liquid was added to the water to break the surface tension of the water so that the water would cover the Perspex prism evenly. When necessary, some of the water was removed out of the tank using a syringe. This allowed the phenomenon to be seen clearly. The photograph below, Figure 4.11, shows what was observed.  *Figure 4.11: Ripple tank representation of refraction using the rectangular Perspex prism* The misconception discussed previously during the intervention pertaining to Figure 4.9 was addressed again. In this demonstration, teachers needed to understand that placing the Perspex prism into the water made the water shallower directly above the prism, thus changing the medium. So, as the waves approached the prism and moved into shallower water, the speed and wavelength of the wave changed while the frequency of the wave remained constant since the frequency was being determined by the source.
Diffraction	The concept of diffraction was first illustrated by placing an obstruction, in the form of the small single metal barrier in the centre of the ripple tank in front of the ripple bar. The waves were observed to move around the obstacle and diffract around the edges (Figure 4.12).

Concept	Activity
	The concept of diffraction was extended further by using the two longer single barriers to produce a slit. The phenomenon was observed and compared for a small slit and for a wider slit (Figure 4.13). This was accomplished by moving the two barriers further and closer together, respectively. The frequency was kept constant. The last illustration of diffraction was shown by keeping the width of the slit constant and by changing the frequency (photographs not taken).

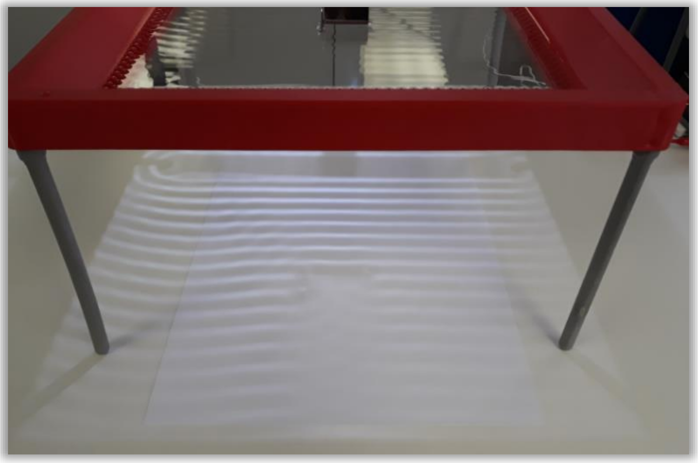
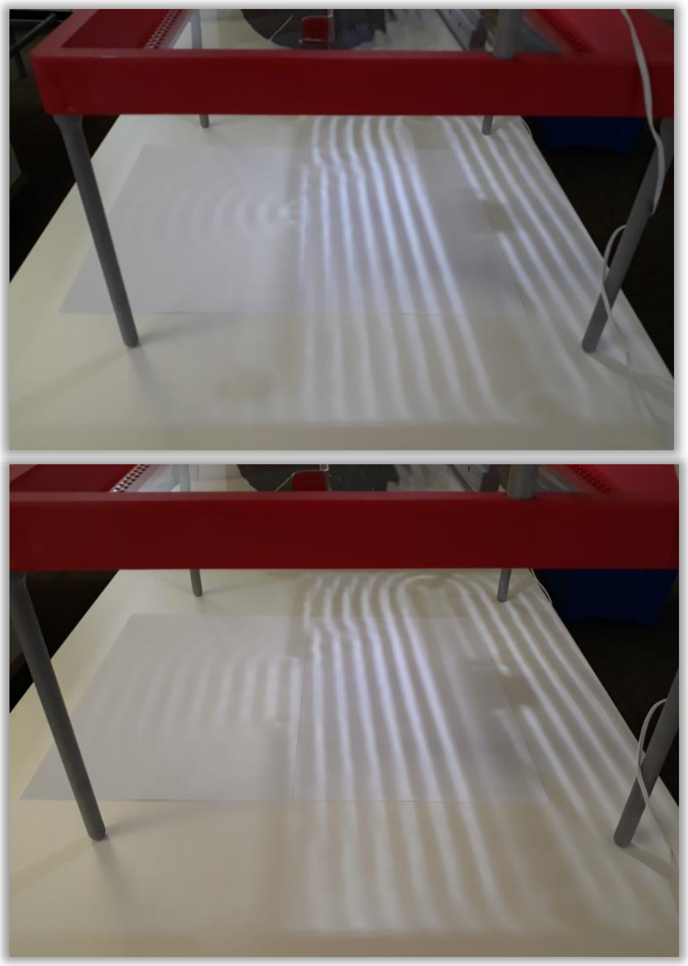


Figure 4.12: Ripple tank representation of diffraction using a small singl obstacle as the small metal barrier

Concept	Activity
	 *Figure 4.13: Ripple tank representation of diffraction through (top) a narrow single slit and (bottom) a wider single slit produced by two of the longer straight barriers*
Interference including superposition	Superposition was demonstrated by using the ripple bar with two balls attached to the ripple bar, which were placed just on the surface of the water. A constant frequency was set using the controller. Figure 4.14 shows what was observed. If the total destructive interference was not clearly visible to the teachers, the room was made darker by switching off the room lights and the teacher was encouraged to stand facing the ripple tank head on and not side on. To further illustrate the phenomenon so that the teacher could fully visualise and understand what was being observed, the trainer drew Figure 4.15 on the board.

Concept	Activity

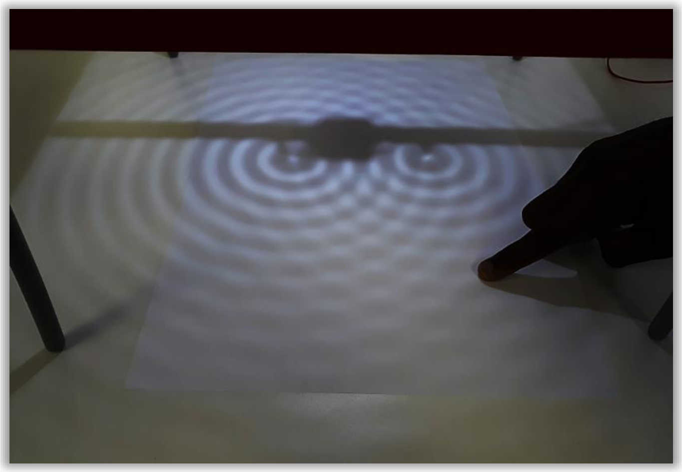


Figure 4.14: Ripple tank representation of superposition using the ripple bar with balls attached

Representing superposition using the ripple tank apparatus covered the third key idea of the study. The principle of the crests being observed as the lighter lines and spots, with the troughs being observed as the darker lines and spots were addressed again. The teachers were made aware that the same principle was being observed during this illustration of superposition. The teachers were also made aware that the even brighter spots were where two crests were superimposed, and the even darker spots were where two troughs were superimposed.

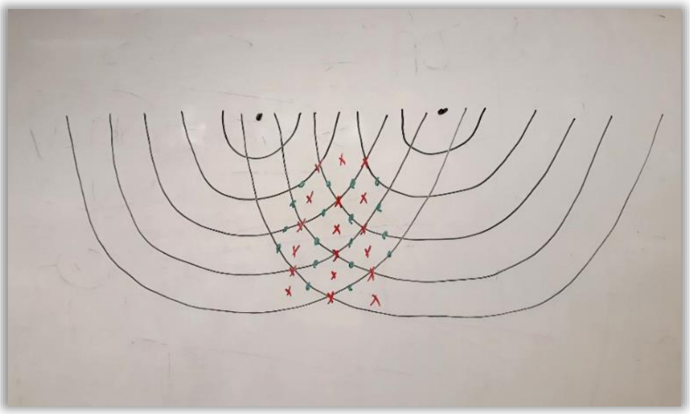


Figure 4.15: Diagram illustrating constructive and destructive interference

It became apparent at the beginning of the interventions with each of the participants that they did not have confidence in using the ripple tank or in its application. Although it was evident that they had not used this specific piece of apparatus before, the participants revealed knowledge about the topic of waves and what the apparatus was normally used for. In my diary reflection, I wrote the following about each participant:

> *Jessica: To begin with, the participant had quite a negative perception of the ripple tank. The participant acknowledged that she does not use the ripple tank to its full extent and relies more on the use of the light kit and the slinky spring to demonstrate waves. The participant asked whether the ripple tank would leak while she was pouring the water into the tank base. This indicated to me that she did not have confidence in the apparatus. The participant also noted that the current ripple tank the school owns is an older wooden version that leaks and has a motor which is slightly faulty.*
>
> *Tshuma: The participant knew what the apparatus was and the section it should be used for. However, he admitted that the last time he saw the apparatus and the apparatus in use was during his teacher training in 1999. He mentioned that an old ripple tank apparatus was somewhere in the next-door classroom but was unworkable.*
>
> *Craig: The participant knew what the apparatus was and the section it should be used for. However, he was not deeply knowledgeable about this specific ripple tank apparatus – this is what I observed while we were setting up the apparatus.*
>
> *He asked whether the apparatus would leak.*

In addition, Tshuma further elaborated that he chose to use a rope and a textbook as resources to teach the section because he could not use the incomplete ripple tank apparatus. Craig indicated that he had never used the apparatus before to teach the topic of waves.

When reflecting on how each participant engaged during the intervention, we noticed that Jessica engaged well with the trainer and myself. She discussed other ways in which she had previously used the light of the ripple tank to display the effect of the ripple tank onto the roof rather than onto paper, which was placed below the tank. As noted in my diary reflection, (Electronic Appendix E) and recalled by the trainer (Electronic Appendix U), Jessica was quite confident in her abilities, contributing to the discussion and responding well when asked questions during the intervention. Despite her reservations about the ripple tank, Jessica seemed excited and enthusiastic about the stroboscope when she was shown how to use it and when she was shown the phenomenon of reflection using the curved metal plate, due to its impressive projection. The participant also enjoyed seeing a real-life example of water diffracting around a western cape island from a google map image. As a concluding statement of the intervention with Jessica, I wrote the following in my diary reflection

> *The participant became fully confident in the apparatus after seeing that the waves were easily observed in the fully lit classroom and that the tank did not leak.*

Tshuma continuously agreed with what the trainer was saying and would often be seen nodding his head. He was receptive and interactive. Furthermore, I noted that:

> *The participant was 'hungry' for knowledge and is a keen learner, and during the training the participant mainly listened and absorbed.*

The trainer indicated that her impression was that Tshuma had never used the apparatus before. In my notes about Tshuma (Electronic Appendix F), I recorded that he enjoyed being shown the stroboscope and how to use it. I also noted that he loved the visualisation of the waves in the ripple tank as he often used the phrase, "nice one". At the end of the training, the participant stated that he was happy and that he had learnt a lot.

Craig was observed to be more receptive than interactive during the duration of the intervention (Electronic appendix G). The participant accepted what was being shown and discussed and often repeated sentences indicating that he was paying attention. In my reflective diary I noted the following:

> *He acknowledged the use of the apparatus and the use of the individual items that made up the apparatus but did not suggest other ways to use the individual items.*

However, when I asked the trainer to recall how she remembered the intervention with Craig and whether she agreed that Craig was more receptive than interactive, she made a very relevant point. The trainer remarked that teachers do not want to 'lose face' and that they do not want to reveal that they may not know something, especially considering that they are already seen as being professionals. It was important for me to note this and to acknowledge that a lack of interaction was not a sound way of judging whether or not the teacher was knowledgeable about the apparatus, representations and demonstrations being shown. At the end of the training with Craig, he stated:

> *Visuals are good, they [the learners] see what is actually happening*.

Furthermore, Craig acknowledged that learners understand better when seeing. When the trainer was asked why she drew diagrams on the board (see Table 4.4), the trainer gave the following response:

> *I feel that… you make meaning of the words when you see the representation of what is being said and often when you have two different kinds of representations… the actual ripple tank and… you can confirm it with another drawing, and… another explanation, I think it is a better way to get the concept across and to get his participation.*

4.3.3 Learners' prior knowledge and misconceptions

The literature has indicated the importance of teachers having an understanding of learners' misconceptions so that they can help learners to reconstruct their pre-instructional concepts about a topic (Van Niekerk, 2012). Just like any other topic, learners possess prior knowledge and hold misconceptions about the topic of waves (Caleon & Subramaniam, 2010). For this reason, the trainer encouraged the teachers during the intervention to continuously determine the learners' prior knowledge, especially during a lesson using a representation, such as the ripple tank apparatus. The misconceptions that were addressed during the intervention (Table 4.1) were as follows:

- The brighter lines projected on the white paper represent the trough and the dark lines represent a crest.
  This was discussed by referring to Figure 4.6. When the wave fronts were observed in the water and projected onto the paper, the lighter lines are formed by the crests and the darker lines are formed by the troughs.

- The speed of the wave changes.
  This was addressed by referring to Figure 4.9. The value of v in the equation $v = \lambda \times f$ remains constant because the medium remained unchanged.

- The speed of a wave remains the same when the medium changes.
  By referring to Figure 4.11, the trainer explained that the speed of a wave changes when the wave travels in shallow water and that this frequency remains constant.

In addition, the concept of frequency and period, together with their similarities and differences, which learners are known to confuse, were also addressed.

About the first misconception, learners think that because light travels through less water at a trough and more water at a crest that it results in the lighter bands being the troughs and the darker bands being the crests. It was only Jessica that indicated during the intervention that she addressed this misconception with her learners.

To further illustrate the integrated nature of the TSPCK components, I refer to Figure 4.6. The diagram was drawn to show why the lighter lines projected on the white paper below the ripple tank are the crests and why the darker lines are the troughs. It was understood by all the participants that Figure 4.6 required an understanding of refraction. Refraction is a more complicated concept that is addressed later in the curriculum. Therefore, the teachers acknowledged that they could either tell the learners that the crests would be observed in the ripple tank as the brighter lines and the troughs as the darker lines, or alternatively would allow learners to guess which was which and to only explain the reasoning to the learners once the wave diagram and the concept of refraction was addressed.

All the participants acknowledged that learners tend to believe that the speed of the wave changes when observed in the ripple tank despite the medium (water) remaining unchanged. Therefore, with the use of the ripple tank and stroboscope, the teachers were shown that when the frequency was increased, it would cause the wavelength to decrease, demonstrating the inverse proportional relationship between wavelength and frequency. The equation of $v = \lambda \times f$ was introduced once this relationship was ascertained, resulting in the understanding that v would remain constant and that as frequency changes, so does the wavelength. The trainer highlighted the importance of discussing this concept with the teachers. This is because it is a concept that is often asked in question papers but learners often get it incorrect because they think speed varies if the frequency varies, and tend to assume that wavelength is constant. As stated in the interview with the trainer:

> *So, they tend to not realise that if you have the same medium then the speed is the same. So, this relationship between speed, wavelength and frequency is not well understood.*

When the trainer was asked why she believed it is important that teachers have an understanding of learners’ misconceptions when teaching the section, she responded by indicating it is so that the teacher can pick up the existence of the misconceptions and then know how to address them. In doing so, the teachers are able to change the learners’ incorrect idea to the correct scientific idea, resulting in the learners' conceptual change and understanding.

This is relevant as it is in line with Van Niekerk (2012), who highlights the importance of understanding learners’ misconceptions so that the reconstruction of learners’ pre-instructional concepts about a topic can be addressed by a teacher who is aware of such misconceptions. Further into the training, the teachers were made aware of the misconception that learners have when a wave is moving from one medium to another, or as demonstrated in a ripple tank, from deeper to more shallow water. The equation of $v = \lambda \times f$ was further used to ensure that the teachers understood that the change in depth of water from deeper to more shallow water decreased the speed of the wave since the frequency, as determined by the source, does not change. The decrease in the speed of the wave was accompanied by not only a change in wavelength, but also a change in the direction of the wave. The term 'bending' was also addressed at this point as it is not the correct use of terminology. The phenomenon was explained by indicating that the wave fronts were experiencing a change in direction and were not bending.

The trainer indicated that teachers should not teach in a 'top down' manner, but rather involve the learners during the demonstration. Asking the learners what they observe affords the learners the opportunity to get involved and to honestly say exactly what they see, even if incorrect terminology is used or if the terminology has not yet been taught. This allowed the teachers to identify their learners' prior knowledge, thoughts and misconceptions on the concept being taught and demonstrated. Furthermore, the trainer indicated to the teachers that it is important to ask learners to predict observations or events because it is the way in which scientists work, and it would help the learners to think critically.

4.3.4 Conceptual teaching strategies

The *knowledge of conceptual teaching strategies* involves the integration of the other four TSPCK components, and the effective interaction of all the components points to well-developed PCK. The participants were in-service teachers and therefore I assumed that they had knowledge of general teaching strategies. The literature has indicated that conceptual teaching strategies involve a teacher having a strategy on how to teach a concept so that it is understood by each learner (Carlson & Daehler, 2019). Furthermore, this involves a teacher knowing a number of ways to explain the same concept and how best to present the concept (Mavhunga, 2014) to aid in learner understanding.

In the interview (Electronic appendix U), the trainer indicated that although the intervention involved showing the teachers how to best employ the ripple tank apparatus, the teachers needed to further practise using the apparatus. The trainer indicated that firstly, it is for technical reasons that one should practise working with the apparatus. This would assist the teacher to determine the practical protocol, such as how much water to put into the tank, where to position the light, how deep into the water the ripple bar should be mounted, and so forth. Further practise would also allow the teachers to consider the sequence in which they would teach the section while going through their own worksheet/s and notes while the apparatus was at hand. Another aspect of 'practise' mentioned by the trainer in the intervention was the technique of teachers learning how to get their learners to participate during the demonstration lesson. This would involve stimulating the learners and asking questions that facilitate critical reasoning.

During the intervention, Tshuma acknowledged that he needed to further practise using the apparatus once the training had concluded (intervention recording). Craig also acknowledged the need to practise through stating that he wanted to explore the apparatus more (intervention recording). As a closing question to the trainer about the interventions in general, I asked the following:

> *You didn't just set up the apparatus and show them how to use it. You… linked the situation, the curriculum, their prior knowledge, the learner misconceptions, the fact that they had to practise, the fact that they had to get the learners engaged. What was your main reasoning for connecting all the dots to the training and not just showing the teachers how to set it up and use it?*

To which the trainer answered:

> *I know what the misconceptions are. I know that if you don't plan a demonstration, it may not happen the way you foresee it. I know how learners respond and I know what's going on in their minds when they respond. I know… things that we learn now, will be important later… so, I would like to impart… my knowledge to the teachers... the same way I would like them to impart their knowledge to learners.*

4.4 CHAPTER SUMMARY

In this chapter, the intervention plan and its structure was shown and discussed. Furthermore, the chapter reports on the information obtained during the intervention, which was carried out in line with the conceptual framework. During the reflection on the three interventions, both through the trainer interview and my own diary reflections, it was evident that all of the participants were enthusiastic and saw the possibilities in using the piece of science equipment. Even Jessica, who displayed the highest confidence in her content knowledge and had the most reservations about the equipment, benefitted from the intervention. It was clear that all three participants realised how much the apparatus could be of help in introducing the concepts to the learners and how much the learners would enjoy it. All of the participants were enthusiastic during the training and were intrigued about what they saw and its significance in teaching the topic of waves and the understating of the concept. The participants seemed grateful for the apparatus and relayed the importance of attending the in-service training as it helped them to improve their knowledge about teaching the topic.
It was evident, and was confirmed by the trainer, that the teachers were receptive and open to the idea of receiving further in-service training. This finding is in line with a study carried out by Johnson et al. (2013), which ascertained that teachers are receptive to receiving more materials and training because they acknowledge what could be achieved. After all three

interventions, having seen that the participants were all willing and enthusiastic, I was quite confident that when it came to observing the teachers in their classroom during the lesson observations, they would plan to use the apparatus during their lessons based on the three key ideas about the topic of waves.

An analysis of the pre-intervention data and the post-intervention data will further allow for an in-depth exploration and discussion of the teachers' PCK development (if any occurs). The information obtained through the (pre)-intervention interactions will be discussed in the next chapter.

CHAPTER 5 - RESULTS ON THE REPORTED PCK AND THE PRE-INTERVIEW

5.1 INTRODUCTION

The CoRe has been described as a useful tool that is centred around teachers' skills and knowledge. It further provides a means to elicit and record PCK directly from a teacher (Kind, 2009). This study used the CoRe instrument before and after an intervention to elicit and record the participants' PCK about the topic of waves, based on the key ideas of wavelength, frequency and superposition. As mentioned in Section 3.4, I assumed that their responses to the prompts were a declaration of their knowledge. Using the data collected from the CoRe, and the information obtained during the pre-interview, this chapter strives to answer the first and second sub-question of this study:

a) What are the levels of the teachers' reported PCK about teaching the wave concept before the in-service training?
b) What are the levels of the teachers' reported PCK about teaching the wave concept after the in-service training?

The chapter consists of two sections. The first section reveals the results, analysis and interpretation of the pre-CoRe and pre-interview for each of the three case studies, answering the first sub-question. The second section reveals the results, analysis and interpretation of the post-CoRe for each of the participants in an attempt to answer the second sub-question. A summary discusses the comparison of the pre-and post-CoRe levels for each participant and whether, if at all, the participants' TSPCK improved.

5.1.1 Expert CoRe

The information obtained from the CoRe gives an understanding of the teachers' knowledge. However, it is difficult to score a teacher's knowledge about a topic without having a baseline understanding of the knowledge a teacher should possess about the topic. Therefore, an expert CoRe (Appendix IV) was developed as an example of exemplary TSPCK about the topic of waves. The expert CoRe is informed by the CAPS document (Appendix I) relevant to the topic of waves for Grades 10, 11 and 12. I employed my knowledge about the topic of waves based on my personal experience as a Grade 10, 11 and 12 Physical Sciences teacher. Two experienced Physical Sciences teachers and a teacher educator helped in designing the expert CoRe to assist in ensuring its validity. The expert CoRe can be regarded as an extensive but not exhaustive representation of the PCK about waves and is considered as the collective PCK belonging to the profession. The information provided by the participants in their pre- and post-CoRes were gauged against the expert CoRe (Appendix IV) and the category descriptions stipulated in the TSPCK rubric for teaching waves (Appendix V). However, other interpretations and approaches were also considered. The participants were not expected to have all the information recorded in their CoRes as seen in the expert CoRe.

5.1.2 Scoring of the pre- and post-CoRes

The rubric design was discussed in Chapter 3. I chose to score the CoRes per key idea for each prompt. Scoring each key idea separately links to the notion of the Refined Consensus Model and the role of grain sizes of PCK (Carlson & Daehler, 2019) because scoring each key idea is scoring the teachers' PCK at a concept level. To obtain an overall score for the TSPCK component for the topic, the 'average' of the scores for the key ideas were taken, similar to what was done in Mavhunga’s (2019) study. While scoring the CoRes, specific scenarios presented themselves, which were addressed using the principles presented in Table 5.1.

Table 5.1:Principles employed when scoring the CoRe's

The scenario	**Principle employed when scoring**
The participants' responses included the two extreme scores of **Limited** and **Rich**.	An **adequate** score was assigned taking the 'average' between the two extreme scores.
The responses were assigned different scores across the prompts for each PCK component.	The score that was revealed to be the most common across the prompts was the final score assigned.
The responses had the same number of two different scores across the key ideas for the same component, i.e. two limited and two adequate scores.	The score assigned was a combination of the two, i.e. **Limited to Adequate** or **Adequate to Rich.**
Responses in the post-CoRe indicated less knowledge than the pre-CoRe.	The post-CoRe was scored considering the knowledge recorded in the pre-CoRe. If the teacher revealed

	certain knowledge in the pre-Core and not again in the post-CoRe, the knowledge was considered to be part of the teacher's personal PCK.

For moderation purposes and validation, the pre-and post-CoRe of all the participants were given to two experienced teacher educators to score using the expert CoRe (Appendix IV) and the TSPCK Rubric for teaching waves, as revealed through CoRes (Appendix V). The scores for Jessica were compared and when the scores differed, discussion followed until an agreement was reached. The aspect that required an agreement to be reached during moderation only pertained to the **Rich (3)** level descriptors, for no reason other than the fact that the other level descriptors did not need any amendments. Table 5.2 summarises the category descriptors that were amended for the relevant component prompts pertaining to the **Rich (3)** level. In some instances, the **Rich (3)** level rubric descriptors were amended and in other cases, the score was changed. The amendments are highlighted in blue.

Table 5.2: Amendments to the category descriptors of the TSPCK rubric for teaching waves

Component prompts	Action Taken	Descriptor for Rich (3)
What do you intend learners to know about each key idea? **1. Wavelength.** **2. Frequency (period).** **3. Superposition.**	The addition of a descriptor.	- Knowledge of key idea identified and understood being aware of the definitions, equations and/or terms. - Explanation links to key ideas. - Subordinate ideas constitute an exhaustive list of concepts to be taught. - Identifies subordinate ideas that focus on understanding of the concepts. - Relationship of the concept to real life application.
What do learners find difficult to understand?	The exclusion of a descriptor because the prompt did not explicitly ask the participants to write about the effect of these difficulties in their response.	- Pinpoints appropriate aspects that learners find difficult relevant to the key ideas. - Gives defined examples of such difficulties. - ~~Explains the effect of these difficulties on other subordinate ideas.~~
What are typical learners' misconceptions when teaching this idea?	The addition of a descriptor.	- Identifies and describes a number of misconceptions or gaps in pre-concepts. - An indication of knowledge about misconceptions and their origin is evident, i.e. confusion in the definition of frequency and period. - Identifies most common misconceptions, i.e. learners believe that wavelength is only measured from a crest to crest or trough to trough.

After the discussion and moderation of the CoRe's for Jessica, and after following through with the above-mentioned amendments, I rescored each of the participants' CoRes. This chapter does not consider the PCK component of *Integration of PCK components* and *Pedagogical reasoning* because it cannot be assessed only through the CoRe, but rather through classroom observations and the VSR interview. These two PCK components are included and discussed in Chapter 6. I included the data obtained from the CoRe for all the TSPCK components since the interaction of the components contributes to the quality of conceptual teaching strategies (Mavhunga, 2018). The effective interaction of all the TSPCK components points to a well-developed PCK.

5.1.3 The pre-interview

Following the framework of the study, to access the teachers' reported PCK, over and above through the CoRes, a semi-structured pre-interview was conducted and is incorporated in the results and discussions that follow in this chapter.

5.2 PRE-CORE AND PRE-INTERVIEW: RESULTS, ANALYSIS AND INTERPRETATION

In the sections that follow, I present and discuss the responses to the prompts in the pre-CoRe results of each participant. This is presented under the headings of the PCK components in line with the TSPCK rubric for teaching Waves (see Appendix V and Section 3.5.1). As discussed in Section 3.5.4, an amendment was made to the rubric so that *Knowledge and Skills related to Representations* could be assessed and discussed separately. For the sake of discussing the participants' responses to each CoRe prompt, I will refer to each prompt using numerical values, as seen in Table 5.3 below.

Table 5.3: Numerical value given to each PCK component prompt.

Numerical value	CoRe Prompt
	Knowledge and skills related to curriculum saliency.
1	*What do you intend the learners to learn about this idea?*
2	*Why is it important for learners to know this?*
3	*What concepts need to be taught before teaching this big idea?*
4	*What else do you know about this idea (that you do not intend learners to know yet)?*

Numerical value	CoRe Prompt
5	*What is difficult to understand?*
6	*What do you consider easy or difficult in teaching this big idea?*
	Knowledge and skills related to learners' understanding.
7	*What are the typical learner misconceptions about this big idea?*
	Knowledge and skills related to representations.
8	*What representations would you use in your teaching strategies?*
	Knowledge and skills related to conceptual teaching strategies.
9	*What effective teaching strategies would you use to teach this idea?*
10	*What questions would you consider important to ask in your teaching strategies?*

Although Prompts 5 and 6 are listed under the component of *Curricular Saliency,* the teacher's reveals a lot about his or her knowledge and understanding of these two prompts under the component of *Learner Understanding*. It is for this reason that the participants' CoRe responses for Prompts 5 and 6 are discussed under the section *Knowledge and skills related to learners understanding*'. Recommendations about this are made in Chapter 7.

The pre-CoRe score results for all three participants are summarised in Table 5.4, displaying the final score allocated to the PCK component for each key idea. The analysis and interpretation of the data considered other relevant information gained through the pre-interview.

5.2.1 Case study one – Jessica

Jessica holds a Bachelor of Science Honours degree and a Post Graduate Certificate in Education. She is a first language English speaker. At the time of the study, she had two years of Grade 10 Physical Sciences teaching experience.

Knowledge and skills related to curricular saliency

Figure 5.1 presents the CoRe constructed by Jessica pertaining to *knowledge and skills related to curricular saliency* (Prompts 1 to 4).

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	* understand what wavelength is. ↳ where it applies i.e. in phase & what that means and that it is successive only to be 1 wavelength. * interested in the length (1 dimension) of a wave.	* Interested in number of cycles in a time period not how long for 1 cycle. * Another way of ~~determining~~ comparing the "speed" of 2 waves if λ the same * it is different for different waves
Why is it important for learners to know this? 2	* relates to terms they're exposed to in daily life * it is a fundamental point of reference/property of a wave as it can define quantity other properties i.e. colour of light/if it can pass through certain objects etc. * needed in wave equation.	* relates to sound and radios which they use every day * relates to other topics i.e. motion or ticker timers. * needed in wave equation
What concepts needs to be taught before teaching this big idea? 3	* Distance (how to measure/convert) * What is a wave/points on a wave * How a wave propagotes * types of wave ~~[illegible]~~ i.e. wavelengh ~~of~~ in longitudinal vs transverse waves.	* what is 1 cycle/partial cycles as not always whole numbers * if calculating how to invert numbers * idea of converting 1/s to Hz and scientific notation.
What else do you know about this idea (that you do not intend learners to know yet)? 4	Initially how it can relate to depth/medium it travels through or how it can be maintained/altered or the specifics in terms of its connection to colour/diffractions/refractions (red vs. blue) etc. Wave equation yet will not be omitted (will be covered later)	* How it relates to sound (literally) we dont do longitudinal waves in detail.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	* interference constructive/deconstructive * How it actually combines (adds) and in some cases it cancels * relate it to real life – concerts/waves (water) or light	
Why is it important for learners to know this? 2	* relevant to everyday * reinforces ideas that certain things when they combine get bigger while others "clash" and get smaller	
What concepts needs to be taught before teaching this big idea? 3	* fundamentals of waves like amplitude/propagation/crests+troughs	
What else do you know about this idea (that you do not intend learners to know yet)? 4	* it can be really complicated like noise/antinodes/nodes * echoes can be influenced/sound clarity	

Figure 5.1: Pre-CoRe for Jessica pertaining to knowledge and skills related to curricular saliency

Her response to Prompt 1 was restricted to an awareness of the definition with no indication of further subordinate ideas. However, she linked the concept to other ideas in the curriculum in her response to Prompt 2. Furthermore, she mentioned important pre-concepts needed to understand wavelength and revealed rich content knowledge, linking wavelength to future concepts such as diffraction, medium and refraction. In her response to Prompt 4 for the key idea of wavelength, she showed evidence of logical scaffolding. As a result, her *knowledge about curricular saliency* of *wavelength* (key idea A) was considered **rich**.

The participant showed limited knowledge about *frequency* (key idea B) in her response to Prompt 1 because it was mainly definition-based and did not include the symbol or unit of measurement, the inverse relationship to wavelength, or how to determine frequency through the use of the speed equation. The knowledge revealed in her response to Prompt 2 and 3 was rich because she related frequency to the world around the learners by referring to sound and radios. She further showed an understanding of the relevance of scientific notation when teaching frequency. As mentioned, she indicated logical scaffolding in her response to Prompt 4 for the key idea of wavelength by stipulating that the wave equation would be covered at a later stage. However, she failed to include the wave equation under the key idea of frequency. As a result, her final score for her *knowledge about curricular saliency* for *frequency* was scored **adequate**.

The participant's response to Prompt 1 about the subordinate ideas related to superposition (key idea C) was adequate because she left out common ideas that one intends learners to know about the concept, i.e. the definition of superposition wave direction and mathematical examples. In her response to Prompt 2, she did not explain the purpose of knowing the key idea of superposition. She did, however, mention the important concepts to be taught before superposition in her response to Prompt 3 and displayed extended knowledge about nodes and antinodes, as seen in her response to Prompt 4. In view of this, I regard her overall *knowledge about curricular saliency* for *superposition* as **adequate**.

The participant indicated in the CoRe that she did not teach longitudinal waves in detail, but did not provide a reason. The participant mentioned that the school followed the IEB curriculum and the SAG document. She was aware that the SAG document differs from the CAPS document, meaning that it does not have waves as a standalone topic and is not examined at Matric level. It was evident that she had knowledge of the concepts that should be taught about the topic of waves and stated in her pre-interview (Electronic Appendix B) that it is important to include in lessons because waves are part of everyday life. This is in agreement with Fazio et al. (2008), who see waves as an important concept.

Knowledge and skills related to learners' understanding

Figure 5.2 presents the CoRe for Jessica pertaining to *knowledge and skills related to learners' understanding* (Prompts 5 to 7).

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
What is difficult to understand? 5	* Length of total wave vs. 1 cycle * Where wavelength can be measured from if not crest-crest trough-trough or rest → rest. * ½ or fractions of wavelengths as they can be difficult to determine * How we can measure it on something with a length so small i.e. light	* maths i.e. conversions. * its "similarity" to period * How it can have 2 units i.e. $\frac{1}{s}$ and Hz * the range in size
What do you consider easy or difficult in teaching this big idea? 6	* As above as if they struggle to understand this, they struggle to learn it as it doesn't make sense. * conversions and scientific notation in calculations i.e. nm → $\times 10^{-9}$ m * particles in phase. is often difficult for some learners	* If covered in motion it can be easy as already known * the similarity to period. Learners always mix them up.
Learner misconceptions		
What are the typical learner misconceptions on this big idea? 7	* Believe it only applies crest → crest trough → trough or rest to rest (can be measured) * 1 wave cycle vs a whole wave. * particles in phase * amplitude relates to wavelength ie big amplitude, big wavelength.	* Bigger numbers of frequency have Bigger/longer waves * Dont understand difference between period/frequency so period misconception start to apply i.e. only interested in whole wave cycles.

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously
What is difficult to understand? 5	* How waves combine & add or destroy each other especially on non-peak or trough points * the areas of total destructive interference
What do you consider easy or difficult in teaching this big idea? 6	* It can be easy to see how it happens on a rope * the actual combinations (especially if destructive) is confusing on non-peak or trough areas as often not nice values so difficult to relate to
Learner misconceptions	
What are the typical learner misconceptions on this big idea? 7	* Total destructive means the wave is no longer there i.e. it stops and starts again later * the interference is only seen on peaks vs peak or crest vs trough

Figure 5.2: Pre-CoRe for Jessica pertaining to knowledge and skills related to learners' understanding of science

The participant displayed *knowledge about learners' thinking* regarding the key idea of *wavelength.* She wrote appropriate aspects that learners find difficult in her response to Prompt 5, giving concrete examples such as how they find it difficult to distinguish between the total length of the wave versus the length of one wave cycle. She also suggested mathematical skills, such as measurement, as aspects that learners struggle with. This is seen in her response to Prompt 6. Jessica mentioned the most common misconceptions regarding wavelength. As a result, her knowledge of learners' understanding of this key idea was scored as **rich**.

The participant did not go into as much detail for the key idea of frequency. She mentioned valid subordinate ideas that learners find difficult in her response to Prompt 5, such as the unit and its meaning and conversions. When responding to Prompt 6, she recognised the difficulty of teaching frequency and period but did not mention other aspects that she considered difficult in teaching this idea, such as determining the number of waves. It was evident that the participant had knowledge of learners' misconceptions in her answer to Prompt 7. However, she left out the well-known misconception of learners believing frequency to be the same as the speed of a wave and that frequency is determined by factors other than the source of the wave. In light of this, her *knowledge about learners' understanding* in terms of the key idea of *frequency* was regarded as **adequate**.

In Jessica's responses to Prompts 5 and 6, she mentioned appropriate difficulties. She also illustrated rich knowledge about learners' misconceptions because she recognised two very common misconceptions. As a result, her overall *knowledge about learners' understanding* was considered **rich** for the key idea of *superposition.*

During the pre-interview with Jessica, she referred to the idea that different learners learn science differently, which illustrated that she considered learners and their prior knowledge. Furthermore, she acknowledged that it is of importance that the learners obtain the foundational concepts of a topic in the earlier grades upon which the Grade 10, 11 and 12 concepts are built. In the interview, the participant revealed that her biggest challenge with learners and teaching Physical Sciences revolved around two aspects. The first was that Physical Sciences is perceived as a difficult subject and the second is that learners who struggle in mathematics also tend to struggle in Physical Sciences. I am aware that these issues mentioned are generic and not topic-specific, but the participant was able to include topic-specific learner difficulties during the pre-interview. She revealed her knowledge about learner misconceptions regarding the three key ideas through the following responses when asked about such difficulties and misconceptions:

Wavelength:

> *…it is confusing because it can be measured anywhere... from crest to crest or trough to trough or from mid-point to mid-point. The fact that there is no strict set rule for it... it can… apply at any point along the wave as long as they [are] consecutive.*

Frequency:

> *They confuse it with period. The biggest mistake, they get them confused.*

Superposition:

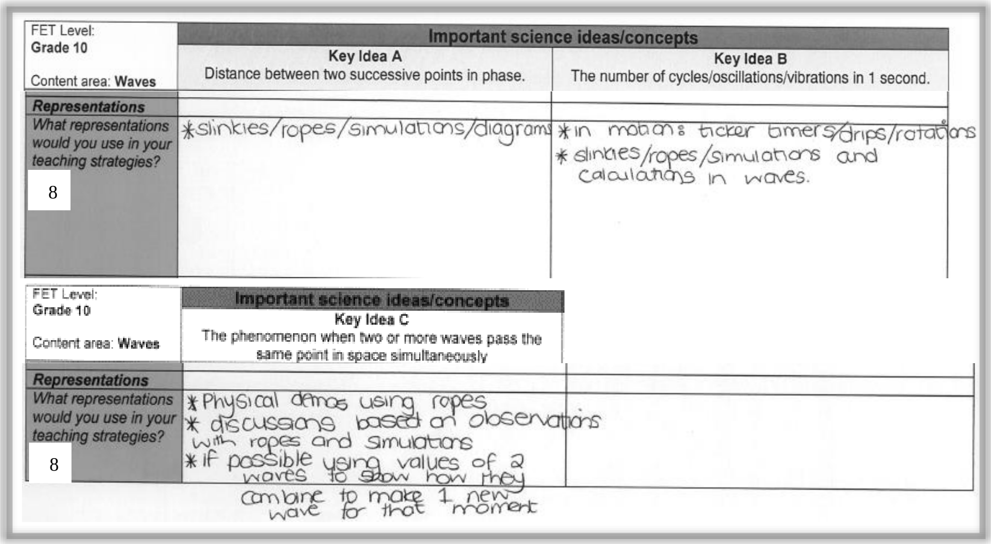
> *They struggle to see how they combine… if it is part of [a] wave and another part of a wave then… They don't really understand why it cancels out… Like why it will cancel out and appear on the other side. They believe that it wouldn't do that. That it would just cancel out and not start again.*

Knowledge and skills related to conceptual teaching strategies

Knowledge and skills related to conceptual teaching strategies includes prompts relating to representations and teaching strategies and, as in the framework, is discussed in two sections. The first will explain the prompts relating to *representations* because the sub-questions of this study relate to the teachers' *knowledge about representations*, and the second section will explain the component of *teaching strategies*.

Knowledge and skills related to representations

Figure 5.3 displays the data collected in the CoRe regarding the *knowledge and skills related to representations* (Prompt 8) for Jessica.



FET Level: Grade 10 Content area: **Waves**	Important science ideas/concepts **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Representations *What representations would you use in your teaching strategies?* 8	*slinkies/ropes/simulations/diagrams	*in motion: ticker timers/drips/rotations *slinkies/ropes/simulations and calculations in waves.

FET Level: Grade 10 Content area: **Waves**	Important science ideas/concepts **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously
Representations *What representations would you use in your teaching strategies?* 8	*Physical demos using ropes *discussions based on observations with ropes and simulations *if possible using values of 2 waves to show how they combine to make 1 new wave for that moment

Figure 5.3: Pre-CoRe for Jessica pertaining to knowledge and skills related to representations

Her knowledge of representations was scored **limited** for the key idea of *wavelength* because the participant gave non-specific examples of representations, i.e. not stipulating which diagram she would use. Although, as with the key ideas of *frequency* and *superposition*, other representations were mentioned over and above the traditional representations of a slinky spring and simulations. As such, her TSPCK level for these two key ideas was scored **adequate**. I believe that a teacher with rich PCK would explain how they would use the representations, even if not explicitly asked.

In the pre-interview, I asked if Jessica believed in using hands-on apparatus during the lesson. The participant remarked:

> *If we can, we will let them do as many hands-on experiments as possible. There are some that we can't… because of lack of equipment or it's quite dangerous. Then…we will take those over [Explanatory note: the teacher would then do a demonstration].*

The participant was then asked the following question: "During that allocated practical time that you talk of, what percent of a lesson would you use simulations, apparatus and textbook images?" The following response was given:

> *Usually, in the practicals its proper experiments. So, we will give them the breakdown. If we do need to show simulation[s], that won't necessarily be done in the pracs, that is usually involved in the actual theory… especially if we didn't get an ideal result.*

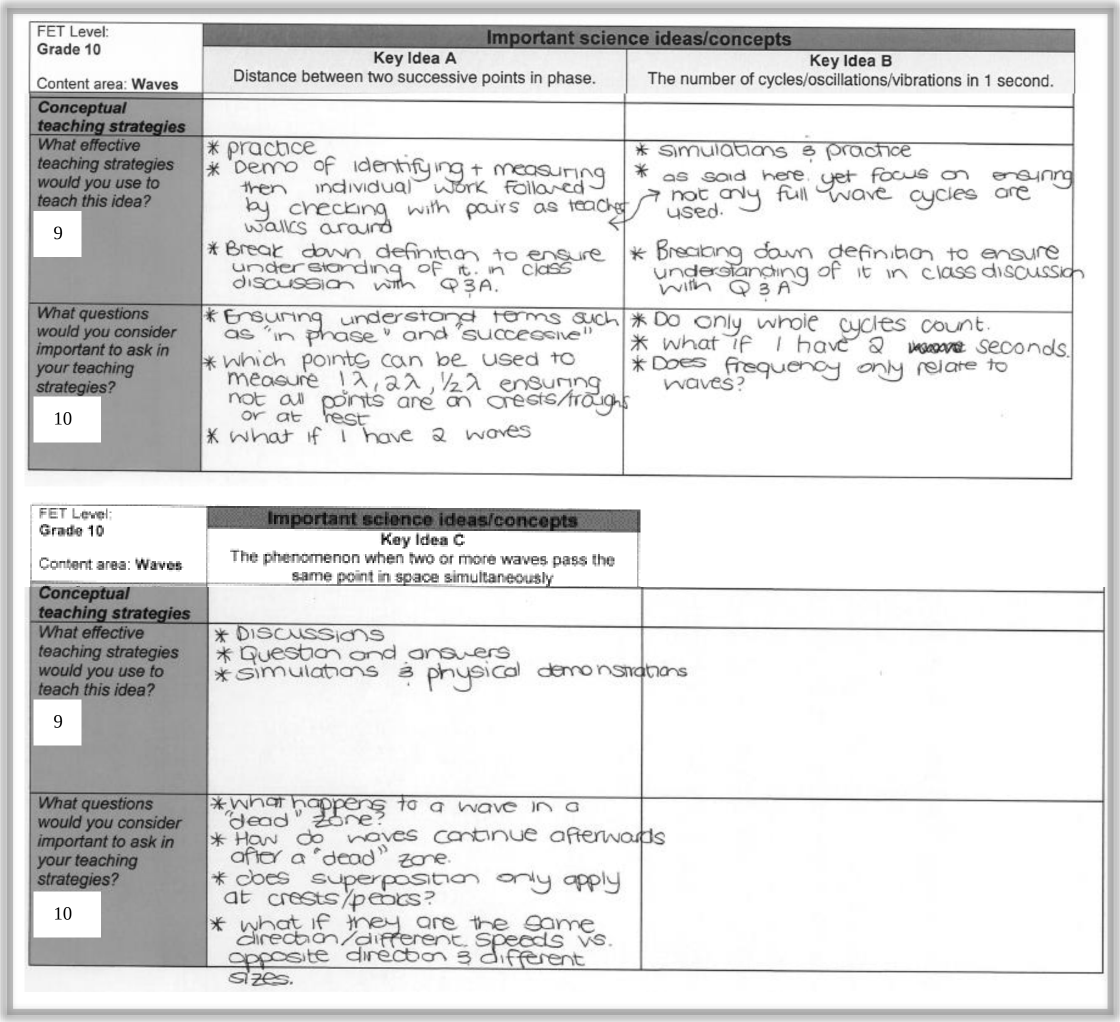
Lastly, in response to the question: "Currently teaching Grade 10, what resources do you usually use to teach and illustrate waves?" The participant responded as follows:

> *…we have light boxes… a lot of the properties like reflection, refraction, diffraction… can be illustrated using the light kit…If not the light kit, it is the ripple tank although that has its big flaws…It is very difficult sometimes to see the actual waves on the ripple tank because of various things… there is also a lot of interference… with the light kits it is easier to see that but obviously the ripple tank is nice because you can also see the actual crests and troughs where with light you can't.*

From the responses above, one can conclude that Jessica believed in using hands-on activities during the lesson but chose when to conduct such an activity based on the availability of equipment or based on how dangerous the experiment may be. She indicated that she currently used the light kit in class but recognised its limitations when teaching certain concepts in the topic of waves. The participant highlighted her concern regarding the ripple tank. However, this changed as she became more enthusiastic about the apparatus through the course of the intervention (see Chapter 4).

Knowledge and skills related to conceptual teaching strategies

The participant's knowledge of conceptual teaching strategies was revealed in her responses to Prompts 9 and 10, as seen in Figure 5.4.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts	
	Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	* practice * Demo of identifying + measuring then individual work followed by checking with pairs as teacher walks around * Break down definition to ensure understanding of it. in class discussion with Q3A.	* simulations & practice * as said here. yet focus on ensuring not only full wave cycles are used. * Breaking down definition to ensure understanding of it in class discussion with Q 3 A
What questions would you consider important to ask in your teaching strategies? 10	* Ensuring understand terms such as "in phase" and "successive" * Which points can be used to measure 1λ, 2λ, ½λ ensuring not all points are on crests/troughs or at rest * What if I have 2 waves	* Do only whole cycles count. * what if I have 2 seconds. * Does frequency only relate to waves?

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts	
	Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	* Discussions * Question and answers * simulations & physical demonstrations	
What questions would you consider important to ask in your teaching strategies? 10	* what happens to a wave in a "dead" zone? * How do waves continue afterwards after a "dead" zone. * does superposition only apply at crests/peaks? * what if they are the same direction/different speeds vs. opposite direction & different sizes.	

Figure 5.4: Pre-CoRe for Jessica pertaining to knowledge and skills related to conceptual teaching strategies

For the key idea of *wavelength,* the participant's conceptual teaching strategies was regarded as **limited to adequate** because a logical sequence was not evident in her teaching strategies. However, this may be because she was not paying attention to sequencing while writing down her response to Prompt 9. The participant formulated questions to help with learners' conceptual understanding about wavelengths, but the questions did not require higher-order thinking skills.

For both the key ideas of *frequency* and *superposition*, again, the participant did not show evidence of logical sequencing in her strategies. However, she illustrated good knowledge in formulating important questions to stimulate conceptual understanding that require higher-order thinking skills. In light of this, her conceptual teaching strategies for both key ideas was rated **adequate**.

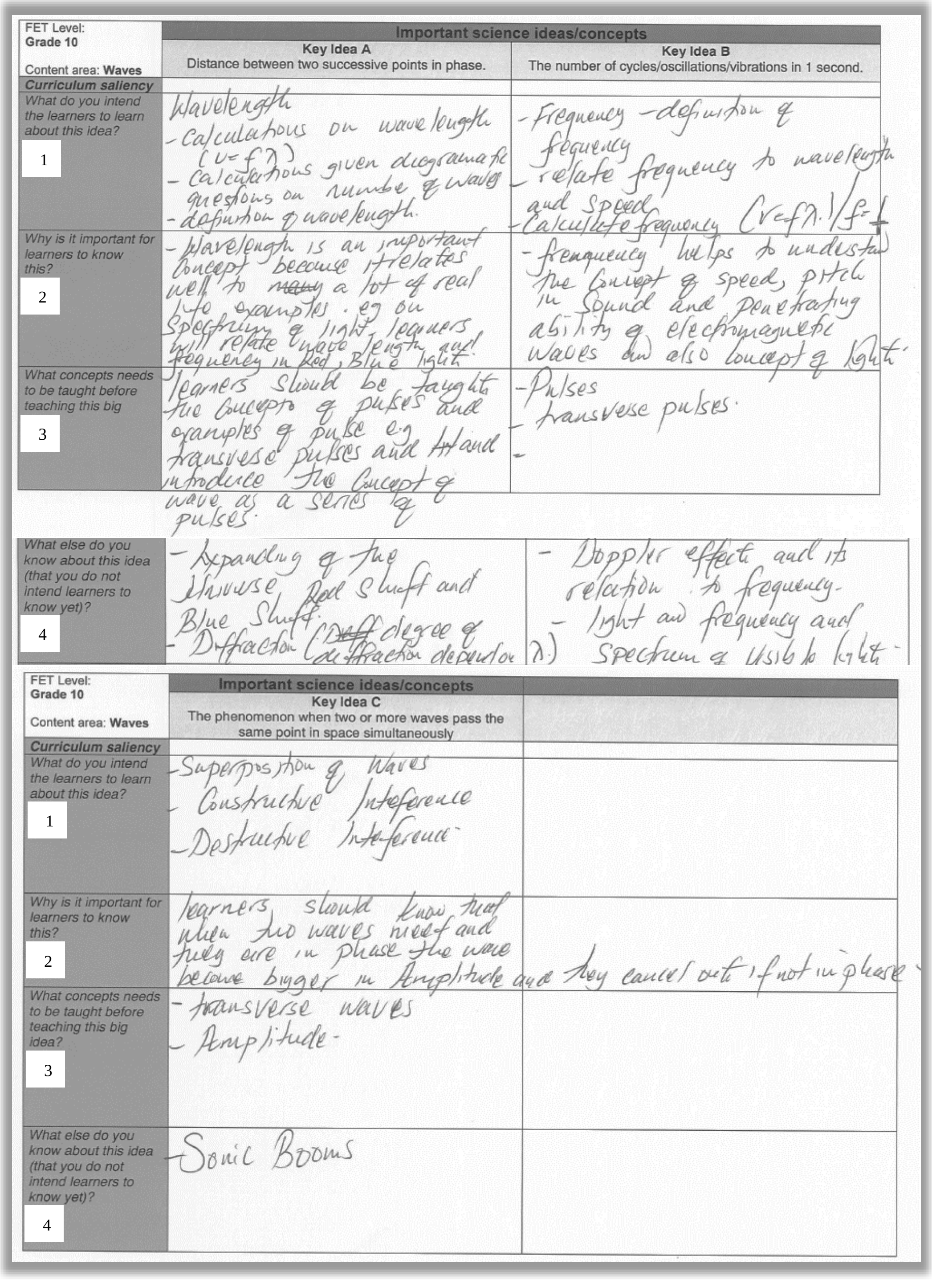
Her planned conceptual teaching strategy that was revealed during her pre-interview (Electronic Appendix B) is presented in Appendix XI. This information is relevant when observing the participant teaching the topic of waves. This is further addressed and discussed in Chapter 6.

5.2.2 Case Study 2 – Tshuma

Tshuma holds a Bachelor Degree in Education majoring in Chemistry, and has a Bachelor Degree in Psychology and does not speak English as a first language. At the time of this study, he had 15 years of experience in teaching Grade 10 Physical Sciences. The figures that follow present the pre-CoRe constructed by Tshuma, while the levels assigned to these prompts are summarised in Table 5.4.

Knowledge and skills related to curricular saliency

The CoRe constructed by Tshuma pertaining to *knowledge and skills related to curricular saliency* (Prompts 1 to 4) can be seen in Figure 5.5 below.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	Wavelength - Calculations on wave length ($v=f\lambda$) - Calculations given diagramatic questions on number of waves - definition of wavelength.	- Frequency - definition of frequency - relate frequency to wavelength and speed - Calculate frequency ($v=f\lambda$)/f=
Why is it important for learners to know this? 2	- Wavelength is an important concept because it relates well to a lot of real life examples. eg on Spectrum of light, learners will relate wave length and frequency in Red, Blue light.	- frequency helps to understand the concept of speed, pitch in sound and penetrating ability of electromagnetic waves and also concept of light.
What concepts needs to be taught before teaching this big 3	learners should be taught the concepts of pulses and examples of pulse e.g transverse pulses and and introduce the concept of wave as a series of pulses.	- Pulses - transverse pulses. -
What else do you know about this idea (that you do not intend learners to know yet)? 4	- Expanding of the Universe, Red shift and Blue shift. - Diffraction (degree of diffraction depends on λ)	- Doppler effect and its relation to frequency. - light and frequency and spectrum of visible light.

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	- Superposition of Waves - Constructive Interference - Destructive Interference	
Why is it important for learners to know this? 2	learners should know that when two waves meet and they are in phase the wave become bigger in Amplitude and they cancel out if not in phase.	
What concepts needs to be taught before teaching this big idea? 3	- transverse waves - Amplitude	
What else do you know about this idea (that you do not intend learners to know yet)? 4	- Sonic Booms	

Figure 5.5: Pre-CoRe for Tshuma pertaining to knowledge and skills related to curricular saliency

Tshuma's response to Prompt 1 illustrates an uncommon sequencing, with the definition of wavelength only being mentioned at the end of his response. However, he identified the suggested key idea as wavelength, and mentioned the important calculations relevant to wavelength. He gave everyday examples in his Prompt 2 response, i.e. the spectrum, red and blue light shift. However, in his response to Prompt 3, the pre-concepts were limited to only the idea of a pulse. Tshuma's response to Prompt 4 mentioned two aspects regarding red and blue shift and diffraction, but did not mention forthcoming ideas in the curriculum relevant to Grade 10, i.e. the wave equation and/or the wave speed. In view of this, the final score for the concept of *wavelength* pertaining to *knowledge about curricular saliency* was considered **adequate**.

Tshuma used a similar approach in his responses regarding the concept of frequency. His response to Prompt 1 included the key idea and its relationship to wavelength, but not to the subordinate idea of period. His response to Prompt 2 revealed sequential development, as well as his appreciation of the learners' understanding of the world around them in relation to future concepts in the curriculum. However, his response to Prompt 3 was limited again to the idea of pulses. He had a good understanding of what else would be required for the learners to understand, and that which they do not yet understand. He indicated this by mentioning concepts such as the Doppler Effect and visible light. As a result, considering the first and second principle employed when scoring (see Table 5.1), I scored the participant as having **adequate** *knowledge about the curricular saliency* regarding *frequency.*

The final score for the concept of *superposition* pertaining to the *knowledge about curricular saliency* was scored **limited to adequate**. His response to Prompt 1 was limited to only the two main subordinate ideas of superposition and had no reference to real life application, i.e. sound. Tshuma's response to Prompt 2 was merely a repetition of the key idea. However, although his responses to Prompt 1 and 2 were restricted, he included the idea of a transverse wave and the amplitude that learners need to understand before the key idea is taught, which were relevant responses to Prompt 3. In addition, his response to Prompt 4 regarding 'sonic booms' is a phenomenon relevant to superposition.

During the pre-interview, the participant further revealed his knowledge of curricular saliency by explaining that he saw waves as an important topic within the Physical Sciences curriculum. It is evident that he recognised the importance of the Grade 10 foundational concepts because it is upon these concepts that the more complicated concepts in Grade 11 (light and diffraction) and 12 (Doppler Effect) are built. This would allow correct learner conceptual development. As such, his response was in line with his **adequate** curricular saliency knowledge score (see Table 5.4).

Knowledge and skills related to learners' understanding

The CoRe constructed by Tshuma pertaining to *knowledge and skills related to learner understanding* (Prompts 5, 6 and 7), which includes learners' thinking and misconceptions, is presented in Figure 5.6.

His response to Prompt 5 regarding wavelength mentioned calculations as an aspect that learners find difficult, but included two step calculations involving frequency, which is the next key idea. Frequency would not be understood at the point of teaching wavelength. The participant mentioned appropriate learner difficulties in his response to Prompt 6, but failed to mention common misconceptions for the idea of wavelength. In view of this, I scored his knowledge of learners' understanding of *wavelength* as **adequate**.

For the key idea of *frequency*, in response to Prompt 5, he was not specific about why learners find $f = \frac{1}{T}$ challenging. In his response to Prompt 6, he recognised appropriate difficulties. His response to Prompt 7 mentioned the misconception of frequency and period, but did not include other relevant examples such as misconceptions based around the ideas of frequency and speed, the wave equation, and which variables remain constant when the medium remains unchanged. Therefore, the knowledge revealed about learners' understanding for this component was considered **adequate**.

The participant revealed **limited** knowledge of learners' understanding about the key idea of *superposition*. For both Prompts 5 and 6, Tshuma's responses did not include points such as how a wave continues in terms of its direction and amplitude after interference. He repeated the key idea for Prompt 6. Although his response to Prompt 7 suggested that learners have problems with the direction of the pulses after interfering, other common misconceptions were omitted.

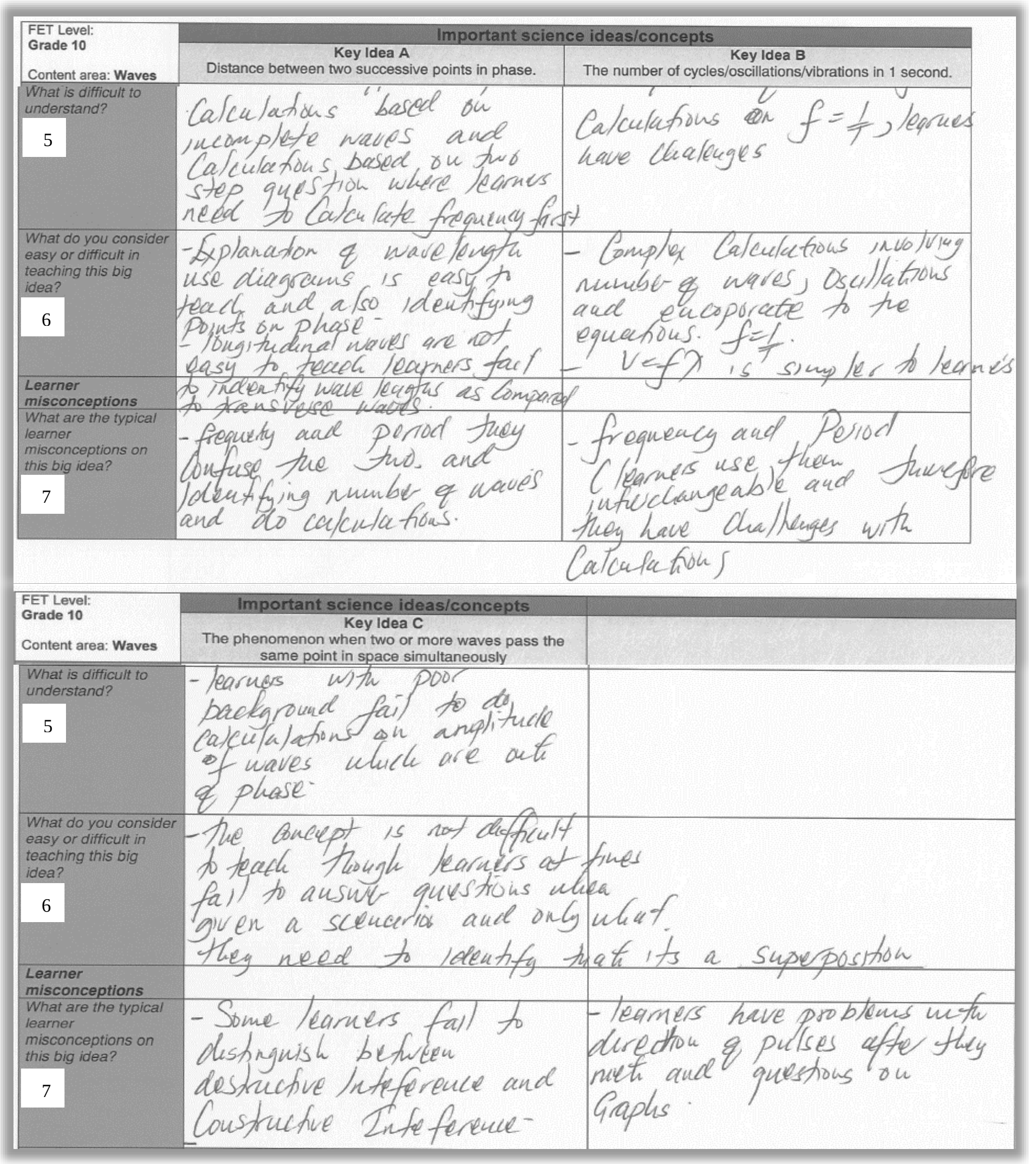
In the pre-interview, the participant revealed his belief in carrying out practicals in the following remark:

> *…they… learn best by being involved, by doing practicals. "I do, I remember"… In science… they should be involved.*

During his pre-interview, Tshuma briefly discussed the problems that learners have in terms of the three key ideas. For the concept of wavelength, he indicated the following:

> *…there is a problem with calculations of wavelengths…when… it's a half wave… when it is not complete, they cannot calculate [the] number of waves. Then it is not easy for them to calculate wavelength.*

However, through his response, I do believe he had started talking about the concept of frequency rather than wavelength.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
What is difficult to understand? 5	Calculations based on incomplete waves and Calculations based on two step question where learners need to Calculate frequency first	Calculations on $f = \frac{1}{T}$, learners have challenges
What do you consider easy or difficult in teaching this big idea? 6	- Explanation of wavelength use diagrams is easy to teach and also identifying Points on phase. - longitudinal waves are not easy to teach learners fail to indentify wave lengths as compared to transverse waves.	- Complex Calculations involving number of waves, Oscillations and encoporate to the equations. $f = \frac{1}{T}$. - $V = f\lambda$ is simpler to learners
Learner misconceptions		
What are the typical learner misconceptions on this big idea? 7	- frequency and period they confuse the two. and Identifying number of waves and do calculations.	- frequency and Period (learners use them interchangeable and therefore they have challenges with Calculations

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
What is difficult to understand? 5	- learners with poor background fail to do calculations on amplitude of waves which are out of phase.	
What do you consider easy or difficult in teaching this big idea? 6	- The concept is not difficult to teach though learners at times fail to answer questions when given a scenario and only what they need to identify that its a superposition	
Learner misconceptions		
What are the typical learner misconceptions on this big idea? 7	- Some learners fail to distinguish between destructive Interference and Constructive Interference.	- learners have problems with direction of pulses after they meet and questions on Graphs.

Figure 5.6: Pre-CoRe for Tshuma pertaining to knowledge and skills related to learners' understanding

When further asked about the concept of frequency, he indicated that learners tended to confuse the concepts of frequency and period.

For the concept of superposition, he revealed the following:

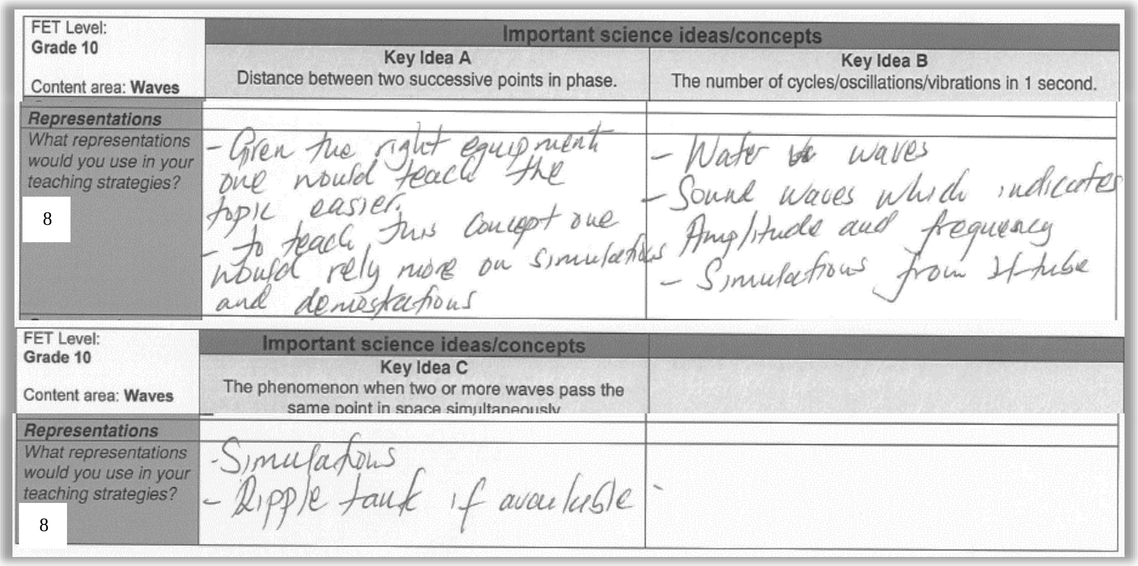
> *…superposition… they always enjoy it. I haven't had any problems with it per se while in class… because I always demonstrate first and then… it is easy for them.*

The responses about wavelength and frequency mention the common misconceptions that learners possess for both concepts. However, his response regarding superposition illustrates his limited knowledge as the common misconceptions were not mentioned. His responses support the final TSPCK scores given for his *knowledge about learner understanding* for the three key ideas (Table 5.4).

Knowledge and skills related to conceptual teaching strategies

Knowledge and skills related to representations

The data collected in the CoRe in relation to *knowledge and skills related to representations* (Prompt 8) is displayed in Figure 5.7.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Representations What representations would you use in your teaching strategies? 8	- Given the right equipment one would teach the topic easier. - To teach this concept one would rely more on simulations and demonstrations	- Water waves - Sound waves which indicates Amplitude and frequency - Simulations from YouTube

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Representations What representations would you use in your teaching strategies? 8	- Simulations - Ripple tank if available	-

Figure 5.7: Pre-CoRe for Tshuma pertaining to knowledge and skills related to representations

The participant's responses to the prompt about representations regarding *wavelength* referred to "the right equipment" but did not specify what equipment would be used or specified what demonstrations would be carried out.

Although more specific examples were given for the key idea of *frequency,* i.e. sound waves, he did not elaborate how he would generate and employ the sound waves to illustrate the idea of amplitude and frequency. In view of giving non-specific examples, for both key ideas I scored his *knowledge about representations* as **limited**.

For the key idea of *superposition,* he named the ripple tank as apparatus that he planned to use to demonstrate the concept. However, he was not specific about how he would use the ripple tank or what simulations he would utilise. As a result, I considered his *knowledge about representations* for this key idea as **adequate**.

During his interview, I asked: “What type of activity or support events would help you grow in your science knowledge?”

> *I would need more experiments, more practical's…that is what is lacking in my school and in my teaching…If I can have all the… necessary equipment… I need now a lot of apparatus. There are a lot of ones [equipment] I don't know how to use, if I can be having those…then it is going to help me grow a lot.*

His response shows that he acknowledged that he did not often carry out practical lessons and that one of the reasons was due to a lack of equipment.

When further asked what he saw as important to do or have to teach Physical Sciences effectively, he responded as follows:

> *Learning aids. I always use course charts and then…enough apparatus, experiments, equipment. That one goes in hand with my presentations and then books with activities…*

His response indicated that he was aware that teaching science effectively is done with a variety of resources, despite not necessarily having the resources at hand. As such, I followed this up by asking whether he believed in using hands-on apparatus during the lesson and, if so, to elaborate how often within a week he conducted lessons with apparatus. The participant responded:

> *Unfortunately, I do not do it often because of the… situation of our school. It is not easy to do it often because we don't have a laboratory there, but I believe in this one. If all the laboratories [were available] then twice or so a week or in the afternoons, especially Grade 12, [we] do it in the afternoons… After school because that is when I do my formal experiments with the Grade 12's… During the day I cannot because it is one period.*

This response again revealed that he lacked apparatus. However, despite this, Tshuma believed in a 'hands-on' approach. He further revealed that he did not often carry out such lessons due to a shortage of time. He explained that the lesson time was too short to complete a practical and he was therefore forced to do practical's after school.

Knowing that he lacked apparatus, I probed further regarding what resources he relied on to teach and illustrate the topic of waves. He stated:

> *Our ripple tank is not functioning. So mostly I rely on my YouTube, [and] on simulations from my YouTube.*

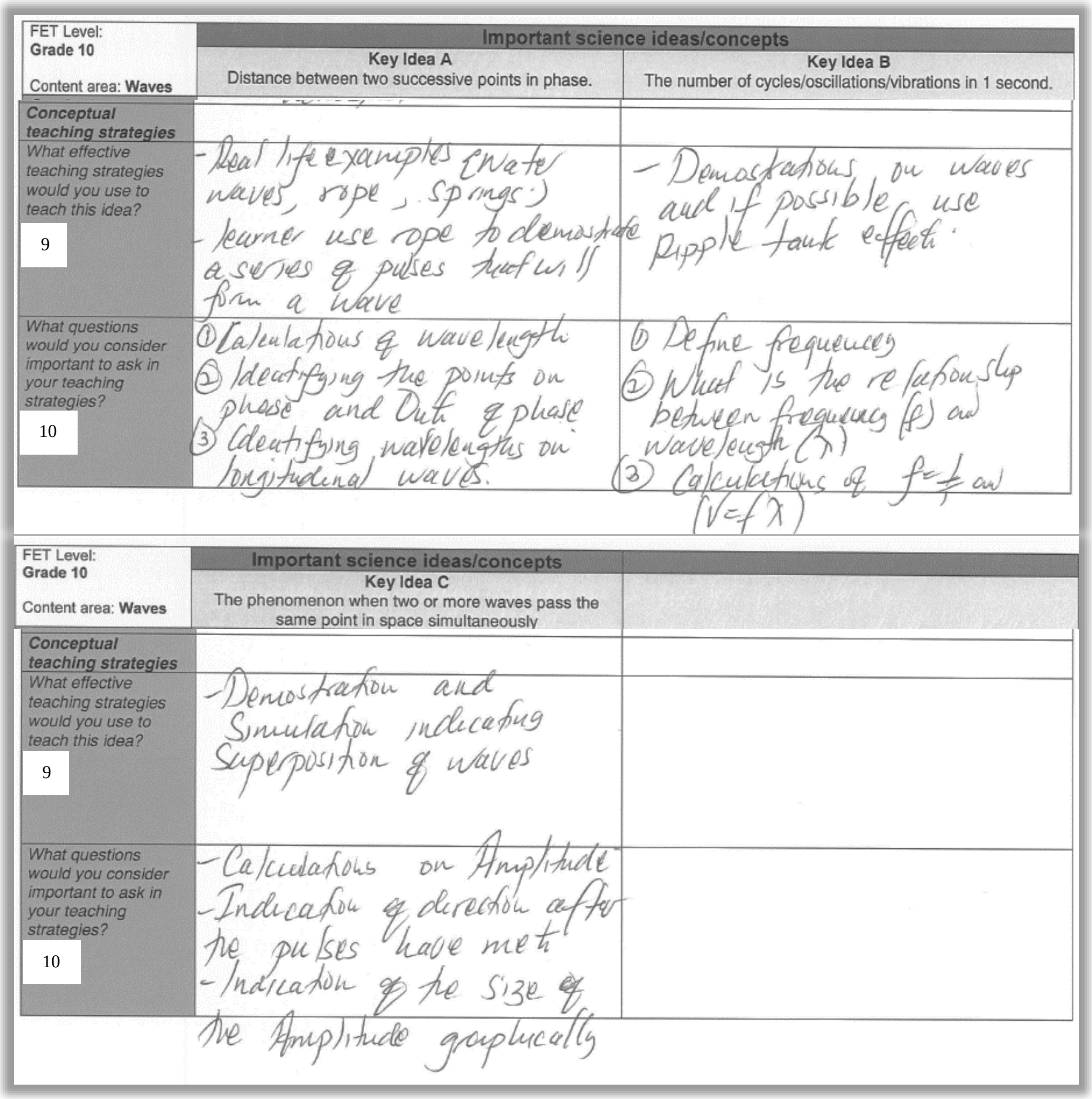
The participant, although realising the importance of practical work, did not carry out many practical lessons due to a lack of apparatus, laboratory space and time, therefore resorting to other forms of visualisation to teach the topic of waves.

Knowledge and skills related to conceptual teaching strategies

The participant's *knowledge of conceptual teaching strategies* was revealed in his responses to Prompts 9 and 10, as seen in Figure 5.8.

In his response to Prompt 9 for the concept of *wavelength*, he mentioned real-life examples, but did not say which real-life examples. He mentioned using a rope, however, a rope is not the best item to use because one cannot observe a full wavelength due to the friction it experiences along the ground. His response to Prompt 10 lacked logical sequencing and was more related to instruction rather than conceptual development. In view of this, I scored his strategy as **limited**.

In his responses to Prompt 9 for the key ideas of *frequency* and *superposition*, Tshuma mentioned demonstration but did not indicate further strategies that could be used to teach the concept. In addition, stating "demonstrations on waves" does not have weight since he explicitly said and acknowledged during his pre-interview that he did not carry out practicals. His responses to Prompt 10 included questions that would lead to conceptual development. For the key idea of superposition, he also revealed poor sequencing. Therefore, his conceptual teaching strategy for both key ideas was scored as **limited**.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	- Real life examples (Water waves, rope, springs) - learner use rope to demonstrate a series of pulses that will form a wave	- Demonstrations on waves and if possible use Ripple tank effect.
What questions would you consider important to ask in your teaching strategies? 10	① Calculations of wavelength ② Identifying the points on phase and Out of phase ③ Identifying wavelengths on longitudinal waves.	① Define frequency ② What is the relationship between frequency (f) and wavelength (λ) ③ Calculations of $f = \frac{1}{T}$ and ($v = f\lambda$)

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	- Demonstration and Simulation indicating Superposition of waves	
What questions would you consider important to ask in your teaching strategies? 10	- Calculations on Amplitude - Indication of direction after the pulses have met - Indication of the size of the Amplitude graphically	

Figure 5.8: Pre-CoRe for Tshuma pertaining to knowledge and skills related to conceptual teaching strategies

During the pre-interview when I asked the participant in what ways he would describe his approach to science teaching, and therefore his conceptual teaching strategy, he responded with the following statement:

> *Science is to me, is about exploring. It is not about content it is about exploring… compared to just feeding the learners…they need to explore and understanding and the world around us…Not just to be taught.*

Although the participant emphasised the idea of allowing learners to explore in order to stimulate conceptual understanding, he had previously admitted that he did not carry out a lot of practical work in lessons and did not reveal any evidence that he knew how to approach 'exploration'. Tshuma's planned conceptual teaching strategy that was revealed during his pre-interview (Electronic Appendix C) is presented in Appendix XI. This information is relevant when observing the participant teaching the topic of waves. The conceptual teaching strategies that he carried out in the classroom environment while I was observing his lessons is further discussed in Chapter 6.

5.2.3 Case Study 3 – Craig

Craig holds a Bachelor of Science Honours degree and a Master's degree in sustainable agriculture and does not speak English as his first language. At the time of the study, he had nine years of Grade 10 Physical Sciences teaching experience. The figures that follow present the pre-CoRe constructed by Craig, while the levels assigned to these prompts are summarised in Table 5.4.

Knowledge and skills related to curricular saliency

Figure 5.9 displays the CoRe constructed by Craig pertaining to *knowledge and skills related to curricular saliency* (Prompts 1 to 4).

Craig’s *knowledge about curricular saliency* for *wavelength* was scored **limited**. The participant failed to mention the name, unit and symbol of the physical quantity referred to in the key idea in his response to Prompt 1, which is of importance when it is a new topic to learners. His response to Prompt 2 was restricted to the general benefit of education with no reference to real-life applications. The participant had an adequate response to Prompt 3 because he followed a logical sequence of definitions, different types of waves, and the structure of a wave with labels. However, he did not specify the terms such as crest, trough and rest position. Craig’s response to Prompt 4 revealed his own misconception and therefore poor conceptual understanding by stating that in-phase points also undergo destructive interference.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
What do you intend the learners to learn about this idea? 1	- Learners should be able to understand what it means when points on a waves are in-phase or out of phase - They should be able to identify points which are in phase and out of phase -	- Learners should be able to identify a complete wave cycle and the time it takes for it to be complete
Why is it important for learners to know this? 2	- It is important because it will be easier for the learners to determine the wavelength from a wave. - It will help in the calculation of the wave speed.	- Learners should know the relationship between frequency and period and be able to do the calculations given one of the variables
What concepts needs to be taught before teaching this big idea? 3	- Different types of waves and definitions of important terms. - the structure of a wave and labelling different parts.	- Definitions of different ~~types~~ of terms in waves such as frequency and period
What else do you know about this idea (that you do not intend learners to know yet)? 4	- When points are in phase, they are at the same position at the same time. - Waves which meet when in phase can construct or destruct each other.	- number of vibrations in a second determines the speed of a particular wave.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	- learners should be able to understand what it means when waves are in phase or out of phase. - understand the concept of constructive and destructive interference and their effects on the amplitude..	
Why is it important for learners to know this? 2	- learners should have an idea on what happens when wave interact as this concept will be necessary in future topics.	
What concepts needs to be taught before teaching this big idea? 3	- They should understand definitions of in phase and out of phase. - Knowledge of positive and negative direction of the waves are on different sides.	
What else do you know about this idea (that you do not intend learners to know yet)? 4	- If both waves have a positive or negative amplitude they build each other but positive and negative they cancel each other.	

Figure 5.9: Pre-CoRe for Craig pertaining to knowledge and skills related to curriculum saliency

For the concept of frequency, he again did not include the name of the physical quantity, its symbol or unit in his response to Prompt 1. He stated what should be known but not why this knowledge is important. In his response to Prompt 2, he highlighted the importance of knowing the relationship between frequency and period, but again, made no mention of real-life application. His response to Prompt 3 mentioned the terms frequency and period, but did not elaborate on the subordinate ideas such as the propagation of a wave. His response to Prompt 4 revealed a classic misconception, namely, the number of vibrations per second determines the speed of the wave. Considering this, his *knowledge about curricular saliency* in terms of the key idea of *frequency* was considered **limited**.

His responses to the prompts about the concept of *superposition* revealed that Craig had knowledge of this key idea, relating it to the important subordinate ideas of constructive and destructive interference, and the effect of interference on amplitude. Although in his response to Prompt 2 he acknowledged future topics based on this key idea, he did not state any examples. He mentioned pre-concepts that are required to understand superposition, such as in and out of phase, but did not relate the concept to other relevant ideas of sound or light in his response to Prompt 4. As a result, I scored his knowledge of curricular saliency on this key idea as **limited to adequate**.

During the pre-interview, the participant revealed the challenges he had in the classroom when teaching Physical Sciences:

> *Because the curriculum… is loaded… time to do practical work is so, so, so limited. It is very, very limited, and that's a cause for concern... but where we are able to do it, we are doing it but not the way we want.*

This response indicates that one of his main concerns about teaching Physical Sciences is how much content makes up the Physical Sciences curriculum. As a result, this impacted the number of practical lessons he could conduct and the depth in which the practicals could be carried out.

Knowledge and skills related to learner understanding

Figure 5.10 presents the CoRe for Craig pertaining to *knowledge and skills related to learner understanding* (Prompts 5 to 7).

Craig’s responses pertaining to Prompts 5, 6 and 7 for the concept of *wavelength* justified a final score of **adequate** for his *knowledge about learners’ understanding*. His responses to all three prompts were centred on in-phase and out of phase points on a wave. His response to Prompt 6 suggests that he experienced the teaching of points that are in-phase to be confusing. He mentioned and clearly formulated concepts that learners find difficult and what he found difficult to teach. Additionally, he listed two learner misconceptions, such as: *all* points on the same level are perceived to be in-phase, and how learners often fail to recognise complete waves.

For the concept of *frequency*, the knowledge revealed about learners’ understanding was considered **adequate**. Craig’s responses were focused on the idea of the number of cycles, which he believed is an idea that learners find difficult to understand (Prompt 5) and is thus difficult to teach.

Although the participant only gave one example in his response to Prompt 5 for the key idea of superposition, he mentioned relevant difficulties in his response to Prompt 6, such as calculations and the direction of waves. However, it is unclear what he meant by *direction* of waves. For the purpose of trying to understand his response, it is taken as the crests and troughs above and below the rest position. In his response to Prompt 7, he mentioned two common misconceptions that learners have: believing that waves do not act independently to one another and that they do not retain their amplitudes after interference. As such, his final score for his *knowledge about learners’ understanding* for *superposition* was **adequate**.

In the pre-interview when the teacher was asked how he thought learners learn science best, Craig responded by saying that he believes that learners’ understanding is better achieved through the use of representations. In the pre-interview, I further probed to discover what the participant believed were the ideas that learners find most difficult and what misconceptions they possess about each idea. He indicated that learners have problems determining wavelength since they do not know where the wave starts, and fail to recognise where it "repeats itself". For the concept of frequency, he mentioned that learners confuse frequency and period and, according to him, learners also confuse these two concepts with amplitude. He had the following response regarding the concept of superposition:

…the difficulties… is the direction of the waves…Are they all in phase or out of phase or… is its positive amplitude and negative amplitude? Are they cancelling or adding each other?

The responses further reveal that he had knowledge of the common misconceptions that learners have about each key idea. This supports the **adequate** knowledge revealed in the CoRe about learners' understanding for all three key ideas (Table 5.4).

FET Level: Grade 10 Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
What is difficult to understand? 5	- Identification of ~~[illegible]~~ points which are in phase and out of phase.	- Determining the number of cycles especially when there is a cycle which is not complete. -
What do you consider easy or difficult in teaching this big idea? 6	- It is easy to show the points which are out of phase but those in phase can be a bit confusing to the learners.	- Learners can easily calculate the number of cycles per second given the number of cycles over a period of time.
Learner misconceptions *What are the typical learner misconceptions on this big idea?* 7	- If two points are on the same level are in phase and not checking if the wave is complete.	- Any complete cycle takes place after every second.

FET Level: Grade 10 Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
What is difficult to understand? 5	- If two waves are not on one side they cancel each other	
What do you consider easy or difficult in teaching this big idea? 6	- It is difficult to calculate the new amplitude during destructive interference because learners forget to consider the direction	
Learner misconceptions *What are the typical learner misconceptions on this big idea?* 7	- Waves act independently and they do not have influence on each other. - Waves will not retain their amplitudes after the interference	

Figure 5.10: Pre-CoRe for Craig pertaining to knowledge and skills related to learners' understanding

Knowledge and skills related to conceptual teaching strategies

Knowledge and skills related to representations

Figure 5.11 presents the CoRe constructed by the participant in relation *to knowledge and skills related to representations* (Prompt 8).

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Representations *What representations would you use in your teaching strategies?* 8	- Simulations from different sources - charts - textbooks - Previous question papers	- simulations - charts - textbooks - previous question papers.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
What representations would you use in your teaching strategies? 8	-Simulations - textbooks - previous question paper.	

Figure 5.11: Pre-CoRe for Craig pertaining to knowledge and skills related to representations

For all three key ideas, Craig merely listed representations such as simulations from different sources and charts. He was not specific about their use. As such, his *knowledge about representations* for all three key ideas was scored as **limited**.

During his pre-interview the participant revealed that he believed that learners better understand and remember the theory of a concept if they are exposed to visualisations. However, in his statement, he referred to an example in chemistry regarding exothermic reaction. This possibly shows that he did not have an example of visualisation relevant to the topic of waves, which may indicate that he had never used visualisations for this topic.

However, he also revealed that he did not make use of practical lessons very often through the following statement:

> *Most of the time… for practical's, we end up using simulations, just going on YouTube… put them on the screen… quick and easy… most of our time is [using] simulations, then a textbook. Like hands on… [it] is taking [a] smaller percentage [of lessons].*

Therefore, when I followed up with a question regarding what he was currently using to teach waves, he reiterated that he mainly used simulations and textbooks. To further probe his reasoning, I asked him whether he found that the CAPS curriculum allowed him time to do all the experiments, to which he replied:

> *The CAPS curriculum is loaded… covering the curriculum… it is exceedingly difficult… to have all the experiments and stuff, unless… if [we] do a lot of extra classes… after school.*

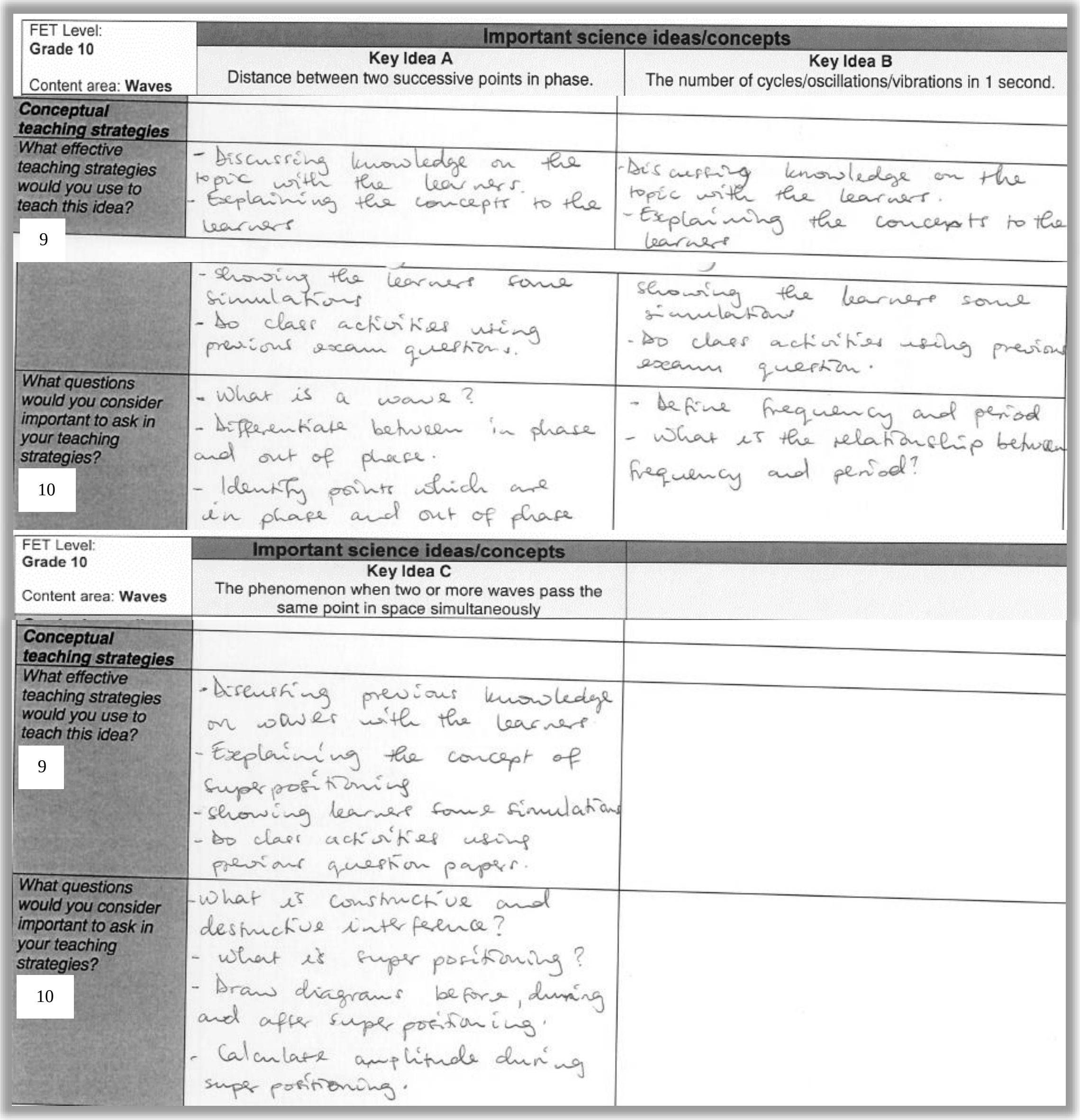
The responses above suggests that the participant believed in using visualisations to help learners better understand and remember theory, but had not made use of such visualisations. This is in line with the **limited** score given for his knowledge of representations in the pre-CoRe. He again elaborated that it is because of the demanding CAPS curriculum that he was unable to make time for a more hands-on approach in his lessons.

Knowledge and skills related to conceptual teaching strategies

Craig's *knowledge of conceptual teaching strategies* was revealed in his responses to Prompts 9 and 10, as seen in Figure 5.12.

The participant gave vague and generic responses that were not specific to the key ideas for Prompt 9 and 10 for both the concepts of wavelength and frequency. He mentioned different strategies such as discussion, simulations and the use of past exam questions. The questions he considered important to ask for the concept of wavelength followed a logical sequence and would develop conceptual understanding. Although the questions for the concept of frequency included the subordinate idea of period, he did not state questions that would develop a conceptual understanding of frequency, such as: using a wave diagram to determine the number of waves; relating frequency to wavelength; or relating to frequency and speed. Consequently, his conceptual teaching strategies for the concept of *wavelength* were scored as **adequate**, and for the concept of *frequency*, his knowledge was scored **limited to adequate**.

For the concept of *superposition*, in his response to Prompt 9, the participant stated that he would relate learners' prior knowledge to the concept and that he would include simulations as a representation, as well as using past question papers. For prompt 10, his response involved questions that were more of an instructive nature rather than questions to develop conceptual understanding. However, the subordinate ideas given were relevant, i.e. diagrammatic representations for all stages of interference. In view of this, the final score given for his conceptual teaching strategy was **adequate**.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	- Discussing knowledge on the topic with the learners. - Explaining the concepts to the learners - Showing the learners some simulations - Do class activities using previous exam questions.	- Discussing knowledge on the topic with the learners. - Explaining the concepts to the learners Showing the learners some simulations - Do class activities using previous exam question.
What questions would you consider important to ask in your teaching strategies? 10	- What is a wave? - Differentiate between in phase and out of phase. - Identify points which are in phase and out of phase	- Define frequency and period - What is the relationship between frequency and period?

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	- Discussing previous knowledge on waves with the learners - Explaining the concept of superpositioning - Showing learners some simulations - Do class activities using previous question paper.	
What questions would you consider important to ask in your teaching strategies? 10	- What is constructive and destructive interference? - What is superpositioning? - Draw diagrams before, during and after superpositioning. - Calculate amplitude during superpositioning.	

Figure 5.12: Pre-CoRe for Craig pertaining to knowledge and skills related to conceptual teaching strategies

During his pre-interview, I asked Craig what he saw as necessary resources to be able to teach Physical Sciences effectively. Below is what he shared:

> *…having materials, when I am saying materials, it's from your textbooks, a variety of textbooks from different guys [authors] then at the same time we [need] equipment… to do some experiments and for them to visualise, then at the end, having a lot of questions so you have a lot of workbooks so that they tackle as many questions as they can.*

This statement reveals that the participant may not have been so much concerned about conceptual development but rather about training learners getting the answers correct.

I also asked how he would describe his approach to science teaching. He revealed the following:

> *…it is a mixture you have to be practical and…there is a lot of content which has to come with it… you have to visualise it for you to understand most of the things… the more you visualise it the more you get the concepts.*

His responses are in line with all the other responses already given. He believed that learners learn best when they visualise a phenomenon. He acknowledged the need for equipment and resources that are best used to allow learners' conceptual understanding through practical work. However, he has also revealed his lack of use of such equipment, which further explains his **adequate** score regarding his conceptual teaching strategy (Table 5.4).

Craig's planned conceptual teaching strategy, as revealed during his pre-interview (Electronic Appendix D), is presented in Appendix XI. This information is relevant when observing the participant teaching the topic of waves. The conceptual teaching strategies that he carried out in the classroom environment during the lesson observations are further discussed in Chapter 6.

Table 5.4: TSPCK levels for the pre-CoRe

Participant	**Idea Taught**	**Knowledge and Skills related to Curriculum Saliency**					**Knowledge and Skills related to Learner Understanding**				**Knowledge and Skills related to Conceptual Teaching Strategies**				
		Prompt 1	**Prompt 2**	**Prompt 3**	**Prompt 4**	**Final Score**	**Prompt 5**	**Prompt 6**	**Prompt 7**	**Final Score**	**Prompt 8**	**Final Score**	**Prompt 9**	**Prompt 10**	**Final Score**
		What do you intend learners to know about each key idea?	Why is it important for learners to know this key idea?	What concepts need to be taught before teaching this key idea?	What else do you know about this idea- (that you don't intend learners to know yet?)		What do learners find difficult to understand?	What do you consider difficult about teaching this idea?	What are typical learners' misconceptions when teaching this idea?		What representations would you use in your teaching strategy?		What teaching strategies would you use to teach this idea?	What questions would you consider important to ask in your teaching strategy?	
Jessica	**Wavelength**	L	R	R	R	**R**	R	R	R	**R**	L	**L**	L	A	**L/A**
	Frequency	L	R	R	A	**A**	R	A	A	**A**	A	**A**	L	R	**A**
	Superposition	A	L	R	R	**A**	R	R	R	**R**	A	**A**	L	R	**A**
Tshuma	**Wavelength**	A	R	L	A	**A**	A	R	L	**A**	L	**L**	A	L	**L**
	Frequency	A	R	L	R	**A**	A	A	L	**A**	L	**L**	L	A	**L**
	Superposition	A	L	A	L	**L/A**	L	L	A	**L**	A	**A**	L	A	**L**
Craig	**Wavelength**	L	L	A	L	**L**	A	A	A	**A**	L	**L**	A	A	**A**
	Frequency	L	L	L	L	**L**	A	A	A	**A**	L	**L**	A	L	**L/A**
	Superposition	A	L	A	L	**L/A**	L	A	A	**A**	L	**L**	A	A	**A**

*L = Limited; A = Adequate; R = Rich

5.3 Post-CoRe: Results, analysis and interpretation

The results, analysis and interpretation are presented per case and in the same format as in Section 5.2 above, but are based on the post-CoRe. For the ease of discussing the participants' responses to each CoRe prompt, I will refer to each prompt using numerical values, as seen in Table 5.3. The post-CoRe levels for all three participants are summarised in Table 5.5, displaying the final allocated level for the particular TSPCK component for each key idea. This was obtained by following the principles employed when scoring the CoRes, as seen in Table 5.1.

5.3.1 Case Study 1 – Jessica

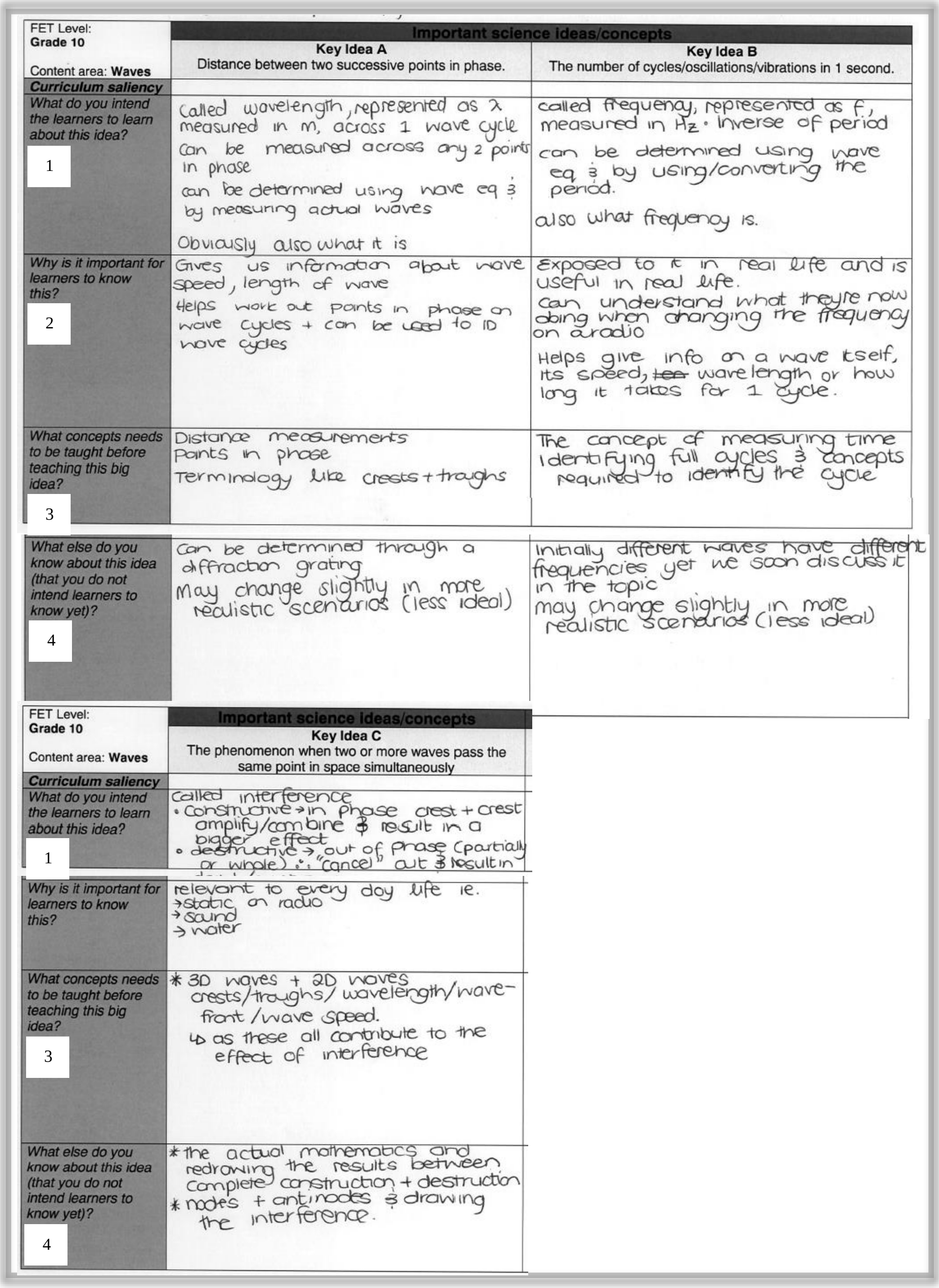
***Knowledge and skills related to curricular saliency* (Prompts 1 to 4)**

The participant expanded on the subordinate ideas for wavelength by stipulating its symbol and units in her response to Prompt 1. It is evident in Figure 5.13 that Jessica did not elaborate in her post-CoRe responses regarding Prompts 2, 3 and 4 as much as she did in the pre-CoRe (Figure 5.1). However, according to the fourth principle employed when scoring the CoRes (see Table 5.1), the participant was not scored lower from her pre-CoRe level. In light of this, her *knowledge about curricular saliency* related to the key idea of *wavelength* was still considered **rich**.

For the key idea of frequency, Jessica stated the unit and symbol in her response to Prompt 1, which is an important aspect, knowing that waves is a new topic to Grade 10 learners. Jessica did not provide any further information in her responses to Prompts 2, 3 and 4 in her post-CoRe, but was not penalised since her response to Prompt 1 had slightly improved. Her *knowledge about curricular saliency* relating to *frequency* was thus regarded **adequate to rich**.

For the key idea of superposition, in her response to Prompt 1, she mentioned the important subordinate idea of interference. The participant gave more examples in her response to Prompt 2 as compared to the pre-CoRe, which revealed her knowledge of the reasons why learners should understand superposition. However, no example regarding diffraction and interference of light was included, which is an important application of superposition. Her responses to

Prompts 3 and 4 respectively mentioned the relevant pre-concepts and displayed strategic thinking. As a result, her final score for her *knowledge about curricular saliency* for *superposition* was rated as **adequate to rich**.



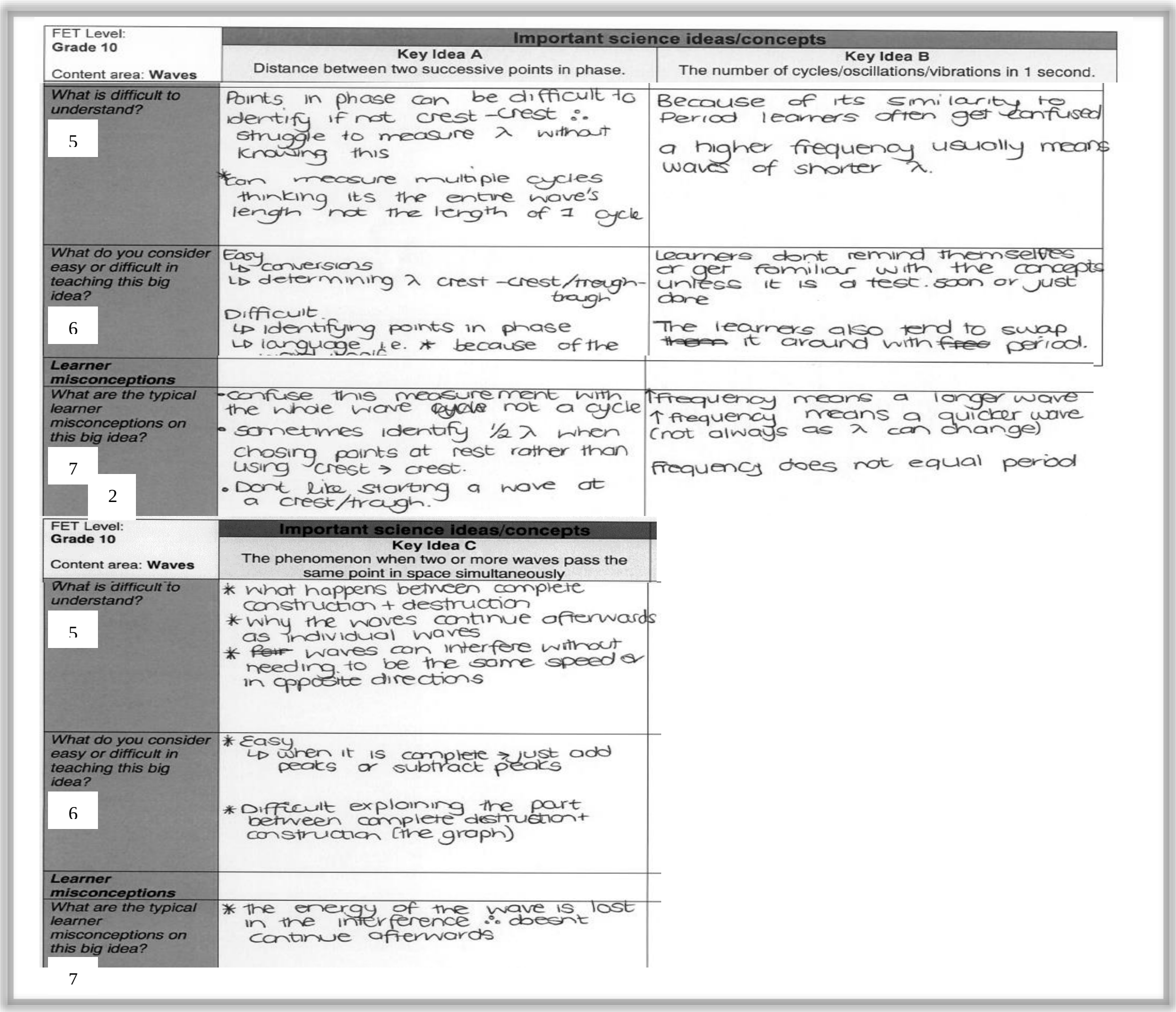
FET Level: **Grade 10** Content area: **Waves**	Important science ideas/concepts **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	Called wavelength, represented as λ measured in m, across 1 wave cycle Can be measured across any 2 points in phase can be determined using wave eq & by measuring actual waves Obviously also what it is	called frequency, represented as f, measured in Hz. Inverse of period can be determined using wave eq & by using/converting the period. also what frequency is.
Why is it important for learners to know this? 2	Gives us information about wave speed, length of wave Helps work out points in phase on wave cycles + can be used to ID wave cycles	Exposed to it in real life and is useful in real life. Can understand what they're now doing when changing the frequency on a radio Helps give info on a wave itself, its speed, ~~too~~ wavelength or how long it takes for 1 cycle.
What concepts needs to be taught before teaching this big idea? 3	Distance measurements Points in phase Terminology like crests + troughs	The concept of measuring time identifying full cycles & concepts required to identify the cycle
What else do you know about this idea (that you do not intend learners to know yet)? 4	Can be determined through a diffraction grating May change slightly in more realistic scenarios (less ideal)	Initially different waves have different frequencies yet we soon discuss it in the topic may change slightly in more realistic scenarios (less ideal)

FET Level: **Grade 10** Content area: **Waves**	Important science ideas/concepts **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously
Curriculum saliency	
What do you intend the learners to learn about this idea? 1	Called interference • Constructive → in phase crest + crest amplify/combine & result in a bigger effect • destructive → out of phase (partially or whole) ∴ "cancel" out & result in
Why is it important for learners to know this?	relevant to every day life ie. → static on radio → sound → water
What concepts needs to be taught before teaching this big idea? 3	* 3D waves + 2D waves crests/troughs/ wavelength/wave-front /wave speed. ↳ as these all contribute to the effect of interference
What else do you know about this idea (that you do not intend learners to know yet)? 4	* the actual mathematics and redrawing the results between complete construction + destruction * nodes + antinodes & drawing the interference.

Figure 5.13: Post-CoRe for Jessica pertaining to knowledge and skills related to curricular saliency

Knowledge and skills related to learners' understanding **(Prompts 5 to 7)**

In comparison to her pre-CoRe (Fig.5.2), Jessica's scores for this component did not change. However, to give the reader an understanding of the approach and thinking that was carried out for the other cases, I discuss her responses in her post-CoRe in full. It is evident in Figure 5.14 that for the concept of wavelength, Jessica gave concrete examples in her response to Prompt 5 about what learners find difficult, such as measuring multiple cycles instead of measuring one cycle. She considered both easy and difficult aspects, as seen in her response to Prompt 6 and mentioned a number of learner misconceptions. As a result of this, her knowledge of learners' understanding remained **rich** for the key idea of *wavelength*.



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
What is difficult to understand? 5	Points in phase can be difficult to identify if not crest –crest ∴ struggle to measure λ without knowing this *can measure multiple cycles thinking its the entire wave's length not the length of 1 cycle	Because of its similarity to Period learners often get confused a higher frequency usually means waves of shorter λ.
What do you consider easy or difficult in teaching this big idea? 6	Easy ↳ conversions ↳ determining λ crest –crest/trough-trough Difficult ↳ identifying points in phase ↳ language i.e. * because of the	Learners dont remind themselves or get familiar with the concepts unless it is a test. soon or just done The learners also tend to swap it around with period.
Learner misconceptions What are the typical learner misconceptions on this big idea? 7	• confuse this measurement with the whole wave not a cycle • sometimes identify ½ λ when chosing points at rest rather than using crest > crest. • Dont like starting a wave at a crest/trough.	↑ frequency means a longer wave ↑ frequency means a quicker wave (not always as λ can change) Frequency does not equal period

2

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously
What is difficult to understand? 5	* what happens between complete construction + destruction * why the waves continue afterwards as individual waves * waves can interfere without needing to be the same speed or in opposite directions
What do you consider easy or difficult in teaching this big idea? 6	* Easy ↳ when it is complete ≥ just add peaks or subtract peaks * Difficult explaining the part between complete destruction + construction (the graph)
Learner misconceptions What are the typical learner misconceptions on this big idea? 7	* the energy of the wave is lost in the interference ∴ doesnt continue afterwards

Figure 5.14: Post-CoRe for Jessica pertaining to knowledge and skills related to learners' understanding of science

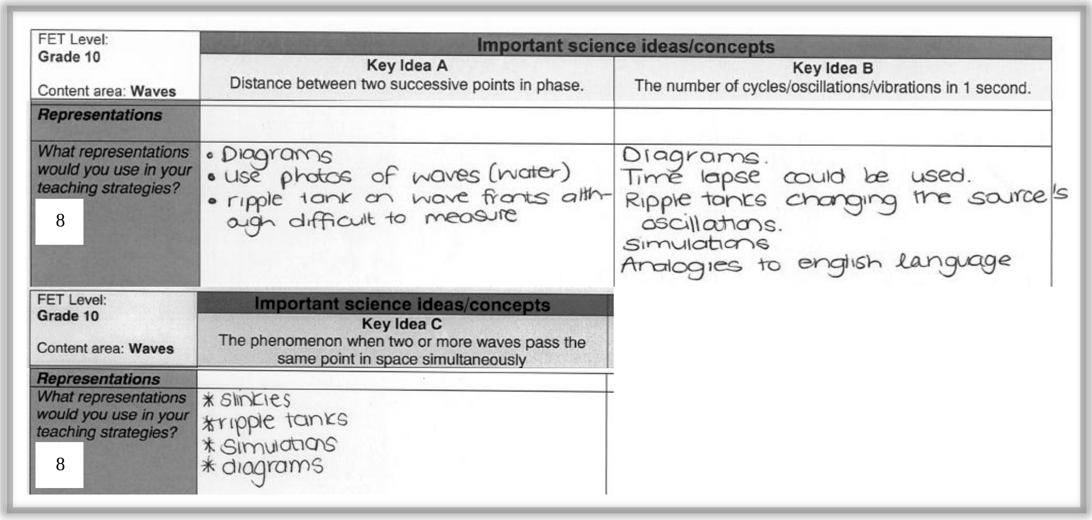
For the key idea of *frequency,* she did not elaborate in the post-CoRe as much as she did in the pre-CoRe for Prompts 5 and 6. She did, however, include in her post-CoRe the difficulties that learners have when distinguishing between frequency and period. The participant mentioned several misconceptions for the concept of frequency, but left out the example of how the frequency is determined by the source of the wave. Therefore, the participant’s knowledge of learners’ understanding for this key idea remained **adequate**.

For the key idea of superposition, in her response to Prompt 5, Jessica mentioned that learners find it difficult to understand why waves continue after interference, which was additional to her response in the pre-CoRe (see Figure 5.2). In her response to Prompt 6, the use of the term 'complete' was not understood. It is assumed that she meant that learners do not understand what happens between full (complete) destructive and full constructive interference. However, her response in the pre-CoRe for Prompt 6 (see Figure 5.2) indicated that she had a rich understanding thereof, which did not change in the post-CoRe. She stated another valid misconception in her response to Prompt 7. However, considering the second and fourth principles employed when scoring the CoRes (see Table 5.1), her *knowledge about learners’ understanding* regarding the key idea of *superposition* remained **rich**.

Knowledge and skills related to conceptual teaching strategies

Knowledge and skills related to representations (Prompt 8)

For the concept of *wavelength,* the participant stated different types of representations and was more specific about how she would use the ripple tank, i.e. to show wave fronts, although difficult to measure (Figure 5.15). However, she did not elaborate on other representations and, as a result, the knowledge revealed about representations was considered **adequate**.



FET Level: **Grade 10** Content area: **Waves**	Important science ideas/concepts	
	Key Idea A Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Representations		
What representations would you use in your teaching strategies? 8	• Diagrams • use photos of waves (water) • ripple tank on wave fronts although difficult to measure	Diagrams. Time lapse could be used. Ripple tanks changing the source's oscillations. Simulations Analogies to english language

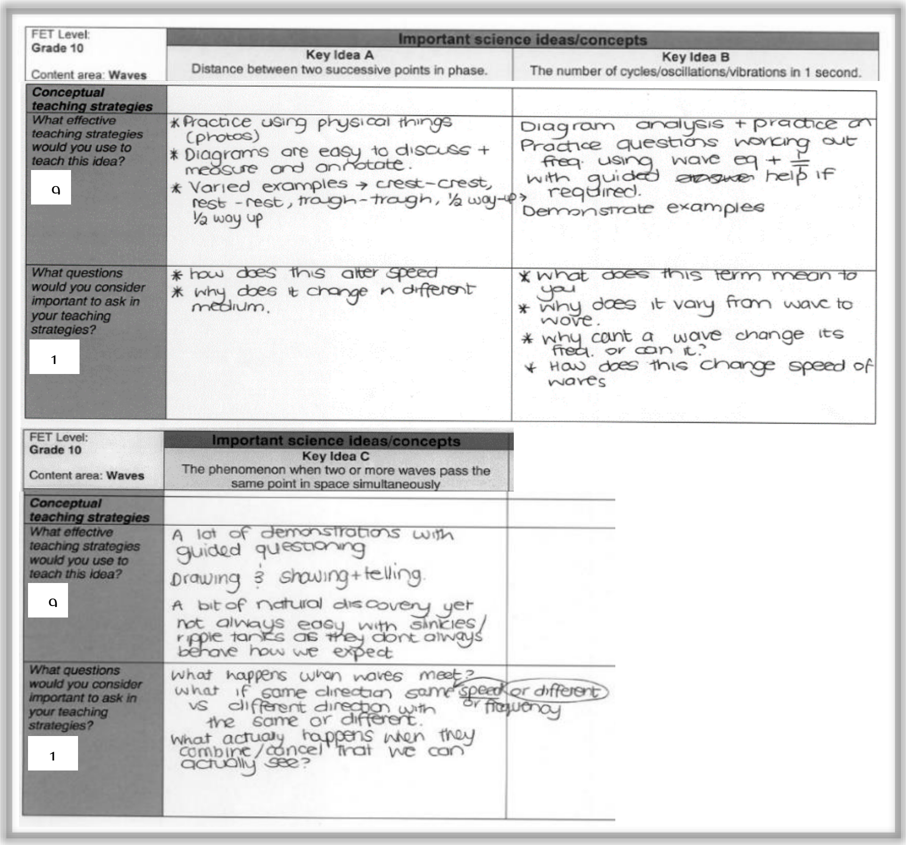
FET Level: **Grade 10** Content area: **Waves**	Important science ideas/concepts
	Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously
Representations	
What representations would you use in your teaching strategies? 8	* slinkies *ripple tanks * Simulations * diagrams

Figure 5.15: Post-CoRe for Jessica pertaining to knowledge and skills related to representations

For the concept of frequency, she listed representations, as done in her pre-CoRe, but the list included creative ideas like time lapse. A time lapse may entail pictures that are taken to capture the change in frequency and wavelength, which can then be compared to one another. She also elaborated on how she would use the ripple tank, i.e. changing the source's oscillations, being more specific in her response as to how she would use the given apparatus. As a result, I considered her knowledge **rich** for the key idea of *frequency*. For the key idea of *superposition,* the participant merely listed representations, however, because a number of different representations were given, I regarded her *knowledge about representations* as **adequate**.

Knowledge and skills related to conceptual teaching strategies (Prompts 9 and 10)

It was evident (see Figure 5.16) that her strategy would support learners' conceptual understanding of wavelength. She mentioned the use of photos in her response to Prompt 9, but in her response to Prompt 10, she did not elaborate or include anything different to what was stated in her pre-CoRe (Fig.5.4). Her response to Prompt 9 revealed improved knowledge and therefore I regard her final score for her conceptual teaching strategies for *wavelength* as **adequate to rich**.



FET Level: Grade 10 Content area: **Waves**	Important science ideas/concepts **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	* Practice using physical things (photos) * Diagrams are easy to discuss + measure and annotate. * Varied examples → crest-crest, rest - rest, trough - trough, ½ way-up → ½ way up	Diagram analysis + practice on Practice questions working out freq. using wave eq + $\frac{1}{T}$ with guided ~~answer~~ help if required. Demonstrate examples
What questions would you consider important to ask in your teaching strategies? 1	* how does this alter speed * why does it change in different medium.	* what does this term mean to you * why does it vary from wave to wave. * why cant a wave change its freq. or can it? * How does this change speed of waves

FET Level: Grade 10 Content area: **Waves**	Important science ideas/concepts **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously
Conceptual teaching strategies	
What effective teaching strategies would you use to teach this idea? 9	A lot of demonstrations with guided questioning Drawing & showing + telling. A bit of natural discovery yet not always easy with slinkies/ripple tanks as they dont always behave how we expect
What questions would you consider important to ask in your teaching strategies? 1	What happens when waves meet? what if same direction same speed or different or frequency vs different direction with the same or different. What actually happens when they combine/cancel that we can actually see?

Figure 5.16: Post-CoRe for Jessica pertaining to knowledge and skills related to conceptual teaching strategies

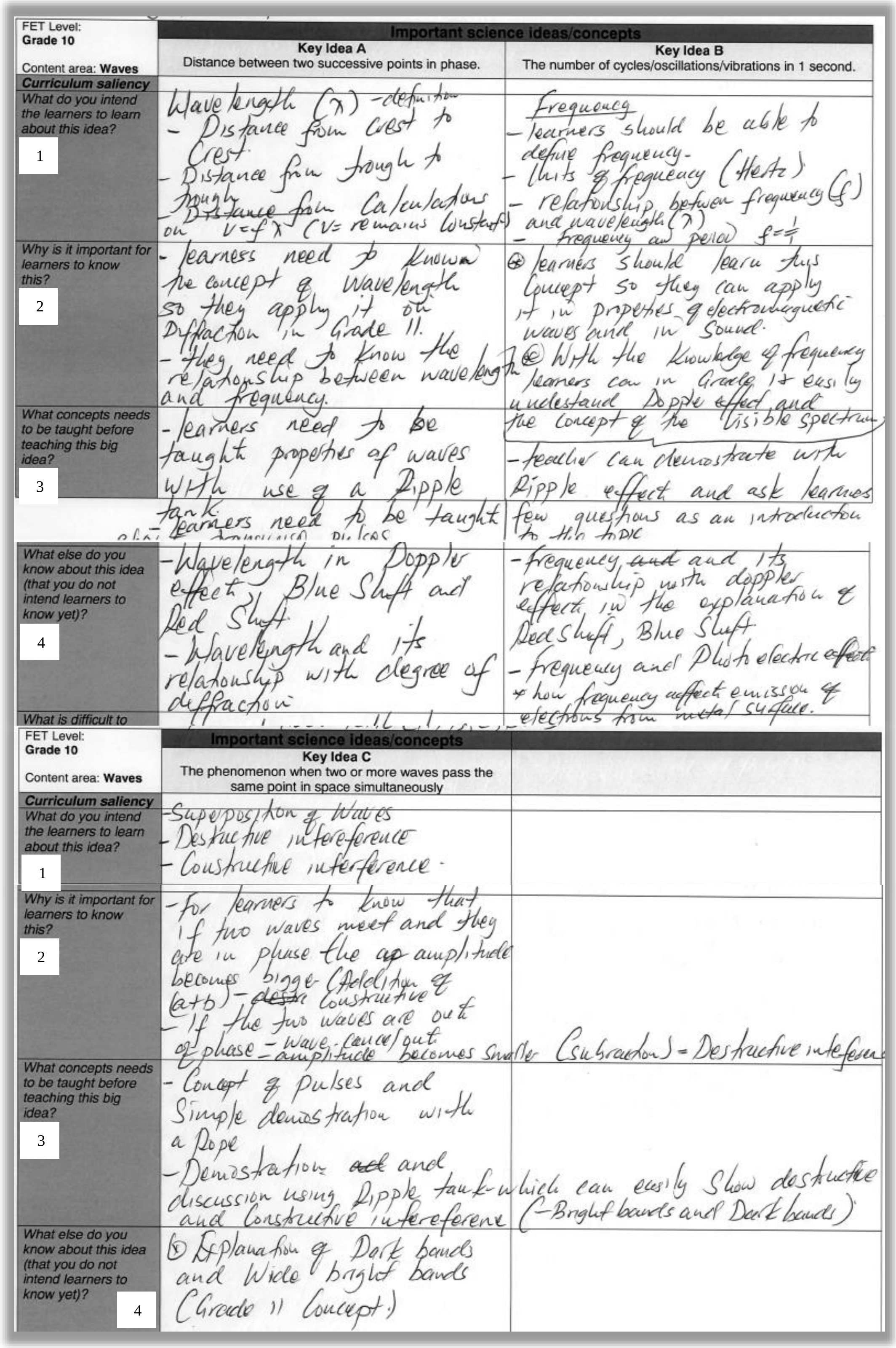
For the key idea of *frequency*, it was evident in her response to Prompt 9 that she had a better understanding of sequencing. It was evident through her response to Prompt 10 that she thought of questions that would lead to conceptual development. Therefore, I scored her conceptual teaching strategies as having **adequate to rich** knowledge.

For the concept of *superposition*, it was evident that her strategy would support learners' conceptual understanding through guiding questions, discovery and demonstrations. The participant again showed to have a better understanding of sequencing, as seen in her response to Prompt 9. Her response to Prompt 10 indicated that she had thought about and formulated questions that would lead to conceptual development of this concept. In view of this, her knowledge of conceptual teaching strategies was considered as **adequate to rich**.

5.3.2 Case Study 2 – Tshuma

Knowledge and skills related to curricular saliency **(Prompts 1 to 4)**

In comparison to Tshuma's pre-CoRe (see Figure 5.5) for the concept of wavelength, his response to Prompt 4 in his post-CoRe (Figure 5.17) included the Doppler Effect, increasing his score. However, as per the first and second principle employed when scoring the CoRes, the final score for his knowledge of curricular saliency for *wavelength* remained **adequate**. For the concept of *frequency,* his response to Prompt 1 included the symbol and unit of the key idea, which is important when a new topic is introduced to the learners, such as waves for Grade 10 learners. As such, the score for his knowledge of curricular saliency increased to **rich**. For the concept of superposition, his response to Prompt 3 and 4 included the wide bright and dark bands, referring to the diffraction pattern of light through a single slit. This is a concept required in Grade 11 (diffraction). As a result, this additional knowledge increased his final score to **adequate** for *knowledge about curricular saliency* relating to *superposition*.

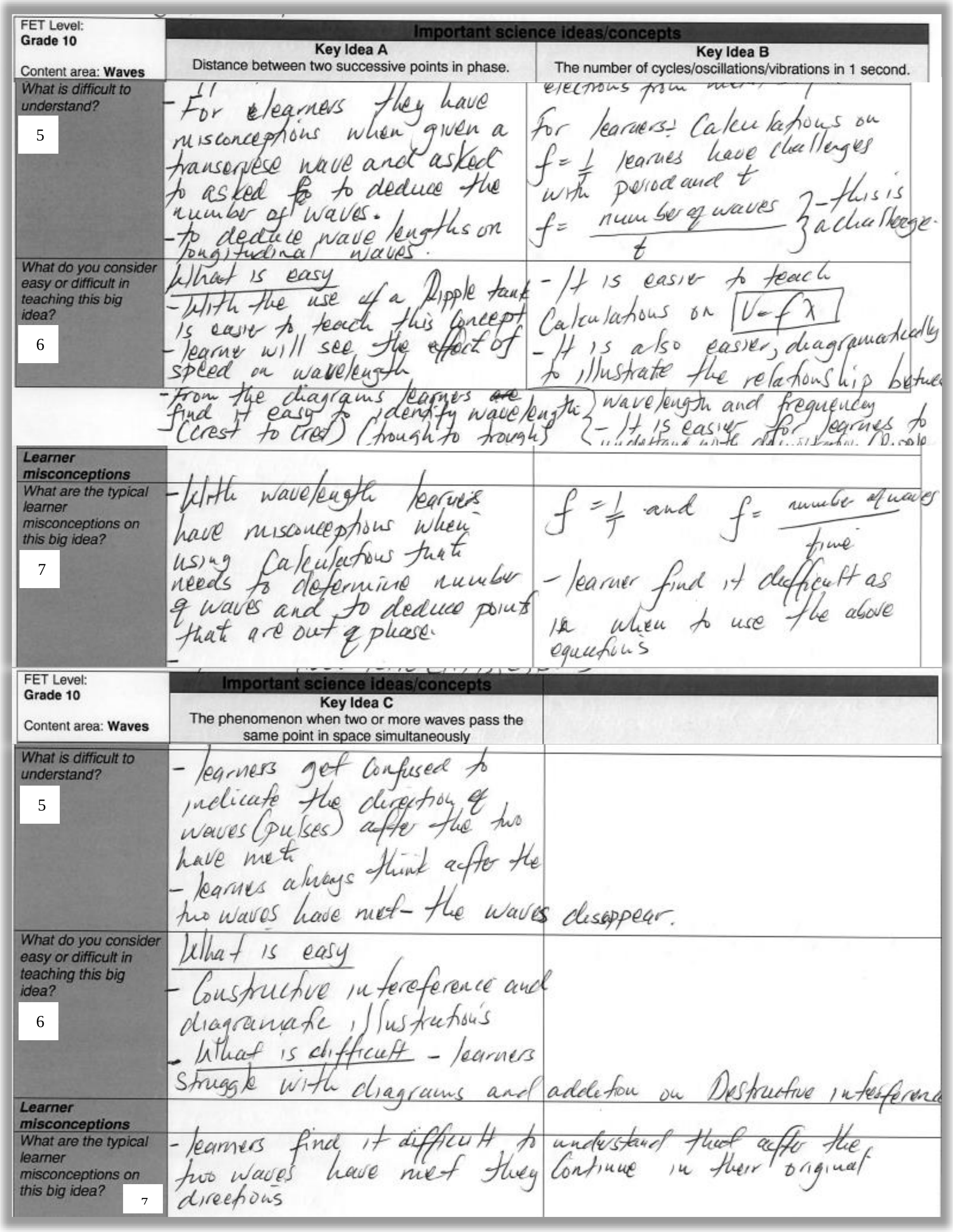


FET Level: **Grade 10** Content area: **Waves**	Important science ideas/concepts: **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	Wavelength (λ) - definition - Distance from crest to crest - Distance from trough to trough ~~Distance from~~ Calculations on $v = f\lambda$ (v = remains constant)	Frequency - learners should be able to define frequency. - Units of frequency (Hertz) - relationship between frequency (f) and wavelength (λ) - frequency and period $f = \frac{1}{T}$
Why is it important for learners to know this? 2	- learners need to known the concept of wavelength so they apply it on Diffraction in Grade 11. - they need to know the relationship between wavelength and frequency.	⊛ learners should learn this concept so they can apply it in properties of electromagnetic waves and in Sound. ⊛ With the knowledge of frequency learners can in Grade 12 easily understand Doppler effect and the concept of the visible spectrum
What concepts needs to be taught before teaching this big idea? 3	- learners need to be taught properties of waves with use of a Ripple tank. - learners need to be taught [illegible] pulses	- teacher can demonstrate with Ripple effect and ask learners few questions as an introduction to this topic
What else do you know about this idea (that you do not intend learners to know yet)? 4	- Wavelength in Doppler effect, Blue Shift and Red Shift - Wavelength and its relationship with degree of diffraction	- frequency ~~and~~ and its relationship with doppler effect, in the explanation of Red Shift, Blue Shift - frequency and Photo electric effect + how frequency affect emission of electrons from metal surface.
What is difficult to	[illegible]	

FET Level: **Grade 10** Content area: **Waves**	Important science ideas/concepts: **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	- Superposition of Waves - Destructive interference - Constructive interference.	
Why is it important for learners to know this? 2	- for learners to know that if two waves meet and they are in phase the ~~ap~~ amplitude becomes bigger (Addition of (a+b) - ~~destr~~ Constructive - If the two waves are out of phase - wave cancel out - amplitude becomes smaller (Subtraction) = Destructive interference	
What concepts needs to be taught before teaching this big idea? 3	- Concept of pulses and Simple demonstration with a Rope - Demonstration ~~and~~ and discussion using Ripple tank - which can easily show destructive and Constructive interference (- Bright bands and Dark bands)	
What else do you know about this idea (that you do not intend learners to know yet)? 4	⊛ Explanation of Dark bands and Wide bright bands (Grade 11 Concept)	

Figure 5.17: Post-CoRe for Tshuma pertaining to knowledge and skills related to curriculum saliency

Knowledge and skills related to learners' understanding **(Prompts 5 to 7)**



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts: Key Idea A — Distance between two successive points in phase.	Key Idea B — The number of cycles/oscillations/vibrations in 1 second.
What is difficult to understand? 5	- For learners they have misconceptions when given a transverse wave and asked to deduce the number of waves. - to deduce wave lengths on longitudinal waves.	For learners: Calculations on $f = \frac{1}{T}$ learners have challenges with period and t; $f = \frac{\text{number of waves}}{t}$ - this is a challenge.
What do you consider easy or difficult in teaching this big idea? 6	What is easy - With the use of a Ripple tank is easier to teach this concept - learner will see the effect of speed on wavelength - From the diagrams learners find it easy to identify wavelength (crest to crest) (trough to trough)	- It is easier to teach Calculations on $v = f\lambda$ - It is also easier, diagrammatically to illustrate the relationship between wavelength and frequency - It is easier for learners to [illegible]
Learner misconceptions: What are the typical learner misconceptions on this big idea? 7	- With wavelength learners have misconceptions when using calculations that needs to determine number of waves and to deduce points that are out of phase.	$f = \frac{1}{T}$ and $f = \frac{\text{number of waves}}{\text{time}}$ - learner find it difficult as in when to use the above equations

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts: Key Idea C — The phenomenon when two or more waves pass the same point in space simultaneously	
What is difficult to understand? 5	- learners get confused to indicate the direction of waves (pulses) after the two have met - learners always think after the two waves have met - the waves disappear.	
What do you consider easy or difficult in teaching this big idea? 6	What is easy - Constructive interference and diagrammatic illustrations - What is difficult - learners struggle with diagrams and addition on Destructive interference	
Learner misconceptions: What are the typical learner misconceptions on this big idea? 7	- learners find it difficult to understand that after the two waves have met they continue in their original directions	

Figure 5.18: Post-CoRe for Tshuma pertaining to knowledge and skills related to learners' understanding

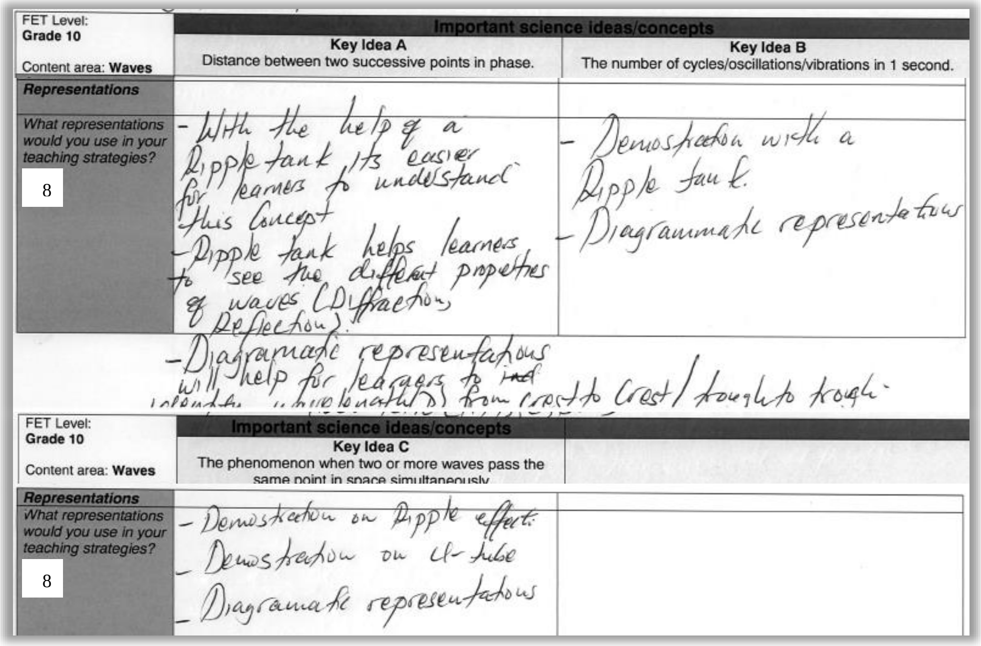
In response to Prompt 5 (Figure 5.18) regarding the concept *of wavelength*, Tshuma added an additional example to the ones mentioned in his pre-CoRe about deducing the wavelength of longitudinal waves. The participant related wavelength to speed in his response to Prompt 6 and indicated how the ripple tank could be used to see the effect of speed on wavelength. I believe this was incorrect thinking as the speed did not change considering the medium remained unchanged. I do believe that this response may have revealed a possible misconception of his own. As such, the final score for this component remained **adequate** despite the additional information given in his response to Prompt 5.

For the concept of *frequency*, the score for his responses to Prompt 6 increased to **rich** because he included the use of diagrammatic illustrations to help teach the relationship between wavelength and frequency. The score increased to **adequate** for his response to Prompt 7 because he elaborated on the equations for frequency. However, his final score for learners' understanding remained **adequate** considering the second principle employed when scoring the CoRes (Table 5.1).

Tshuma's score for knowledge of learners' understanding in terms of the concept *superposition* increased from limited to **adequate to rich** because in his response to Prompt 5, he included how learners find it difficult to understand the direction and amplitudes of the pulses after interfering. Furthermore, for Prompt 6, he no longer simply repeated the key idea, but gave examples such as explaining constructive interference using diagrams as being easy to teach.

Knowledge and skills related to conceptual teaching strategies

Knowledge and skills related to representations (Prompt 8)



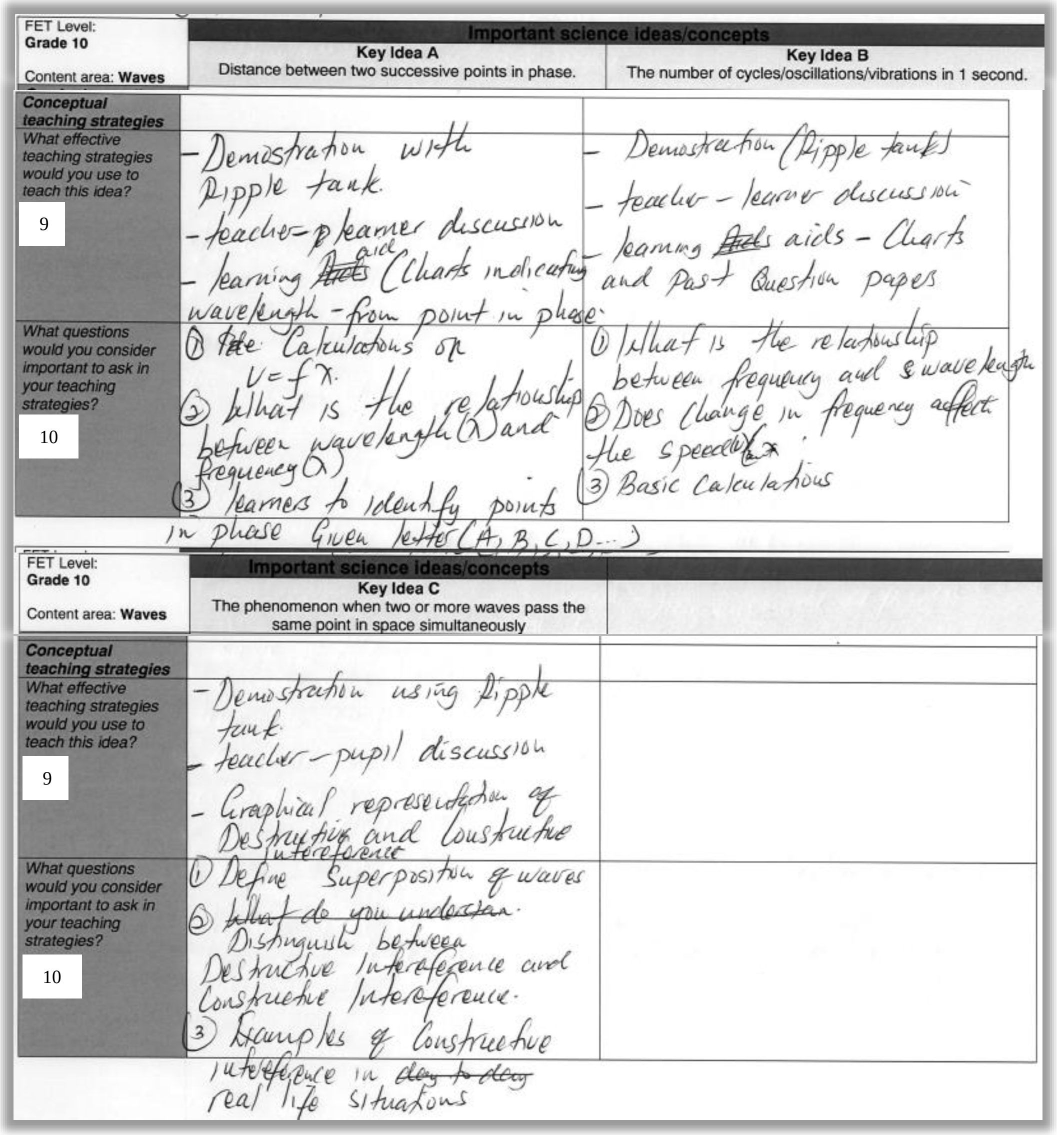
FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Representations What representations would you use in your teaching strategies? 8	- With the help of a Ripple tank its easier for learners to understand this Concept - Ripple tank helps learners to see the different propeties of waves (Diffraction, Reflection). - Diagramatic representations will help for learners to ind[?] wavelength from crest to Crest / trough to trough.	- Demostration with a Ripple tank. - Diagrammatic representations

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Representations What representations would you use in your teaching strategies? 8	- Demostration on Ripple effect. - Demostration on U-tube - Diagramatic representations	

Figure 5.19: Post-CoRe for Tshuma pertaining to knowledge and skills related to representations

When the participant’s response to Prompt 8 was compared to the pre-CoRe (Figure 5.7) for the concept of wavelength, the participant explained in more detail how he would use diagrammatic representations, i.e. crest to crest/trough to trough to allow better learner understanding. Consequently, the score for his *knowledge about representations* for the concept of *wavelength* was scored **adequate**. The scores for the key ideas of *frequency* and *superposition* remained the same.

Knowledge and skills related to conceptual teaching strategies (Prompts 9 and 10)



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Conceptual teaching strategies What effective teaching strategies would you use to teach this idea? 9	- Demonstration with Ripple tank. - teacher-learner discussion - learning ~~Aids~~ aid (Charts indicating wavelength - from point in phase.	- Demonstration (Ripple tank) - teacher - learner discussion - learning ~~Aids~~ aids - Charts and Past Question papers
What questions would you consider important to ask in your teaching strategies? 10	① ~~The~~ Calculations on $v = f\lambda$. ② What is the relationship between wavelength (λ) and frequency (λ) ③ learners to identify points in phase Given letter (A, B, C, D...)	① What is the relationship between frequency and wavelength ② Does change in frequency affect the speed (x). ③ Basic Calculations

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Conceptual teaching strategies What effective teaching strategies would you use to teach this idea? 9	- Demonstration using Ripple tank. - teacher - pupil discussion - Graphical representation of Destructive and Constructive interference	
What questions would you consider important to ask in your teaching strategies? 10	① Define Superposition of waves ② ~~What do you understan.~~ Distinguish between Destructive Interference and Constructive Interference. ③ Examples of Constructive interference in ~~day to day~~ real life situations	

Figure 5.20: Post-CoRe for Tshuma pertaining to knowledge and skills related to conceptual teaching strategies

When comparing the pre-CoRe (Figure 5.8) and post-CoRe (Figure 5.20), the scores for Tshuma's responses increased for all three key ideas for this TSPCK component. For the concepts of wavelength and frequency, his response to Prompt 9 mentioned strategies such as teacher and learner discussions, demonstrations, and learning aids such as charts, which all support conceptual development.

In addition, for the key idea of frequency, the participant mentioned a question that would address a common learner misconception about the speed of a wave being determined by the source of the wave. The question he proposed to ask was: Does change in frequency affect the speed? As a result, the final score for his conceptual teaching strategies for *wavelength* was scored, **adequate** and for the concept of *frequency*, **adequate to rich**. For the concept of *superposition*, he had additional information in his response to Prompt 10, which included graph-based representation of constructive and destructive interference and, as such, his score increased for his conceptual teaching strategy to **adequate to rich**.

5.3.3 Case Study 3 – Craig

Knowledge and skills related to curricular saliency **(Prompts 1 to 4)**

When the participant's responses in his pre-CoRes (Figure 5.9 to Figure 5.12) were compared to his responses in the post-CoRes, I generally found that Craig did not respond to the prompts in the post-CoRe (Figure 5.21 – Figure 5.24) in as much detail. However, following the fourth principle employed when scoring the CoRes (Table 5.1), he was not scored lower for his post-CoRe responses because the responses already given in his pre-CoRe were considered part of his personal PCK.

The score for his response to Prompt 1 for the concept of *wavelength* (Figure 5.21) increased to **adequate** because his response was not only limited to the idea of points that are in and out of phase as was the case in the pre-CoRe. The additional ideas mentioned were about how the light lines observed in the projection of the ripple tank are the crests and the darker lines are the troughs. As such, his final score for his *knowledge about curricular saliency* for *wavelength* increased and was scored as **limited to adequate**. The scores for the concepts of *frequency* and *superposition* remained the same.

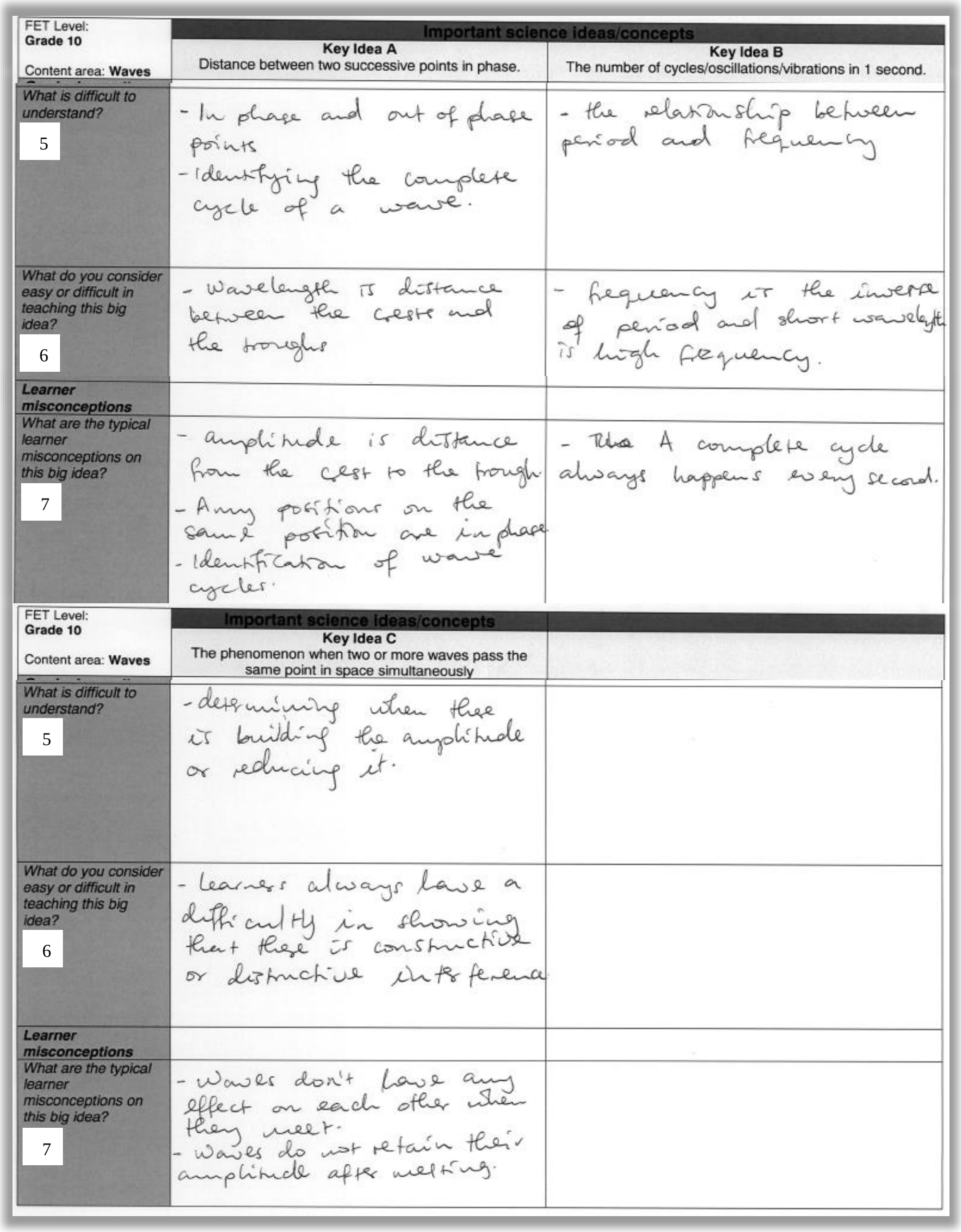
FET Level: Grade 10 Content area: **Waves**	Important science ideas/concepts **Key Idea A** Distance between two successive points in phase.	 **Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	- the learners should visualise the movement of the waves. - Knowing that there are crests and troughs => light lines are crests and dark lines are troughs - distance between crests or troughs is wavelength	- the number of cycles per second is the frequency.
Why is it important for learners to know this? 2	- This helps the learners to determine the speed of a wave	- It gives the period of a wave which is needed to determine the speed of the wave.
What concepts needs to be taught before teaching this big idea? 3	- Inphase and out of phase concept of waves. - Amplitude is disturbance from the zero or resting position.	- the relationship between period and frequency.
What else do you know about this idea (that you do not intend learners to know yet)? 4	- the speed of a wave depends on the wavelength of the wave.	- the frequency of the wave depends on the number of vibrations in the medium

FET Level: Grade 10 Content area: **Waves**	Important science ideas/concepts **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea? 1	- Waves meeting on the same point in space interfere with each other. - Interference is either constructive or destructive.	
Why is it important for learners to know this? 2	- It helps learners to know that waves can increase the amplitude or reduce when they meet.	
What concepts needs to be taught before teaching this big idea? 3	- If waves meet at the same space in time, it can be crests and troughs meeting or a crest and trough	
What else do you know about this idea (that you do not intend learners to know yet)? 4	- that the effect on waves when they are meeting can be constructive or destructive.	

Figure 5.21: Post-CoRe for Craig pertaining to knowledge and skills related to curriculum saliency

Knowledge and skills related to learners' understanding **(Prompts 5 to 7)**

Comparing Craig's post-CoRe (Figure 5.22) to his pre-CoRe (Figure 5.10) responses for the concept of *frequency*, he included the relationship between frequency and wavelength in his response to Prompt 6, increasing his score to **rich**. However, because of the second principle employed when scoring, the final score for knowledge of learners' understanding for the concept of *frequency* remained **adequate**. The other two scores were unchanged.



FET Level: Grade 10 / Content area: Waves	Important science ideas/concepts — Key Idea A: Distance between two successive points in phase.	Key Idea B: The number of cycles/oscillations/vibrations in 1 second.
What is difficult to understand? 5	- In phase and out of phase points - Identifying the complete cycle of a wave.	- the relationship between period and frequency
What do you consider easy or difficult in teaching this big idea? 6	- Wavelength is distance between the crests and the troughs	- frequency is the inverse of period and short wavelength is high frequency.
Learner misconceptions		
What are the typical learner misconceptions on this big idea? 7	- amplitude is distance from the crest to the trough - Any positions on the same position are in phase - Identification of wave cycles.	- ~~The~~ A complete cycle always happens every second.

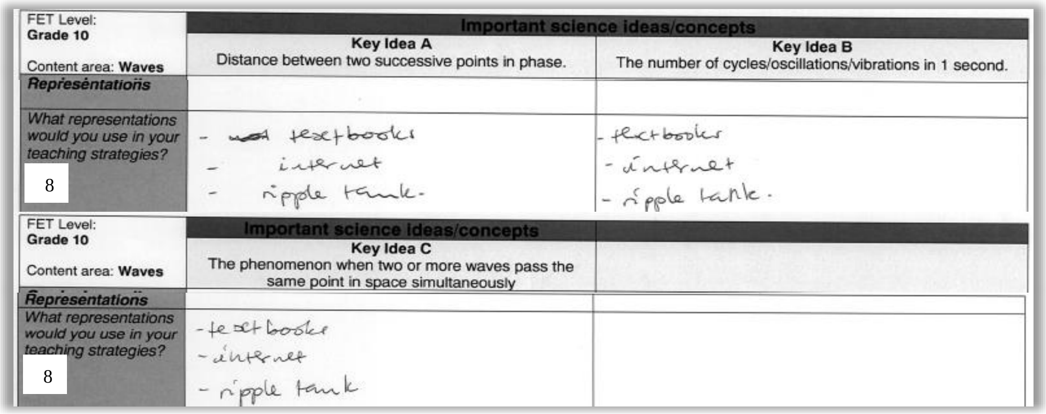
FET Level: Grade 10 / Content area: Waves	Important science ideas/concepts — Key Idea C: The phenomenon when two or more waves pass the same point in space simultaneously	
What is difficult to understand? 5	- determining when there is building the amplitude or reducing it.	
What do you consider easy or difficult in teaching this big idea? 6	- learners always have a difficulty in showing that there is constructive or distructive interference	
Learner misconceptions		
What are the typical learner misconceptions on this big idea? 7	- Waves don't have any effect on each other when they meet. - Waves do not retain their amplitude after meeting.	

Figure 5.22: Post-CoRe for Craig pertaining to knowledge and skills related to learners' understanding

Knowledge and skills related to conceptual teaching strategies

Knowledge and skills related to representations (Prompt 8)

The score given for Craig's *knowledge about representations* for all three key ideas remained **limited**. The reason for this was that the participant, again, merely listed the representations and was not specific regarding their use. However, unlike in his response in the pre-CoRe (Figure 5.11), the participant included the ripple tank as a chosen representation (Figure 5.23).



FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea A Distance between two successive points in phase.	Key Idea B The number of cycles/oscillations/vibrations in 1 second.
Representations		
What representations would you use in your teaching strategies? 8	- textbooks - internet - ripple tank.	- textbooks - internet - ripple tank.

FET Level: Grade 10 Content area: Waves	Important science ideas/concepts Key Idea C The phenomenon when two or more waves pass the same point in space simultaneously	
Representations		
What representations would you use in your teaching strategies? 8	- textbooks - internet - ripple tank	

Figure 5.23: Post-CoRe for Craig pertaining to knowledge and skills related to representations

Knowledge and skills related to conceptual teaching strategies (Prompts 9 and 10)

Although the scores for this component did not change for any of the key ideas, the participant revealed that he would incorporate the use of the ripple tank into his teaching strategy as part of his response to Prompt 9. In addition, the questions he wrote down as a response to Prompt 10 were very similar to his responses in the pre-CoRe, resulting in the same scores.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	- providing notes to learners - class discussions - demonstration using a ripple tank.	- providing notes to learners - class discussions - demonstration using a ripple tank.
What questions would you consider important to ask in your teaching strategies? 10	- Identify points which are in phase - Determine the wavelength of a wave - Determine the wave speed	- Define frequency of a wave. - Determine the frequency given the period.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea? 9	- providing notes to the learners - class discussions - demonstration using a ripple tank.	
What questions would you consider important to ask in your teaching strategies? 10	- Determine the amplitude of a wave. - Determine the amplitude of a wave during superpositioning. - Draw a diagram to show ~~superpos~~ constructive & destructive interference.	

Figure 5.24: Post-CoRe for Craig pertaining to knowledge and skills related to conceptual teaching strategies

In conclusion to Craig's data from the post-CoRe, his TSPCK levels for the post-CoRe are presented in Table 5.5 below.

Table 5.5: TSPCK levels for the post-CoRe

Participant	Idea Taught	Knowledge and skills related to curriculum saliency					Knowledge and skills related to learners' understanding				Knowledge and skills related to conceptual teaching strategies				
		Prompt 1	**Prompt 2**	**Prompt 3**	**Prompt 4**	**Final Score**	**Prompt 5**	**Prompt 6**	**Prompt 7**	**Final Score**	**Prompt 8**	**Final Score**	**Prompt 9**	**Prompt 10**	**Final Score**
		What do you intend learners to know about each key idea?	Why is it important for learners to know this key idea?	What concepts need to be taught before teaching this key idea?	What else do you know about this idea- (that you don't intend learners to know yet?)		What do learners find difficult to understand?	What do you consider difficult about teaching this idea?	What are typical learners' misconceptions when teaching this idea?		What representations would you use in your teaching strategy?		What teaching strategies would you use to teach this idea?	What questions would you consider important to ask in your teaching strategy?	
Jessica	**Wavelength**	R	R	R	R	**R**	R	R	R	**R**	A	**A**	R	R	**A/R**
	Frequency	A	R	R	A	**A/R**	R	A	A	**A**	R	**R**	A	R	**A/R**
	Superposition	A	A	R	R	**A/R**	R	R	R	**R**	A	**A**	A	R	**A/R**
Tshuma	**Wavelength**	A	R	L	R	**A**	R	R	L	**A**	A	**A**	R	L	**A**
	Frequency	R	R	L	R	**R**	A	R	A	**A**	L	**L**	R	A	**A/R**
	Superposition	A	L	R	A	**A**	R	A/R	A	**A/R**	A	**A**	A	R	**A/R**
Craig	**Wavelength**	A	L	A	L	**L/A**	A	A	A	**A**	L	**L**	A	A	**A**
	Frequency	L	L	L	L	**L**	A	R	A	**A**	L	**L**	A	L	**L/A**
	Superposition	A	L	A	L	**L/A**	L	A	A	**A**	L	**L**	A	A	**A**

*L = Limited; A = Adequate; R = Rich

5.4 CHAPTER SUMMARY

In Chapter 5, I presented the pre-CoRe data and interpreted the pre-CoRe together with the pre-interview for each participant. The pre-CoRe TSPCK scores for all three case studies are summarised in Table 5.4. After which, the post-CoRe was presented and interpreted per participant. Table 5.5 summarises the post-CoRe TSPCK scores for all three case studies. Table 5.6 below is a summary of the participants *final* pre-and post-CoRe scores for the TSPCK components and key ideas, taken from Table 5.4 and Table 5.5.

Table 5.6: Summary of the pre-and post-CoRe scores across the TSPCK components and three key ideas for each participant.

		Knowledge and Skills related to Curriculum Saliency (Prompts 1-4)		Knowledge and Skills related to Learner Understanding (Prompts 5-7)		Knowledge and Skills related to Conceptual Teaching Strategies			
						Representations (Prompt 8)		Conceptual Teaching Strategies (Prompts 9-10)	
Participant	**Idea taught**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Jessica	**Wavelength**	R	R	R	R	L	**A**	L/A	**A/R**
	Frequency	A	**A/R**	A	A	A	**R**	A	**A/R**
	Superposition	A	**A/R**	R	R	A	A	A	**A/R**
Tshuma	**Wavelength**	A	A	A	A	L	**A**	L	**A**
	Frequency	A	**R**	A	A	L	L	L	**A/R**
	Superposition	L/A	**A**	L	**A/R**	A	A	L	**A/R**
Craig	**Wavelength**	L	**L/A**	A	A	L	L	A	A
	Frequency	L	L	A	A	L	L	L/A	L/A
	Superposition	L/A	L/A	A	A	L	L	A	A

* Levels seen in bold and in red indicate the improved TSPCK levels

The information provided by the participants in their respective pre- and post-CoRe were used to establish their reported PCK. The raw data was discussed in length about the participants' pre-CoRe (Section 5.2) and post-CoRe (Section 5.3), therefore as a summary, a brief comparison of the pre-and post-CoRe is given. The analysis of the pre- and post-CoRe confirms that there were improvements in at least one of the TSPCK components for each participant. The first and second sub-questions of this study focused on investigating the level of the teachers' PCK for all the TSPCK components since the effective interaction of all the TSPCK components points to a well-developed PCK. Collectively, the participants showed the most improvement for the *knowledge and skills related to curriculum saliency* and *knowledge and skills related to conceptual teaching strategies* categories. A summary of the most important differences and/or improvements in the participants' PCK is presented below.

Knowledge and skills related to curriculum saliency

Jessica and Tshuma improved their knowledge of the key ideas of *frequency* and *superposition*. Both participants included the unit and symbol for the key idea of frequency, which is important when it is a new concept for learners. Jessica mentioned interference as an important subordinate idea and indicated the reasons why learners should understand superposition. Tshuma added additional information about the importance of understanding superposition as it is a concept needed to understand diffraction, which is covered in Grade 11. Craig had an improvement for the key idea of *wavelength* because he added additional ideas to his response about how the light lines observed in the projection of the ripple tank are the crests and the darker lines are the troughs.

Knowledge and skills related to learners' understanding

Only Tshuma displayed an improvement for this TSPCK component for the key idea of *superposition* due to his post-CoRe response, which included an explanation about constructive interference being made easy to teach using diagrams.

Knowledge and skills related to representations

Jessica and Tshuma showed improvement regarding the key idea of *wavelength*. In the post-CoRe, Jessica was more specific about her use of the ripple tank to illustrate wave fronts. Tshuma explained in more detail how he would use representations to improve learners' understanding, i.e. a diagram to show crest to crest/trough to trough. Jessica showed additional improvement regarding the key idea of frequency, again, because she was more specific about her use of the ripple tank to illustrate the concept.

Knowledge and skills related to conceptual teaching strategies

Jessica and Tshuma displayed improved levels for all three key ideas. In their post-CoRe responses, both participants mentioned the use of demonstrations and representations (knowledge of representations), the use of questions to support conceptual development and to address common learner misconceptions (knowledge of learner thinking)/ They also both illustrated a better understanding of curricular sequencing (knowledge of curricular saliency). Both participants illustrated knowledge regarding the integration of the TSPCK components into their teaching strategy. Craig's scores remained unchanged, however, the participant revealed that he would incorporate the use of the ripple tank apparatus into his teaching strategy, which had been made available to him after the intervention took place.

Chapter 5 has uncovered the relevant information and compared the differences in the levels of the teachers' reported TSPCK on waves before and after the in-service training. The results gained from the qualitative analysis of the classroom observations, the VSR interview, and semi-structured post-interview will be expanded on in Chapter 6.

CHAPTER 6 - RESULTS ON THE PARTICIPANTS' ENACTED PCK: CLASSROOM OBSERVATIONS AND INTERVIEWS

6.1 INTRODUCTION

In this chapter, I report on my investigation regarding whether the participants were able to employ the science equipment introduced, and enact the PCK and skills taught during the in-service training when teaching the wave concept. The data comprises three video recordings of the participants formally teaching the topic of waves, a VSR interview and a semi-structured post-interview for each participant. The data obtained is reported and discussed in order to answer the third sub question:

c) How do the teachers enact PCK when teaching the wave concept after in-service training?

The classroom observations formed part of Interaction 4 (Figure 3.1). I observed and video recorded all three participants teaching the topic of waves in their classrooms. All three teachers taught the topic during the same time period of Term 1. It was essential that the teachers communicated their weekly planning to me to prevent the overlapping of lessons.

In this study, I set out to determine the participants' reported PCK through a semi-structured pre-interview and pre-and post-CoRe, which are discussed in Chapter 5. To reveal the enactment and the reasoning behind the participants' PCK through interactive teaching (Carlson & Daehler, 2019; Gess-Newsome, 2015), I conducted classroom observations, the VSR interviews and semi-structured post-interviews. The VSR interview afforded me the opportunity to access the participants' *pedagogical reasoning* during reflection on their classroom practice since Chan et al. (2018) argue that pedagogical reasoning is not only assessed through observational data. The semi-structured post-interview (Appendix VIII) gathered the participants' general views and opinions regarding the intervention. The methodology chosen was in line with that of Chan et al. (2018, p. 4-5), who state:

> *Static PCK is a fixed form of teacher knowledge, in contrast to dynamic PCK. The former is related to investigating what teachers know or think (i.e. static PCK) […] while the latter refers to know-how (i.e. skills and techniques) and knowing-to-act in the moment (Mason*

& Spence, 1999) that is inherently linked to, and situated in, the act of teaching within a particular classroom.

As such, the three data collection methods obtained as much detail about the teachers' PCK about the topic of waves as possible.

A relevant study about the development of pre-service teachers' PCK carried out by Coetzee (2018) made me cognisant of the possible observer effects, which I needed to be aware of while I analysed and interpreted the data for this study. The observer effects that were of relevance are presented in Appendix XII.

An assumption that I made in this study (Figure 3.2) was that the intervention drew from the collective PCK belonging to the profession of teaching, which in turn would develop the personal PCK of the participants (Carlson & Daehler, 2019). Since the participants were in-service teachers, I had to keep in mind that the PCK revealed during the observations was not entirely obtained from the intervention. As a result, I based my conclusions on the aspects of the TSPCK components that were uncovered through the pre-interview, pre-and post-CoRe, and further revealed during the observations based on what was discussed during the intervention.

6.1.1 Analysis of the video recorded classroom observations and VSR interview

The recorded observation videos were watched twice - once to get an overview of the lesson and for a second time to dissect the videos into sections, which are numbered in the order that they occurred in the video. Each section reveals and describes what was being taught at that particular time, which would include either the discussion about previous knowledge, the teaching of a new key concept or subordinate idea, re-teaching a key concept or subordinate idea using representations, or the allocation of activities and/or homework. The section lengths vary from 2 minutes 51 seconds to 18 minutes 8 seconds. A narrative account was written for each section. Each section was coded using the codes as shown in Table 6.1 below. The codes and examples that indicate evidence of enacted TSPCK components were based on a study by Coetzee (2018). I adapted the examples of evidence for the TSPCK components of *representations*, and *conceptual teaching strategies* to include evidence that the ripple tank apparatus was used (Table 6.1).

Table 6.1: Codes used in the analysis of lesson observations, adapted from Coetzee (2018)

Codes	Examples of evidence
Curricular saliency (CS)	The teacher reveals knowledge about the sequencing of concepts.
	The teacher displays an awareness of the knowledge that should be in place before a certain concept is taught.
	The teacher is aware of the application of the concept in real life and uses it in the lesson.
What is difficult to teach (WDT)	The teacher reveals and uses knowledge about the way in which learners think and concepts that learners find difficult to understand.
Learners' prior knowledge (LP)	The teacher reveals and uses knowledge about typical misconceptions and other ideas learners have pertaining to the topic.
Representations (RP)	The teacher uses a representation (demonstration, video, analogy, simulation and/or diagram) to support the explanation of a specific concept.
Representations using the ripple tank (RPRT)	The teacher uses the ripple tank apparatus to support the explanation of a specific concept.
Conceptual Teaching strategy (TS)	The teacher's knowledge of a teaching strategy in terms of sequencing of concepts and use of representations is evident.
	The teacher uses questioning in the pursuit of conceptual development.
	The teacher uses questioning and discourse in combination with knowledge of typical misconceptions and representations to support conceptual change.
	The teacher integrates other components creatively and effectively into a conceptual teaching strategy.
	The teacher integrates the ripple tank creatively and effectively into a conceptual teaching strategy.

From the lesson sections, I chose the sections that were rich in information relevant to the study and the key ideas, and which revealed evidence of the enactment of one or more of the TSPCK components (as seen in Table 4.1).

During my analysis of the sections, I searched for evidence that correlated to the themes discussed during the intervention (Table 4.1) while considering what was described in the post-CoRe, which was taken as the participants declared PCK. After watching the videos and giving the narrative account for each video, I evaluated the participants' PCK using the rubric for enacted PCK (Appendix VI). The participants were evaluated per TSPCK component and per key idea and scored as having either **restricted, adequate** or **rich** knowledge. An experienced teacher educator scored and moderated the scoring for validation. The moderator scored the enacted PCK using the rubric for enacted PCK (Appendix VI) and the scores were then compared. Where differences existed, we engaged in discussion until consensus was reached.

After the classroom observations had taken place, a VSR interview was conducted. Although the literature indicates that it is best to carry out a VSR interview within a 48 hour time period (Denley & Bishop, 2010), the literature also acknowledges that a delay is a possibility due to teacher availability. In this study, there was a lack of teacher availability within the 48hour time period and thus all three VSR interviews took place more than two days after the observation. Before the VSR interview took place, I chose sections from the videos that were rich in information pertaining to the TSPCK components of *knowledge about representations* and *learners' prior knowledge* when teaching the three key ideas of wavelength, frequency, as well as the subordinate idea of period and the key idea of superposition. The VSR interview was semi-structured to allow further relevant questions to be asked and for the participants to elaborate where necessary.

The VSR interviews were recorded and transcribed [Electronic Appendices: Jessica (Appendix N); Tshuma (Appendix O); Craig (Appendix P)].

6.1.2 Analysis of the semi-structured post-interview

It was important to receive feedback from the teachers to determine whether the in-service training that was provided, which actively involved the teachers, provided them with an opportunity to construct knowledge to develop themselves in some way or another. It is for this reason that the semi-structured post-interview was conducted.

After an account of the results, an analysis and interpretation of the video recorded classroom observations and VSR interview is given, and a summary of each participant's semi-structured post-interview is presented.

6.2 RESULTS, ANALYSIS AND INTERPRETATION OF THE VIDEO RECORDED CLASSROOM OBSERVATIONS AND VSR INTERVIEW

6.2.1 Case Study 1 – Jessica

Jessica taught in the school following the IEB curriculum and SAG document. I observed three of her lessons covering the key ideas of wavelength, frequency and superposition. From the three lessons, 16 sections were identified and are presented in Table 6.2

Table 6.2: Lesson sections for Jessica

Section 1	*Start of Lesson 1* – Teaching the definition of a wave and subordinate ideas of a medium and source [4min 2s].
Section 2	Teaching wave terminology with the use of a demonstration (Slinky spring) [8min 32s].
Section 3	Re-teaching wave terminology with the use of a diagram [4min 51s].
Section 4	Teaching a new key idea: wavelength [8min 52s].
Section 5	Teaching subordinate ideas: in- and out- of phase and amplitude [9min 16s].
Section 6	Teaching a key idea: frequency; and subordinate idea: period [7min 55s].
Section 7	*Start of Lesson 2* – Introduction to the concept of interference, reflection, refraction, diffraction and wave fronts [13min 2s].
Section 8	Re-teaching wave fronts using demonstration (ripple tank) [4min].
Section 9	Re-teaching the concept of interference, reflection, refraction using demonstration (ripple tank) [8min 41s].
Section 10	Re-teaching the concept of reflection with interference, and diffraction using demonstration (ripple tank) [4min 12s].
Section 11	Re-teaching the concept of refraction, reflection, diffraction using circular waves and a demonstration (ripple tank) [9min].
Section 12	Learner participation using demonstration on concepts of interference, reflection, refraction and diffraction (ripple tank) [5min].

Section 13	*Start of Lesson 3* – Discussion on the concepts of reflection, refraction, diffraction and interference [3min 5s].
Section 14	Teaching a key idea: superposition with demonstration (slinky spring) [12min 15s].
Section 15	Re-teaching superposition with the use of a diagram and simulation [10min 59s].
Section 16	Re-teaching superposition with demonstration (ripple tank) [15min 48s].

A lesson narrative is given for each section that is described in Table 6.2 (Electronic Appendix K). Four sections were chosen for in-depth analysis: Sections 4, 6, 14 and 16. These four sections were chosen because they are rich in data and are relevant to the three key ideas on which this study focused. Sections 4 and 6 will be discussed separately, addressing the key ideas of wavelength and frequency respectively. Sections 14 and 16 will be discussed together, both pertaining to the key idea of superposition. In this case study, I include the full narrative and will discuss the results in detail. This is to give the reader an idea of the analyses, the thinking and methodology that were employed throughout all three case studies.

6.2.1.1 Section 4 of Jessica's lesson and discussion of components

In Section 4 of her lesson, Jessica was teaching the key idea of *wavelength* (Electronic Appendix K). Figure 6.1 is a coded, narrative account of the section (using the codes from Table 6.1).

Section 4: Teaching a new key idea: wavelength

The teacher refers to what the learners called *the wave* being from the start of the crest to the end of the trough and indicates that she will correct their use of terminology and therefore use the word *pulse* (**LP**). She explains it as one wave cycle. The teacher discusses particles again and the way they move, i.e. how some are about to go up and others that are about to go down. She indicates that particles are not all in the same movement (thus in and out of phase but doesn't use that terminology). The teacher tells the learners to be careful when answering questions about a wave and a wave cycle. When a question refers to a *wave;* it refers to the whole diagram that has been drawn referred to in the question and is not just referring to a wave cycle, which is one pulse (**WDT**; **LP**). The teacher then moves on to talk about the wave height, using the terminology that the learners originally used (**CS**; **LP; TS**). The teacher starts to discuss the idea of particle movement from the rest position to the highest point. She asks the learners to indicate the term used for this, leaving the learners to answer (**LP**; **TS**). One learner answers using the term *amplitude* (**TS**) which the teacher indicates is correct. The teacher explained that the learners used the phrase *length of the wave* when observing the wave using the slinky spring (**CS**; **LP; TS**). She asks a specific learner to name what he thinks the term is going to be (**LP**; **TS**). The learner answers “wavelength”. She mentions that it is how long one cycle is. She introduces the Greek symbol of lambda (**CS**) and indicates that it represents one wavelength, the length of one pulse. A learner asks the teacher if a pulse and wavelength are not the same thing. The teacher indicates that a wavelength can be from crest to crest, trough to trough or halfway up to halfway up of the next point (**CS**; **LP**). She explains that a pulse is describing the image drawn on the board involving one crest and one trough and that wavelength is the length of that wave cycle as a distance (**LP**).

Another learner asks for clarification between a pulse and a wave cycle. The teacher goes back to refer to what the learners saw on the floor with the slinky spring (**LP**) and then draws another wave cycle in another colour on the board (**RP**) and names it a 2nd wave cycle. This clarifies the learner's confusion (**WDT**; **LP**). The teacher indicates that the starting point of a wave is where the *source* is (**CS**). A learner asks: how do you measure where one pulse ends and another starts? The teacher explains either through measurement using a diagram but otherwise using a measuring machine or device or if one could take photos and snap shots, then it would be possible to measure it (**CS**; **WDT**). The teacher feels the need to redefine *wavelength* and indicates that it can be measured from different points along the waves but as long as you measure between two consecutive points that are in phase (**TS**). A learner indicates that she is confused about a pulse and one wave cycle. She asks if they are the same thing. The teacher indicates that they are (**WDT**; **LP**). The teacher again reiterates that if one is drawn it is referred to as a ‘pulse’ and if many are drawn consecutively then it is referred to as ‘wave cycles’ because there are many pulses being repeated (**WDT**; **LP; TS**). Another learner asks if a wavelength can be defined as the length of a pulse but the teacher says not to use that definition and indicates that the booklet contains the correct definition. The teacher reiterates that the wavelength can be from peak to peak (**TS**). It is the same thing but by changing the point of reference; as long as they have the same starting points it will give the wavelength i.e. hence one uses the terms *two consecutive points*.

Figure 6.1: The lesson narrative for Section 4 of Jessica's lesson.

Curricular saliency

The key idea of *wavelength* was taught during this teaching section. The participant showed awareness of the scaffolding of concepts, i.e. covering the subordinate idea of pulse, particle movement, wave height, amplitude, wavelength and source in this sequence. She built on the learners' knowledge using the terminology that they themselves used, i.e. *wave height* (line 8) and *length of the wave* (line 12) when they observed a wave using the slinky spring (during Section 2) in order to stimulate and develop the learners' conceptual understanding (Figure 6.2). The participant explained different ways in which one can measure wavelength (line 16 & 17) and, as such, indicated awareness of the application of wavelength to scenarios outside of the classroom environment (line 24-26). As a result, the knowledge revealed about curricular saliency was considered **rich**.

During Jessica's VSR interview, we viewed a clip where she was using the slinky spring at the back of the classroom to generate a wave cycle. She asked the learners, "what can you say about that wave? What can you say about the slinky?" When I asked her to reflect on the event, she responded as follows:

> *I was asking them to relate it to something and describe what they were seeing, so, [to] try and describe what was happening in their own words. If that's in their own words, they're able to explain it.*

The participant allowed the learners to answer in their own words and terminology in order to stimulate their conceptual development. Figure 6.2 below shows Jessica's demonstration.

Figure 6.2: Use of the slinky spring by Jessica to develop conceptual understanding through discovery in Section 2, which assisted in conceptual development in Section 4

Learners' prior knowledge

The participant referred to what the learners had observed in Section 2 when using the slinky spring (Figure 6.2) and linked what they observed with the terminology they used, i.e. wave height and the length of a wave. From there, the participant built on their existing knowledge to further develop understanding of the concept and adjusted their terminology to the correct terminology. The participant paid attention to most of the known misconceptions relating to the idea of *wavelength*, i.e. how wavelength is measured (line 16-17). She spent a lot of time making sure that the learners understood this key idea by reiterating the important aspects (line

26, 32-35). She continuously assessed the learners' understanding through questions (line 10 & 13), which were aimed at conceptual development.

However, from Section 4, it is evident that Jessica had her own misunderstanding about the subordinate idea of a pulse and a wave cycle. She referred to a wave cycle as one pulse (line 2-3). She further indicated that lambda represents one wavelength, which is the length of one pulse (line 15) and that the diagram on the board, which had one crest and one trough (Figure 6.3), represented a pulse (line 18). When a learner got confused and asked if a pulse and a wave cycle were the same thing, the participant indicated that they were (line 28-29). As such, the participants' *knowledge about learners' prior knowledge* was scored as **adequate**.

In her VSR interview the teacher further explained:

> *I… try and make sure that they make their own connections. I try and help them make sure that they did think by themselves and allow them the freedom to ask and find their own answers.*

Through her reflection, her response links to what was observed during the lessons. She made a concerted effort to allow the learners to facilitate and construct their own conceptual understanding through exploration. This further motivates the **adequate** score that was given to her, despite the revealed misunderstanding about a pulse and wave cycle.

Representations

In this particular teaching section, Jessica did not use representations other than referring back to the diagram of a wave cycle (line 7 & 25) that she drew during Section 3 (Figure 6.3). It is worth mentioning that it was in Section 2 where she initially introduced the idea of the *length of the wave* using the slinky spring as a representation. The ripple tank was not used to illustrate the key idea of *wavelength*. The participant relied on a diagram only and did not support the explanation with a physical demonstration. In view of this, I considered her knowledge as **adequate.**

Figure 6.3: Jessica using the wave diagram as a representation

Conceptual teaching strategies:

The participant revealed **rich** conceptual teaching strategies because she allowed the learners to learn through exploration, building from their own terminology (line 9 and 12-13) and reconstructing their ideas through guidance and questioning (line 10 and 13) in the pursuit of conceptual development. She facilitated the development of ideas and terminology while addressing learners' errors, confusion and the common misconceptions about *wavelength* and how to determine a wave cycle (line 22). Although she did not have the correct idea of a pulse, she was observed to adapt her strategy based on the learners' needs when she realised that the learners required further explanations and reiterations about the subordinate ideas of a wave cycle and waves, and the concept of wavelength and how to measure it (line 26, 29-30 and 33).

Integration of PCK components

The participant indicated knowledge of curricular saliency through the way in which she sequenced the teaching of concepts. She built on the learners' prior knowledge to reconstruct their ideas and to teach the correct ideas and terminology. Jessica addressed the learners' concerns and confusion unhurriedly. She recognised what is normally difficult to understand and alerted the learners to the common misconceptions in order to prevent them from developing the same misconceptions. Although no representations were used in this particular teaching section, a good choice of representations was used in previous sections to stimulate conceptual understanding of *wavelength*. As a result, her knowledge is considered **rich**.

Pedagogical reasoning

During the VSR interview, the issue was raised as to why she chose not to use the ripple tank to illustrate *wavelength* (and *frequency*) and rather went straight into using the ripple tank to illustrate the concepts of interference, reflection, refraction and diffraction. When I asked her to reflect on this, she responded:

> *…the topic of that session was mostly doing the different properties…of the waves. I also think that with changing the frequency and with getting them to measure the wavelength, because it's difficult to see and… because I didn't have the stroboscope, I didn't think they would be able to really see that clearly. I could supposedly have changed the frequency, and I think I did try [not observed], but I was also scared that they wouldn't see the effects.*

Jessica's explanation for why the ripple tank was not used to illustrate wavelength did not reveal rich *pedagogical reasoning*. Her reasoning did not make much sense knowing that she was trained on how to use the ripple tank and stroboscope to show wavelength and frequency. Furthermore, during the intervention, she showed enthusiasm when she was shown how to use it, and was excited about its benefits while observing the change in *frequency* and *wavelength* while adjusting the ripple tank controller. As such, her *pedagogical reasoning* was rated as **limited**.

6.2.1.2 Section 6 of Jessica's lesson and discussion of components

During Section 6 of her lesson, the participant was observed teaching the key idea of *frequency*. Figure 6.4 is a narrative account of the section, which includes the coded events (using the codes from Table 6.1).

Section 6: Teaching a key idea: frequency; and subordinate idea: period

The teacher talks about the unit for amplitude and that wavelength is also measured in meters, but that [2]wavelength units can be converted to smaller units such as nanometres or millimetres. This would involve having to incorporate scientific conversions. At this point, the teacher makes learners aware of the terms [4]*frequency* and *period* (**CS**). The teacher refers to how the learners previously referred to the *speed* of the wave when they were observing the wave, using the slinky spring illustration (**LP**). She explains that she is [6]going to now use the term *frequency* and asks the learners what is meant by the term 'frequency'(**CS; LP**).

A learner answers by saying that it means 'how much'. Teacher asks: how much what? (**TS**) Another learner answers: 'how many times you have it'. The teacher further probes asking: how many times you have it in what? (**TS**) A learner answers: How often something happens in a period of time (**TS**). The teacher indicates that when talking about frequency, it is related to a specific time; how often that cycle happened per month or how often you are paid per week etc. The teacher links everyday examples of the term *frequency* (**CS**; **LP; TS**). The teacher moves on to relate frequency to waves and asks the learners, "what do you think we are going to be talking about?"(**LP; TS**). A learner answers: "How many waves pass in a certain amount of time." The teacher refers to the diagram that was previously drawn on the board and is still seen on the board (**RP**). The teacher shows the learners using the diagram that if one has one wave cycle then a next wave cycle, all happening in one second, then they have two waves happening in that period of time, i.e. one second. The teacher further defines frequency as how frequent that wave is passing a point in a certain amount of time. She reads the definition of frequency from the booklet. The teacher then talks about the unit of frequency; Hertz (Hz) and that it is named after someone. Thus, one must use a capital *H* when writing Hz (**CS**; **TS**). She further discusses that it's the number of waves per second and is thus referred to as 1/s or s^{-1} (**CS**). The teacher moves into introducing the subordinate concept of period (**CS**). She asks the question: "If there is only one pulse, how do we know its speed then?" (**TS**). A learner answers that it is how long it took to make that pulse. The teacher explains that period is when one talks about how long each wave cycle is. The teacher makes sure that the learners understand that they need to know the difference regarding frequency and period (**WDT**; **LP**). The teacher further cements the difference between the two by explaining another way of looking at each (**LP; TS**). She says that with the one (frequency) one does not know how many waves occurred per second. However, for the other (period) it is the other way around. One knows how many waves occurred but not the time they took to occur. The teacher reiterates and pleads with the learners that they should not confuse the two (**LP; TS**). She states that she believes some of them will because it is one of the easiest things to confuse (**WDT**; **LP**). The teacher refers to the booklet to further discuss the definitions of frequency and period. The lesson ends and the teacher concludes by asking the learners to go over the definitions for homework knowing that they have a test to learn for, for the following day.

Figure 6.4: The lesson narrative for Section 6 of Jessica's lesson

Curricular saliency

The participant had **rich** knowledge of curricular saliency for the key idea of *frequency*. Although Jessica directly made use of the term frequency, she ensured that the learners understood the meaning of the word and then in terms of waves (lines 4-13). She discussed its unit, adding why Hertz needs to be written with a capital 'H', adding general knowledge about writing units in science (line 18-20). The participant extended the learners' knowledge by explaining that Hertz means 'per second'. She then moved onto the subordinate idea of period (line 20-21). It is therefore evident that she had knowledge of the appropriate sequencing of applicable ideas that should be in place and therefore linked the concept of frequency to the pre-concepts and other future ideas.

Learners' prior knowledge

Knowledge of learners' thinking was evident as Jessica began to teach the concept, relating it to what the learners originally termed as 'speed' (line 4). Through this, it was evident that she had knowledge of learners' understanding and used this knowledge about the way in which the learners were thinking during the lesson. The participant quickly addressed this incorrect term by using the correct term 'frequency', but did not define the term 'speed' at that point. From there, she built learners' understanding from the everyday word 'frequent' and linked it to the topic of waves (line 6-13). This, again, revealed her knowledge about the way in which the learners were thinking. The teacher broke down difficult ideas into understandable units, which were seen to be sequenced logically, i.e. she addressed frequency first, then period, then she indicated their differences, rewording their definitions for further clarification (line 25-28). She paid attention to possible learner misinterpretations, warning them that frequency and period can easily be confused (line 28-29), although she did so in a way that may have caused more confusion for the learners. After addressing the important aspects of frequency and that Hertz means 'per second' she illustrated on the board how Hertz can be written as $\frac{1}{s}$ because it means per second [line 20], (Figure 6.5). During the latter part of the section, line 22, Jessica reused the term 'speed', which was used incorrectly and could have confused the learners' understanding about the term, considering it had not yet been discussed. In addition, as seen in line 23, she used the words "how long each pulse or wave cycle **is**" which refers to its length and not the time interval which the word 'takes' would have referred to. This may have confused the learners'. In light of this, I scored her knowledge of learners' prior knowledge as **adequate** for the key idea of *frequency*.

Figure 6.5: Explanation of Frequency and Hertz carried out by Jessica.

Representations

Again, the participant was not observed to use a variety of representations in this section other than referring to the diagram of a wave cycle that she drew during Section 3 (line 4-15). In addition, the ripple tank, which was made available to her, was not used to illustrate the key idea of *frequency* in this teaching section or in any of the sections to follow. The use of representation did not fully support the development of the key idea. She used a diagram that was a snapshot of a wave, but the motion of the wave could not be appreciated by the learners. She did not use representations in combination. As a result, her knowledge was considered **adequate** for this component.

Conceptual teaching strategies

Jessica's conceptual teaching strategies were scored as **adequate to rich** for the key idea of *frequency.* The participant achieved learners' conceptual development by correcting them in their use of the term *speed* to the correct term of frequency (line 4). At this early stage of understanding frequency, the participant, however, did not explain that $v = f \times \lambda$. She showed awareness of sequencing of ideas, making sure that learners understood the concept of frequency before teaching the subordinate idea of period (line 20-21). She made use of the diagram previously drawn on the board (line 4-15) and applied the technique of using a different approach by rewording the definitions of frequency and period to further cement their ideas (line 24-30). Her knowledge of teaching strategies in terms of concept sequence, use of a representation, and through the integration of a different approach into her strategy to support conceptual change and development was evident. However, at times, the participant used confusing explanations (lines 26-28), causing her teaching strategy to collapse slightly, which may have been due to the limitations in her own conceptual understanding.

Integration of PCK components

Jessica introduced *frequency* and the subordinate idea of period in a logical order during this teaching section. However, she did not use other representations to assist in learners' understanding of frequency other than a diagram drawn on the board, and did not address any further learner difficulties. As a result, her competence in integrating the components was considered **adequate**.

Pedagogical reasoning

It is for similar reasons, as explained in the narrative in Section 4, that I considered Jessica's *pedagogical reasoning* to be **limited**. The participant stated her actions and decisions, but failed to provide a rationale for her decision regarding the use of the ripple tank for the illustration of *frequency*, despite having been shown how during the intervention.

6.2.1.3 Sections 14 and 16 of Jessica's lesson and discussion of components

In Sections 14 and 16 of her lesson, Jessica taught the key idea of *superposition* (Electronic Appendix K). Figure 6.6 and Figure 6.7 respectively show the narrative accounts of the sections that have been coded as per Table 6.1.

Section 14: Teaching a key idea: superposition with demonstration (slinky spring)

The teacher indicates to the learners that they will not be covering interference in too much detail because it is not entirely important to know for the matric paper (**CS; TS**). The teacher introduces the concept by indicating to the learners that there are two types of interference and that they need an understanding about when interference happens in a 'good way' and a 'bad way' (**CS; LP**; **TS**). She asks what learners understand by the term 'good interference' and what it will do to the waves (**TS**). A learner answers by saying that it may make them bigger (**TS**). The teacher agrees and indicates that it will increase in size. The teacher used every day terminology to initiate learner thinking by saying, "If I interfere in things in a good way, what do we call it?" (**LP**; **TS**). The learners answered in chorus saying, "*constructive*" (**CS**). The teacher briefly explains verbally about constructive interference using two pulses. The pulses would combine and get bigger. The teacher moves on to the other type of interference. She asks, "When I interfere in a bad way, what it is called?" (**TS**). A learner indicates that it is when "we get smaller". The teacher brings in how it can be cancelled out for a moment. She then asks them to give it the right term by thinking of the opposite to constructive interference. No one answers and she supplies the correct term as *destructive* (**CS**).

At this point, a learner takes it quite literally and asks the teacher if the destructive interference is a bad thing and if the constructive interference is a good thing. The teacher explains that it is just an analogy to help learners understand that bringing a person up through something constructive is making them 'bigger' to illustrate making waves bigger and that destructive, which is a bad thing in life, is making the waves smaller (**LP**; **TS**).

The teacher goes to the back of the classroom to illustrate the concept using a slinky spring to generate pulses (**CS; RP**). The teacher gets the learners involved by getting two learners to hold the slinky spring on either side and to stretch it out. She reminds the learners about a pulse (**LP**) and a learner uses the slinky to re-illustrate it as a reminder to the learners. She asks one of the two learners holding the slinky to generate two pulses with the one after the other. She explains that the two pulses seen do not affect each other because they are going the same speed and in the same direction. The teacher comments on the beauty of seeing the slinky spring when waves are coming from different directions. She explains that the waves have different sources and thus different directions. She asks the two learners holding the slinky spring to each generate a pulse to each form a crest. She states that the two waves would be from different sources and would be moving in opposite directions. The illustration is not effective but the learners continue to try. Eventually, the teacher realises that it is being illustrated too fast to observe. She asks the learners what is happening? (**TS**) A learner answers: They meet and go back (**WDT**). The teacher then further stimulates the learners thinking by asking the following: So, what happens when they meet? (**TS**). The learners still believe that it bounces back by stating as their response to the teachers question that "the waves bounce back". The teacher pauses (**WDT; LP**). The teacher therefore asks *one* of the learners who is holding the slinky spring to illustrate one pulse again and shows the learners that the pulse continues along the slinky spring all the way to the end (**RP**). She then asks why when there would be two pulses from opposite ends that they think it would now bounce back? (TS). A learner answers that it is because there are two and so they bounce off each other. On a side note, a learner talks about seeing reflection in the slinky spring and the teacher agrees. She also tells the learners that they are observing it because a learner is holding the one end and it will naturally reflect off the learners' hand. She tells the learners to ignore the reflection for now (**LP**; **TS**).

The teacher then tells the learners that they should be observing something when the pulses meet. She allows the learners to observe the effect again and to try to explain what it is they observe. The learners battle to answer and the teacher asks the two learners holding the slinky spring to carry out the illustration again for the learners (**LP; RP; TS**). The teacher asks again: what did we see in the middle? (**TS**) Still the learners do not answer and she suggests that the slinky is made to be less stretched. She reminds the learners that it happens quickly. Eventually a learner says, "there were two that became one", which the teacher repeats. She then asks them to compare the two that they see to the one that they observe. She further asks: What can we say about the one in the middle compared to the one on the sides? (**TS**) A male learner tries to explain, but he also states that when there is one it's a good interference and when there is none it is a bad interference (it is the same learner that asked earlier about 'good' and 'bad' interference) – the teacher indicates his wrong thinking (**WDT**; **LP**; **TS**).The teacher eventually explains to the learners that there is a bigger wave in the middle because they are joined. The learners that are holding the slinky spring try use it to illustrate the concept again but off the floor. The learners seem to see it better illustrated this way (**RP**). The teacher then explains that the crests on either side are combining and as a result getting a new crest that is the same height as the two pulses combined.

She indicates that what they observe is constructive interference, which is seen better at the crests and troughs. Crests to make bigger crests and the same for the troughs. The teacher goes back to what the learners were stating earlier regarding the term 'bouncing back' (**LP**). The teacher goes straight into explaining that the pulses are not actually bouncing back and are in fact carrying on through. She explains that they are only appearing to be bouncing back because the pulses return to the same size that they were.

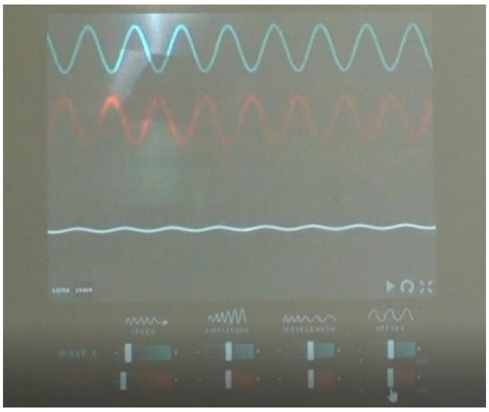
The teacher then asks what they think the difference is in terms of destructive interference (**TS**). A learner says, "moving the slinky in opposite directions", while indicating on the floor that the one learner must move the slinky up and the other must move the slinky down. The teacher elaborates and indicates that instead of a crest meeting a crest;one would introduce a crest meeting a trough. She goes back to their new understanding about how a crest meeting another crest gets bigger. She then asks: what will happen when it is crest to trough? (**TS**) A learner straight away says that they will even out and become flat. The teacher allows the learners to illustrate the concept using the slinky spring but it is not easily seen. They do all acknowledge that there is not a large crest in the middle, as before. After doing the illustration using the slinky spring "sideways along the floor, they illustrate the idea of using the slinky spring off the floor (perpendicular to the floor). Gravity is against them and they realise it will not work. The teacher tells them that they are meant to see 'cancelation' which carries on after waves meet.

Figure 6.6: The lesson narrative for Section 14 of Jessica's lesson

Section 16 took place in the middle of the lesson. Jessica had put up a simulation showing three waves, each illustrated as a different colour. Wave 1 and Wave 2 were two separate waves seen one above the other. Wave 3 was the product of the two waves when they interfered. The learners were already observing the simulation at the point where Section 16 begins.

Section 16: Re-teaching superposition with demonstration (ripple tank)

The teacher states that interference but of water waves will be seen later using a ripple tank. She states that they have not yet answered the question: what the bright or dark lines represent** (**LP**; **TS**) She promises to illuminate this at a later stage. While still looking at the simulation, the teacher asks them to choose, for illustration purposes, what they believe the lines will represent (**LP**; **TS**). The learners choose the bright lines to represent the crests. The teacher then asks the learners: When the crests combine, what do they think will happen to the brightness of the lines? (**TS**). A learner answers and the teacher repeats her answer, stating



that they will get brighter. She asks in a similar manner: if the troughs are then the darker lines, what will happen when they meet? (**TS**) In chorus the learners say, "they will get darker". The teacher indicates that this is what they will see in the ripple tank:

The teacher starts to illustrate interference using the ripple tank at the back of the classroom (**RPRT**). The teacher indicates that using the ripple tank, she is going to illustrate interference. She first illustrates interference using the option of the longer metal barrier placed at an angle (**CS; LP**, **RPRT**). She indicates that the learners should not only see waves moving towards the barrier, but that they are also interfering with those that are reflecting off the surface of the barrier. She produces a pulse using the ripple bar. She asks if they can see the 'cubes' indicating interference due to reflection (**TS**). She does the same, but with the motor, to illustrate the same principle but using waves.

A learner points out the interference and reflection. The teacher uses this opportunity to discuss how lines appear darker and lighter because of the interference of crests being higher and troughs being lower (**CS; LP**). The teacher agrees that the learner is interpreting it correctly, where the crests and troughs meet bigger crests and troughs form. She also indicates that, according to the learners, the crests would then be the bright lines which form even brighter lines when they interfere and darker lines when the troughs interfere. A learner then comments: "according to science". The teacher interrupts the learner and remarks that it may be the opposite effect according to science but will prove it to them later when they cover refraction in more detail (**LP**,**WDT**,**TS**). She leaves the learners intrigued by this statement, not correcting them or indicating if they are correct, she moves on(**TS**).She asks if the learners see a change in the intensity of the light and dark "spots" and explains that it is as a result of the interference just discussed on the board using the diagram and simulation (section 15) (**TS**). The teacher asks: what do you think would happen if one use circular ripples? (**CS; TS**). No one answers and she sets the tank up to illustrate it. She asks: what is going to happen to the waves when they start to interfere as circular waves? (**TS**). She indicates that she will do a pulse to allow the learners to think and predict before illustrating the effect using wave fronts (**RPRT**). A learner says that they will interfere. The teacher says: yes, but how? She pauses and allows the learners to think and predict A learner suggests hypnotism – although very off the topic. The teacher made the learners aware that it was not hypnotism and made them focus on what was at hand again.

Another learner says that the circles will interfere with each other. The teacher indicates that, again, they should see the bright and dark lines but they are not going to be squares as seen with reflection off the barrier and that the wave pattern will be something different (**LP**). She then sets the ripple tank up with two balls to illustrate the effect (**RPRT**). While trying to do so, the battery of the controller became flat. The teacher showed the effect manually pushing the ripple bar down to illustrate the principle, until the battery was changed (**RPRT**). She made the learners aware of the sections where the waves seemed brighter and darker and where they seemed to disappear and cancel each other out. The motor is then used and the teacher points out that the areas of interference are more like dots and therefore there are dots that are lighter and others that are darker. The teacher makes the learners aware of lines coming from the source (balls) and then asks them what they think is happening at those points. (**TS**) A learner uses the term *arcs* and says that they continue on. Some learners are battling to see the effect and the teacher uses her finger to show the learners the areas of complete destructive interference again (**RPRT**; **LP**) and refers to them as grey lines. She asks the learners again: what is happening? (**TS**) A learner answers that they are cancelling out. The teacher then asks: why do you think they are cancelling out? (**TS**). The learners battle to answer her so the teacher goes back to the foundational ideas. She asks: how do we see waves? (**LP**; **TS**) They answer by saying that there are crests and troughs. She then asks: how are they seen in water? (**TS**) The learners answer that it is through light and dark lines (**LP**). She then asks: So then, if there were no waves? (**TS**). The bell rings to indicate the end of the lesson and therefore the teacher is forced to tell the learners that the grey lines represent areas of total [52]cancellation.

**The bright and dark lines are the projection of the water waves on the white table underneath the ripple tank.

Figure 6.7: The lesson narrative for Section 16 of Jessica's lesson.

Curriculum saliency

It is evident that Jessica made an effort to follow a logical sequence and displayed awareness of ideas needing to be in place before superposition could be fully understood, i.e. that there were two types of interference (line 3-13 of section 14), although the example of good and bad interference was not a very scientific example. However, the statement made in line 2 may indicate teaching to the test and not for conceptual development. She reminded the learners of their prior knowledge regarding a pulse (line 19 of section 14). She first introduced the concept of interference using reflection and linear wave fronts (line 12 of section 16) before moving onto the idea of interference using circular waves (line 27 of section 16). She also engaged the learners in higher-order thinking by introducing the idea of lighter and darker ripples (line 17 of section 16) but only once the easier subordinate ideas were addressed. In view of this, her knowledge was rated as **rich**.

Learners' prior knowledge

The participant made a concerted effort to help learners understand that there were two types of interference by using terms to which learners could relate, i.e. good and bad interference (line 3-13 of section 14), although as mentioned, it was not a very effective or particularly a scientific explanation and was an analogy that a learner took quite literally (line 14 of Section 14). However, this still revealed her knowledge of the topic and use of knowledge about the way learners were thinking regarding the concept. The teacher illustrated her patience while responding to and addressing the learners' confusion. During the slinky spring illustration, the learners were battling to understand and were not seeing the effect of constructive interference in the slinky (lines 32, 41, 43 and 50 of Section 14). The participant adjusted her teaching techniques to address their concerns. The effect was eventually seen. It was through the teacher continually asking questions, not giving up on the slinky illustration (Figure 6.8 (a) and (b)), and her repetition and amended approaches that assisted and guided the learners to understand the concept (coded TS in Section 14 and 16). The participant also kept the learners intrigued with the idea of which part of the waves were projected as lighter and darker lines (lines 17, 41, 49). Jessica knew that the answer lay in a section describing the phenomenon of refraction, which had not yet been addressed. However, she guided them through questioning towards conceptual understanding.

Furthermore, when asked during her VSR interview to reflect back on which lessons she believed best approached and dealt with learners' misconceptions, she responded as follows:

> *I think when they are with the representations…when they [are] actually seeing what's happening and try[ing] to make sense of it in their heads, then they can ask the questions and also because of the way… I did prompt them, they were able to discover what was going on. I was able to see what they were getting, what they were not getting because they were more vocal about it*

The participant displayed *knowledge about representations* and *learners' difficulties* by referring to the benefits of using representations to become aware of learners' misconceptions. As such, her knowledge of learners' thinking was rated as **rich**.

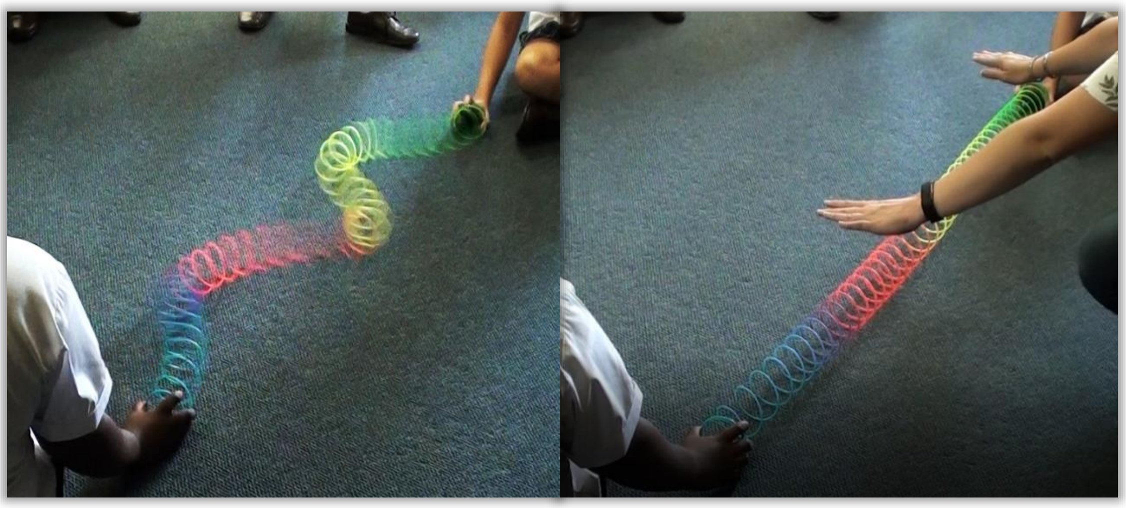


Figure 6.8: (a) and (b): Using the slinky spring to facilitate conceptual understanding about interference

Representations

The participant was rated as having **rich** knowledge of representations. From Section 14 through to 16, Jessica used a number of different representations, i.e. a slinky spring (referred to from line 19 to 67 of Section 14), a pulse diagram drawn on the board (referred to in line 26 of Section 16), a simulation (referred to in line 27 of Section 16) and the ripple tank apparatus (Figure 6.8 (a) and (b), Figure 6.9 (a) and (b)) (referred to from line 10 of Section 16). Through the extensive use of the representations and learner discovery, she supported learners' understanding of the concept of superposition and stimulated conceptual reasoning through the questions that she asked.

When she was asked during the VSR interview to explain her reasoning for going to the back of the classroom to use the slinky spring and then to the board to draw a diagram, she responded as follows:

> *… that was to create an image that they could refer to mentally when they are revising…at the end, we took it back to the board because that is common[ly] how they are going to be assessed, so putting it in a format that they can be familiar with for any assessments.*

The participant was aware of the importance of representing the concept to ensure learners' understanding, as well as the importance of linking the representation in a format necessary for assessment purposes.

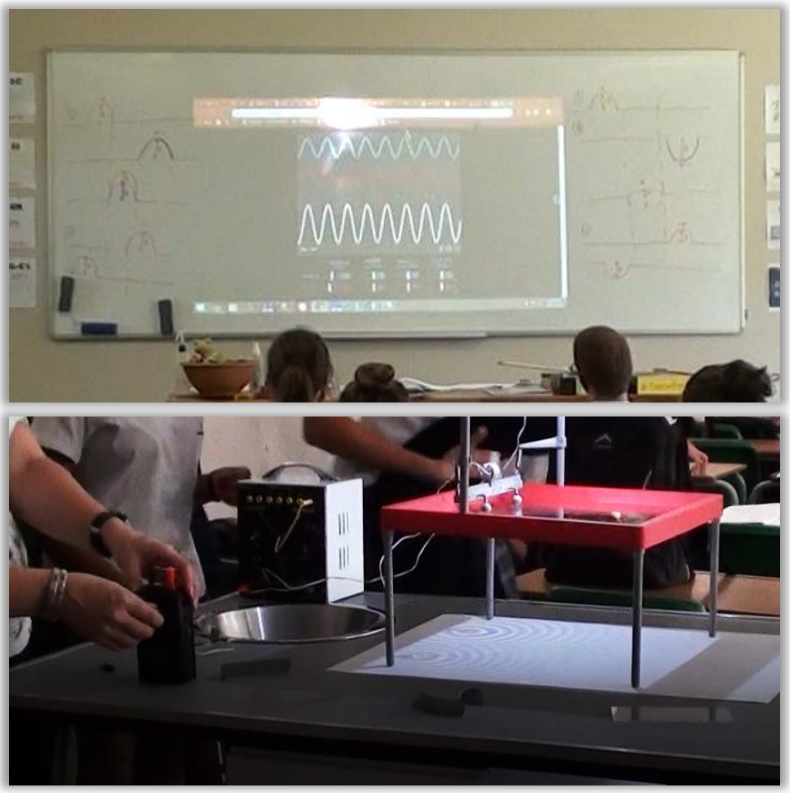


Figure 6.9: (a) Simulation and diagrammatic representations used by Jessica for the topic of superposition; and (b) Use of the ripple tank to explain the topic of superposition

Conceptual teaching strategies

Jessica's conceptual teaching strategies were of a high standard. She understood what was necessary to teach, recognising that the concept was not essential for Grade 12 assessment (line 1-2 of Section 14). Her teaching strategy supported conceptual reasoning through questioning and representations that followed a logical sequence. She continuously asked questions to elicit learners' thinking and would wait for responses before giving answers (examples include lines 4, 5, 12, 14, 29 of Section 14 and lines 5, 7, 14, 25, 27 of Section 16). Through this questioning and discourse, in combination with her knowledge of typical misconceptions and through the use of representations, Jessica supported conceptual development. Furthermore, all other components and representations were incorporated in a logical sequence, adding to her teaching strategy (evidence discussed under *representations*). It is for these reasons that the participant's knowledge was considered as **rich**.

Integration of PCK components

The sections indicate a well thought-out lesson with curricular saliency being evident in Jessica's approach. Her approach showed evidence of her thinking about learners' prior knowledge, as seen through the use of the specific terminology mentioned by the learners. She addressed the misconception of waves continuing along their path, bouncing back after interference. The participant used a slinky spring, a diagram, a simulation and the ripple tank apparatus as representations. When the participant realised that learners were battling to recognise the concept using the slinky spring illustration, she remained flexible and adjusted the lesson based on the learners needs. As a result, her score for the *integration of PCK* components is considered **rich**.

Pedagogical reasoning

In the VSR interview, Jessica indicated that through reflection on the lessons, superposition was one of the concepts that she found the easiest to teach and that it was a concept that the learners found the easiest to understand. Evidence of this was made seen in the following statement:

> *…I do think they found interference… quite easy… in terms of noticing it. Not necessarily explaining it, but noticing it. There were so many examples of it during the sessions… they… have a good idea [of] how to identify interference.*

It was evident during the lessons that the participant believed that superposition was one of the easiest concepts to teach, however, she did not reflect on the difficulties learners had in understanding that the waves did not bounce back from the point of interference. However, the learners were observed to eventually have a good understanding and were able to identify the phenomenon while it was being demonstrated. In view of this, I scored her *pedagogical reasoning*, **rich**.

6.2.1.4 Other evidence concerning the use of the ripple tank as a representation

The teacher used the ripple tank as suggested in the intervention (see Figure 6.10 (a) and (b)), but not when teaching wavelength and frequency. However, it must be noted that the participant used the ripple tank to illustrate the concepts of reflection, refraction and diffraction (see narrative accounts, coded as RPRT, for Sections 9, 10 and 11 in Electronic Appendix A).

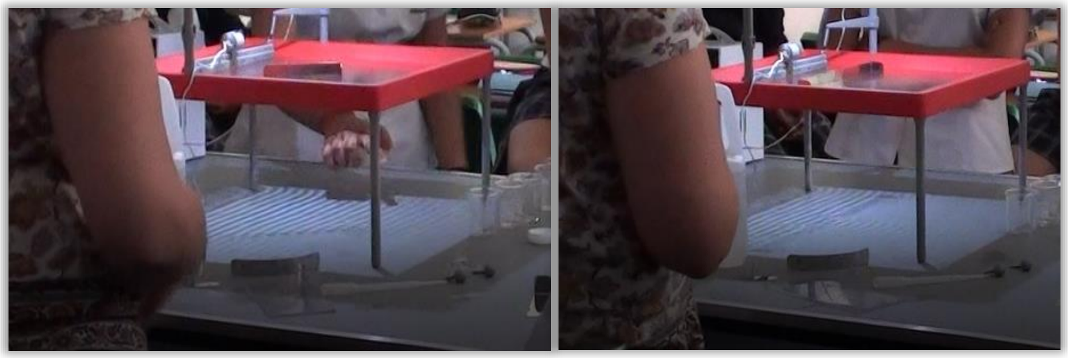


Figure 6.10: (a) Example of the use of the ripple tank to illustrate the concept of reflection; and (b) Diffraction

6.2.1.5 Other evidence from the VSR interview not relevant to the sections chosen

Other evidence was obtained from the VSR interview but was not relevant to the sections chosen, therefore this evidence is presented in Appendix XIII.

6.2.1.6 Semi-structured post-interview

In the semi-structured post-interview (Electronic Appendix Q), the participant revealed that the training was clear, useful and beneficial. She indicated that her perceptions of the ripple tank were changed, having originally been quite opposed to using it. She indicated that the intervention showed her that there were more things that could be done using the ripple tank. She explained that the training gave her more confidence but that she felt at times "a little bit insecure" because it showed her that she did not know everything that she could have known. The participant disclosed that her content knowledge had been broadened and that she learnt more about the apparatus and its use to illustrate the different phenomena of interference, reflection, refraction and diffraction. She believed that she benefited from the in-service training and liked best that the training was at a slow pace, allowing her to talk and ask questions. She stated that she enjoyed that it was interactive because at other training sessions, she felt distant and rushed.

It is interesting to note that the participant also mentioned that the rest of her department was using the ripple tank that was provided and that she had trained a new colleague on the use of the same apparatus after she was provided with the in-service training. When the participant was asked whether she would recommend the same in-service training to other teachers, she indicated that she would because "one never stops learning". The participant stated that the learners had drawn wave fronts "better or clearer" as compared to the learners from the previous year who were not exposed to the illustration of wave fronts using the ripple tank apparatus. Furthermore, she said that the learners seemed to grasp concepts much quicker after observing waves using the ripple tank. The participant compared PhET simulations to the hands-on apparatus and mentioned that she felt that simulations were helpful in reinforcing the concept that she was trying to teach but that they did not aid in the initial teaching of the concept. She explained that even if the learners did not understand everything to begin with, the ripple tank was a good tool to show the learners, giving them a mental image of what "is going on" while asking them what they observed. She stated that she would continue to use the ripple tank because it is vital and has great benefits as compared to the use of simulations or a stationary diagram drawn on the board. Her final comment was that she felt that the training could have been longer in order to gain more "tricks and techniques". This information provided by the participant is relevant and can be considered for future in-service teacher training.

6.2.2 Case Study 2 – Tshuma

Tshuma taught in a school following the CAPS curriculum. I observed three of his lessons, however, when it came to the first observation, it was clear that he had already started teaching the topic. I therefore did not observe him teaching the foundational concepts of wavelength, frequency or the subordinate idea of period. Instead, I observed the teaching of these ideas when the teacher reinforced them while working through past examination paper questions. Therefore, the scores given for the two key ideas of wavelength and frequency were based on what I observed during these lessons. I did not observe the participant teaching superposition and therefore no scores could be allocated for the key idea of superposition. From the three lesson observations, 14 sections were identified and are presented in Table 6.3 below.

Table 6.3: Lesson sections for Tshuma

Section 1	*Start of Lesson 1* – Revision of knowledge and application of: transverse waves, wave equation, propagation, phases and wavelength (past paper questions as a handout) [11min 22s].
Section 2	Application of knowledge about transverse waves: amplitude (past paper questions as a handout) [3min 58s].
Section 3	Application of knowledge about transverse waves: period, frequency and speed (past paper questions as a handout) [7min 16s].
Section 4	Application of knowledge about transverse waves: questions referring to wavelength, frequency and phases (past paper questions projected up on the board) [16min 49s].
Section 5	Application of knowledge about transverse waves: questions referring to wavelength and amplitude (past paper questions projected on the board) [4min 28s].
Section 6	*Start of Lesson 2* – Review on basic principles about longitudinal waves [2min 51s].
Section 7	Discussion of class exercise about longitudinal waves (carried out by two learners) [11min 47s].
Section 8	Continuation on the discussion of class exercise about longitudinal waves: calculations involving wavelength, the wave equation and the concept of speed (carried out by two learners) [6min 11s].
Section 9	Continuation of the discussion of the class exercise about longitudinal waves: calculations involving frequency (carried out by two learners) [4min 27s].
Section 10	Continuation of the discussion of the class exercise about longitudinal waves using a poster: further calculations involving frequency, wavelength and determining the number of waves (carried out by two learners) [6min 30s].
Section 11	Continuation of the discussion of the class exercise about longitudinal waves, allowing learners to complete the exercise related to examples of longitudinal waves that are experienced daily (carried out by the teacher) [6min 45s].
Section 12	*Start of Lesson 3* – Continuation of longitudinal waves: sound [6min].
Section 13	Continuation about sound waves with class discussion and textbook examples [9min 12s].
Section 14	Allocation of a textbook exercise on the concept of sound to the learners with further discussion about the exercise [21min 26s].

A lesson narrative is given for each section that is described in Table 12 (Electronic Appendix L). Unlike Jessica, where wavelength and frequency and the subordinate idea of period were covered in separate sections (Sections 4 and 6 of Jessica's lesson respectively), Tshuma covered the two key ideas and the subordinate idea of period collectively in Sections 1, 3 and 4. These sections were chosen to be discussed extensively because they are rich in data and are relevant to the two key ideas of wavelength and frequency on which this study focused. Although Sections 7, 8, 9 and 10 also address the concepts of wavelength, frequency and the subordinate idea of period, the lesson was primarily carried out by two volunteering learners and not by the participant. I therefore could not use this data as it was not observing the participant himself. Sections 11 through to 14 were related to the concept of sound waves and therefore are not relevant to the key ideas on which this study focused. The lesson narratives for Case Study 2 are available in Electronic Appendix L).

6.2.2.1 Sections 1, 3 and 4 of Tshuma's lesson and discussion of components

The full narratives for Sections 1, 3 and 4 can be seen in Electronic Appendix L. In Sections 1 (see Figure 6.11), 3 (see Figure 6.12), and 4 (see Figure 6.13), the participant was observed revising content, after which he continued teaching about the application of knowledge about transverse waves.

Relevant segments from Section 1: start of Lesson 1 – revision of knowledge and application of transverse waves, wave equation, propagation, phases, and wavelength (past paper questions as a handout)

Start of lesson 1: By writing on the board using the formula $v = f \times \lambda$ the participant explains to the learners that wave speed is equal to frequency x wavelength, with wavelength written as 'lambda'(**CS**). The teacher reminds the learners that they have covered the concept of *wavelength* and asks a specific learner to give its definition (**CS**; **LP**; **TS**). The learner answers correctly. The teacher reiterates that the wavelength can be measured from successive crests or troughs and can also be from one point to another point that is in phase (**CS; LP**; **WTD**; **TS**). He tells the learners not to forget what they have just discussed because they will see this type of question in examinations (**LP)**. The teacher further reiterates that the wavelength is not always measured from crest to crest and trough to trough (**CS**; **LP**, **WDT**, **TS**). He moves on to discuss the formula of $v = f \times \lambda$ while writing on the board and reminds the learners that they have already done calculations (**CS**; **LP**). The teacher tells the learners that sometimes they will be asked to calculate the *frequency*, without being given the speed and the wavelength of the wave (**CS**; **LP**; **WDT**; **TS**). He asks the learners what they would do in such a case (**TS**). A few learners answer that frequency equals the number of waves divided by the time. The teacher writes it on the board. The teacher then revises the idea that frequency can also be calculated by putting *1/T*, which represents one divided by the period of the wave (**CS**). The teacher then writes down *T* = and asks the learners how they will work out

T if they do not have the frequency (**TS**; **LP**). They discuss that they will use time divided by the number of waves and that T is also equal to *1/f* (**CS**; **LP**; **TS**) - he writes these on the board. The teacher reads out the question from the question paper, "Identify the type of wave shown above" and asks the learners to raise their hands if they know the answer (**TS**). A learner responds by stating that it is a transverse wave. The teacher asks him to explain why (**TS**), which leads to the next question of how the wave is propagated. No one answers to begin with and then a learner answers but incorrectly by stating that it has a trough and a crest. The teacher asks again how the wave is propagated and how a particle moves. The learner answers by saying: the disturbance is perpendicular to the propagation of the wave. He asks the learners if they are "fine" (**TS**) and then points out that they are going to start fighting over the next question, then he asks,"How many completed waves are indicated in the sketch". The teacher reminds them that they previously had a similar question and that they struggled to identify the number of waves (**LP**; **WDT**). The teacher reveals that he is aware that this is a challenge (**WDT**, **LP**). The teacher says that they should take their time to answer the question (**WDT**; **TS**). He asks the question again and the learners answer in chorus (**TS**). Some learners answer with "five waves" others answer that there are four waves. The teacher discusses the question with them while they follow him and his instruction while looking at the diagram (**TS**; **RP**). He shows that there are five-and-a-half waves. There is a huge class discussion over this, but the teacher allows this discussion to continue (**TS**). The teacher then indicates to the learners that alternatively, instead of measuring from crest to crest, the learners should start measuring from the beginning of the wave (**LP**; **WDT**; **TS**). He says this twice over. Eventually, the learners agree that there are five-and-a-half waves. The teacher again asks if the learners are "fine" (**LP**; **WDS**; **TS**).

Figure 6.11: The lesson narrative for Section 1 of Tshuma's lesson

Relevant segments from Section 3: application of knowledge about transverse waves: period, frequency and speed (past paper questions as a handout)

The teacher moves onto the next question, which says, "Show that the period of the wave is 0.67 s". The teacher tells the learners to think first and to see what it is they have been given (**TS**). He revises the two equations that they know, which are used to work out period and writes them on the board as being: *1/f and* time/number of waves (Fig.6.14) (**CS**; **LP**; **TS**). He allows the learners to discuss this question and to come up with the answer (**TS**). He poses the question: what do you have? And tells the learners not to rush (**LP**; TS). He asks the learners if they have information about frequency and they agree that they do not have the value for frequency. He then asks: what do you have? The learners indicate that they have information about the time and the number of waves. He does the calculation on the board (**TS**). He probes the learners by asking if they have information about the wavelength or speed (**TS**). The learners indicate that they have the value for the period of the wave. On the board, he writes the relevant equation for frequency: $f = 1/T$ and they substitute in the values as a class (**TS**). A learner points out that they could have used the other formula for frequency, which is the number of waves divided by time. The teacher agrees and they do the calculation together to prove that they get the same answer (**TS**).

Figure 6.12: The lesson narrative for Section 3 of Tshuma's lesson

Relevant segments from Section 4: application of knowledge about transverse waves: questions referring to wavelength, frequency and phases (past paper questions projected on the board)

The teacher puts another set of questions up on the whiteboard using the projector and states that they have 10 minutes to complete the questions (**TS**). The teacher reads through the question information with the learners (**TS**). The question is based on a ripple tank. He points out that they now have a ripple tank and so he will be using it to demonstrate to the learners how it works. The question information states that the distance between 13 consecutive wave crests in a ripple tank is 1.8m and that the wave travels through the water at a speed of 0,225 m/s. The teacher asks the learners if he can give them a clue for Question 2.2.1, which is to calculate the wavelength of the wave in meters and that it is to draw the 13 consecutive wave crests in order to determine the number of waves (**LP; TS**). He explains this because the question does not state 13 consecutive waves, it states 13 consecutive wave crests (**CS**). The teacher makes the learners aware of the fact that they may make this mistake and write down 13 as the answer to the number of waves (**LP**; **WDT**). He tells the learners how to work out the wavelength of the wave by taking the distance given as 1.8m and dividing it by the number of waves. He then allows the learners to continue answering the questions on their own. The teacher points out that they could not have used the formula $v = f \times \lambda$ to determine the wavelength. The teacher reiterates that to work out the wavelength, they will have to take the total distance given and divide it by the number of waves (**CS; TS**). He asks the learners how many waves they see to be present after drawing the 13 consecutive waves (**TS**). The learners indicate that there are 12 waves. He stipulates that through a simple division they get the answer to Question 2.2.1.

[18]The participant goes over the definition of period again describing that it is the time taken for one cycle (**CS; LP**). He asks the learners if they remember what the definition of 'period' is while he walks [20]around the class watching the learners do the calculations (**CS**; **TS**).

Figure 6.13: The lesson narrative for Section 4 of Tshuma's lesson

Curriculum saliency

Wavelength

In Section 1 (Figure 6.11), Tshuma followed his own logical sequencing, however, in Section 3 (Figure 6.12) and Section 4 (Figure 6.13), he was guided mainly by the question paper layout (seen in the participant's hand in Figure 6.14). In Section 1, Tshuma revealed knowledge about the sequencing of concepts and the knowledge that should be in place before certain concepts are used in applications. This was carried out by revising the knowledge of wavelength and its unit, followed by discussing its definition and the idea that it can be measured from a number of different successive points and how it can be calculated (lines 2-8). In Section 4, he reminded the learners of the pre-concepts applicable to wavelength to develop conceptual understanding before and during the application of their knowledge to calculate wavelength with the given information from the questions (lines 7-12). As a result, his knowledge about *wavelength* was considered **rich**.

Frequency

In Section 1 (Figure 6.11), the participant again displayed an awareness of curricular saliency and the knowledge required to understand frequency, as well as the subordinate idea of period (Figure 6.14) [lines 15-14]. Frequency was addressed after the concept of wavelength. He revised the different ways in which frequency can be calculated and discussed the respective formulae (lines 11-14). He discussed the definition of frequency and then moved onto the subordinate idea of period (lines 15-17). He first discussed the definition of period and then explained how to calculate it.

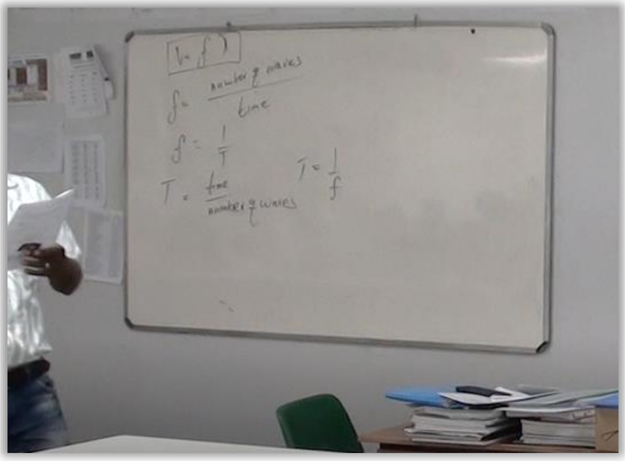


Figure 6.14: Tshuma revising the knowledge required to understand the concept of frequency and period.

Section 3 (Figure 6.12) is mainly centred on the concept of frequency and the subordinate idea of period. In this section, he again revised the necessary equations to calculate frequency (lines 3-4) and period (lines 10) before they were applied in solving problems. He further reiterated the concept of period in Section 4 (lines 18-20). He revealed an awareness of effective sequencing of concepts in this topic, and I thus considered his knowledge **rich**.

During the VSR interview, when asked how he had approached the teaching of wavelength, frequency, and superposition in my absence, Tshuma had the following response:

> *…I introduced the concept of [the] transverse pulse and then [the] superposition of pulses, destructive and constructive interference… I also looked at [the] transverse wave. I explained the concept of [a] crest, trough and amplitude and then also the out of phase and in phase points. I ended [by talking] about the calculations based on… speed, frequency and also period and then definitions of those keywords.*

The sequencing elicited in his response did not seem to have a logical approach. However, I am not sure if he relayed the actual order in which he carried out the lessons. It is for this reason that I scored purely on what I observed.

Learners' prior knowledge

Wavelength

Tshuma's *knowledge about learners' prior knowledge* was scored **rich** due to his ability to mention the possible difficulties that learners had with the idea of wavelength. In Section 1 (Figure 6.11), Tshuma ensured that the learners understood wavelength as he discussed its definition and the various methods to determine wavelength, i.e. from two successive points in phase (lines 2-8). Prompts in the VSR interview elicited the following response about his *pedagogical reasoning* regarding his teaching of wavelength:

> *I think we [were] talking about wavelength to make sure that it is not always about being crest to crest, they should also look for points that are in phase…I stressed that it is successive crest and troughs. They always forget that…[the] points that are in phase, is also a wavelength, because I saw the misconception…from some learners.*

In Section 1 (Figure 6.11), Tshuma predicts that he and the learners were going to start arguing over how many wave cycles were seen in the diagram of the question (lines 24-25). In the VSR interview while viewing the relevant clip, he recalled the followings:

> *I think from my learners I considered [that] they have got a problem when it comes to [the] number of waves… I saw it was a problem. So, I was just trying to make sure that they can easily count [the] number of waves.*

Both responses illustrated that he was aware of the common misconceptions that learners have about wavelength. This corresponds with the **rich** score given during his lesson, for the TSPCK component of learners' understanding for wavelength (Table 6.5).

Frequency

In Section 1 (Figure 6.11), Tshuma told the learners that they could be asked to calculate frequency without being given the speed or wavelength of the wave (lines 10-11). This revealed his knowledge about other ideas that learners could find difficult. He also engaged with the learners, asking them how they would approach such a question (line 12). He also made it apparent that he knew that the learners found it difficult to recognise the number of waves (lines 23-26).

For both concepts through Sections 1, 3 and 4, Tshuma continuously engaged with the learners and assessed their understanding. He also stimulated thinking through questions that were aimed at problem solving and conceptual development (lines 12, 15 and 20 are examples from Section 1 lines 5, 7, 8-9 are examples from Section 3; and lines 6, 15 and 19 are examples from Section 4). He let the learners answer such questions on their own and would further probe the learners by encouraging them to explain why an answer was relevant (line 20 of Section 1). Furthermore, he used a teaching method that involved learners conducting a lesson, although this was not relevant to his teaching strategy, it included a workable strategy involving learners (see Sections 7 through to 10, and Section 13, as well as Figure 6.15). As a result, the teacher's knowledge for both *wavelength* and *frequency* were considered **rich**.

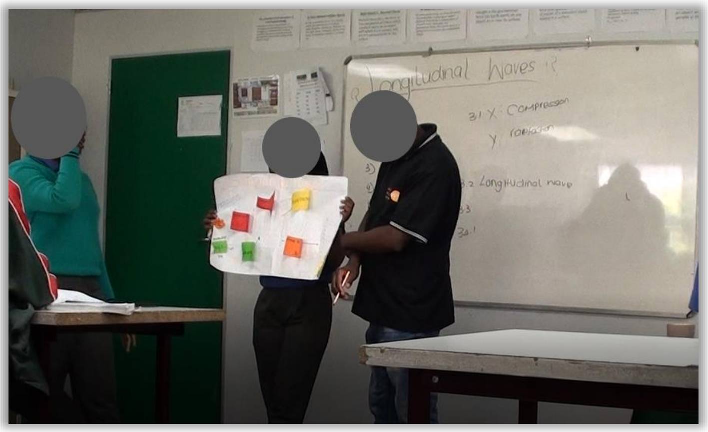


Figure 6.15: The two learners conducting most of lesson 2 (Sections 7 - 10)

During the participants' VSR interview, I asked him to explain his reasoning for always asking the learners "why?" once they had given an answer. He responded:

> *…I always tell my learners…in Grade 10 that physics is not all about memorising, because they can… they like to just to know things and in depth they don't even know… I like them to relate where, how, why is this happening. Why is it so?... if they explain, they know better.*

This response illustrated the importance the participant placed on asking the question why, which was to further elicit the learners' knowledge and understanding so that they would be able to explain in greater detail and therefore give higher-order responses. This is in line with his **rich** score for learners' understanding for the concept of frequency (Table 6.5).

Representations

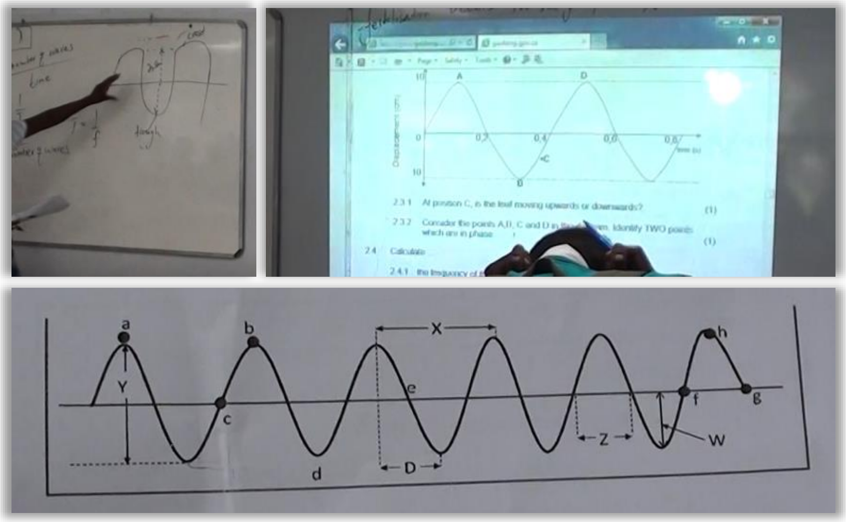


Figure 6.16 (a): Wave diagram drawn on the board, (b) Wave diagrams used projected from a past paper; and (c) Wave diagrams used from the next past paper

For both the concept of *wavelength* and *frequency*, Tshuma's *knowledge of representations* is considered **limited**. The participant did not utilise a variety of representations. The only representation used was the wave diagram seen during Section 1 (Figure 6.16(a)) and the diagrams seen in the past paper questions (Figure 6.16(b) and (c)). This was despite the following remark made by the teacher, as recorded in my narrative for Section 4: *He points out that they now have a ripple tank and so he will be using it to demonstrate to the learners [on] how it works.*

Conceptual teaching strategies

Tshuma's conceptual teaching strategies carried out during Sections 1, 3 and 4 on the key ideas of *wavelength* and *frequency* were scored as **adequate**. He facilitated learning with his knowledge of the sequencing of concepts (i.e. he addressed wavelength in Section 1 in lines 1-

10, then frequency in lines 11-14, followed by period from lines 15-17). He further used questioning and discourse in combination with his knowledge of typical misconceptions (lines 23-26 of Section 1). While doing so, he very rarely answered his own questions, allowing the learners to discuss and answer (line 29-32, Section 1) while further probing them to indicate the reasons as to why (line 20, Section 1) they had given such answers. He also integrated a different approach into his teaching by involving two learners in the second lesson (Section 7-10). However, he emphasised his teaching strategy around the application of the concepts in calculations and less about the real-life relevance and application thereof, which could have been done through discovery. During the VSR interview, I asked the teacher why he decided to use past paper questions during his lessons, to which he answered:

> *When it comes to… their final… to identify some concepts on the graphs, crest, trough, wavelength… we normally use test book questions and then I could see… they were fine. It's not difficult questions, I just said, "now let me go to the past papers because they will [have] low order to high order questions". So that they can [know] that they're not only simple questions.*

This raises questions as to whether his teaching style was exam centred as it was more based on books, and the chalk and talk method. However, I must acknowledge that I did not observe him teach the first lesson. Due to his lack of use of representations to facilitate conceptual development, and his tendency to rush through the time given to learners to approach the questions (which he was aware of as discussed as a 'weakness' during his semi-structured pre-interview), the decision was made to score the participant as enacting an ***adequate*** *knowledge of conceptual teaching strategies.*

Integration of PCK components

For both the concepts of *wavelength* and *frequency,* I considered his competence in integrating the components as **adequate**. He illustrated knowledge of curricular saliency through developing the learners' theoretical understanding of the concepts, and discussing their definitions before moving onto concept application. During the observation, it was evident that there was hardly any need to adjust the lessons due to learners that did not understand a concept or pre-concept. This in itself reveals that he elicited the relevant questions and interacted well with the learners, therefore having knowledge of the relevant information needed to allow the learners to understand the concept and to develop their conceptual understanding. He lacked representations and did not include the use of the ripple tank or any other apparatus in his teaching. Other than using two learners to help teach part of Lesson 2, he lacked creative components in his strategy.

Pedagogical reasoning

Tshuma's *pedagogical reasoning* was scored **limited** for both *wavelength* and *frequency*. He stated his intention during Section 4 to use the ripple tank apparatus but then failed to carry through with it. Furthermore, as seen in his post-CoRe (see Figure 5.19), he indicated knowledge of having the ripple tank at his disposal and wrote it down as a representation to be used. When asked during his VSR interview to explain his reason for not using the ripple tank, he had the following response:

> *Yes. I think if only I had time… I would have loved to because with my learners, the way they are so keen to learn, it was going to help them a lot. So, the only key factor there was time.*

The participant made the decision to rather use the time available to work through a number of problems than to use the ripple tank. He acknowledged that using the ripple tank would have helped the learners a lot, yet he opted for working through exam questions. This reveals his set belief that if learners know how to do the calculations, then they understand the work. This finding is similar to the results of a study carried out by Rollnick et al. (2008). In their study, they found that due to the ease in which numbers can be substituted mathematically into equations, unchangeably, the teachers spend more time on calculations rather than ensuring that learners understand the concept. This is especially the case when there is pressure to perform during examinations, which outweighs ensuring a conceptual understanding of the concept. The participant then went on to explain how he would use the apparatus if he had had the time. The following was recorded from his VSR interview:

> *…I was saying, demonstrate, not say a lot, let the learners identify everything. Then I [would] ask them "what do you think that is?" I won't explain much. I will just let them observe, learn from discovery. So, from there they observe, then they tell me what they*

think… then I will start the topic from there. So that is going to be demonstration… ask learners to identify key points. Then I'll identify from there.

Therefore, having acknowledged that using the ripple tank would have assisted the learners' understanding of the concept, he still decided to focus on calculations during the available time. I therefore scored his *pedagogical reasoning* as **limited**.

6.2.2.2 Other evidence from the VSR interview not relevant to the sections chosen

Other relevant evidence taken from the VSR interview related to Tshuma can be found in Appendix XIII.

6.2.2.3 Semi-structured post-interview

In the semi-structured post-interview for Tshuma (Electronic Appendix R), he mentioned that the training was clear and helpful and that he learnt a lot. He indicated that the training was relevant because it was near 20 years ago that he last observed a demonstration using the ripple tank. Therefore, he felt that the training helped him practically and not just theoretically. When the teacher was asked if he benefitted from the in-service training, his response was as follows:

…100 percent, I did. I really benefitted and, in future, I think, the starting point will be the ripple tank and then from there I start the theory of waves.

The participant mentioned that he had never used the ripple tank and did not have confidence in it. When asked if his perception on the ripple tank had changed, he stated the following:

After seeing it happening, so that means now I can see that all the things about the ripple tank, they really apply to what is written, especially… in our curriculum, so my perception changed for positive. It really shows what is happening.

When the participant was asked why he chose not to use the ripple tank to teach the topic to his Grade 10 learners, he had the following answer:

...the challenge... was... our timetable, our setting because I need a double period with practical's. If only I had time, I was going to use the ripple tank.

As a concluding remark, the participant indicated that originally, he did not like teaching the topic. He was a chemistry major and favoured chemistry, however, after the training and the explanations, he had become interested in the topic. He further added that it is never too late to "develop" and indicated that he was developed through the training.

6.2.3 Case Study 3 – Craig

Craig taught in a school following the CAPS curriculum. I observed three of his lessons. From the three observed lessons, the following 13 sections were identified and are presented in Table 6.4.

Table 6.4: Lesson sections for Craig

Section 1	*Start of Lesson 1* – Introduction to the new topic of waves and relevant terminology [14min 10s].
Section 2	The continuation of teaching the wave terminology: Amplitude [3min 2s].
Section 3	Teaching the subordinate idea: transverse pulse with the use of a diagram [7min 38s].
Section 4	*Start of Lesson 2* – Discussion of answers to the homework exercise [4min 27s].
Section 5	Teaching the new key idea: superposition with the use of diagrams – constructive interference [18min 8s].
Section 6	The continuation of the key idea of superposition – destructive interference [8min 26s].
Section 7	*Start of Lesson 3, first half a double period (3a)* – re-teaching the concepts of transverse waves using demonstration (ripple tank) [7min 51s – set up time] and [11min 30s – teaching time].
Section 8	Re-teaching the concept of superposition using demonstration (ripple tank) [5min 57s].
Section 9	Demonstrating the concept of diffraction (ripple tank) [11min 16s].
Section 10	*Start of Lesson 3, second half of a double period (3b)* – re-teaching the concept of superposition using demonstration (ripple tank) [4min 43s].
Section 11	Review about transverse waves and terminology using a wave diagram [14min 49s].
Section 12	Continuation of the review about transverse waves and terminology using the wave diagram: amplitude and wavelength [9min 36s].
Section 13	Continuation of the review about transverse waves and terminology using the wave diagram: in and out of phase points [15min 30s].

A lesson narrative is given for each section that is described in Table 6.4 (Electronic Appendix M). Seven sections were chosen for in-depth analysis. In Sections 1, 7 and 11, the participant taught the key ideas of wavelength and frequency. Therefore, these sections were selected to discuss and score the participant’s enacted PCK about the key ideas. Sections 5, 6, 8 and 10 will be discussed separately from the above-mentioned sections as they address the key idea of superposition. It must be noted that Craig's personal nature came across as apprehensive and not as self-confident as the other two participants. The lesson narratives for Case Study 3 are available in Electronic Appendix M. Like Case Study 2, only relevant segments from the selected sections will be presented and discussed.

6.2.3.1 Sections 1, 7 and 11 of Craig's lesson and discussion of the components

The full narrative accounts for Sections 1,7 and 11 can be obtained from Electronic Appendix M. In Sections 1 (Figure 6.17), 7 (Figure 6.18) and 11 (Figure 6.19) of his lesson, the participant was introducing the new topic of waves, specifically, transverse waves.

Relevant segments from Section 1: start of Lesson 1 – introduction to the new topic of waves and relevant terminology

The teacher has the textbook open on the desk in front of him. He indicates to the learners that they are going to start a new physics section today called ‘waves’. The teacher reveals that they are going to be discussing waves, sound and light and writes *waves, sound and light*, as a heading on the board. Under this topic, he reveals that they are going to be dealing with transverse waves and draws a branch from the heading and writes it on the board, under which he then writes the words *pulse* and *waves* (**CS**). From the heading he also draws a branch and writes *longitudinal waves* (**CS**). He draws another branch down from the heading and writes *electromagnetic spectrum* (**CS**). He indicates that what he wants to start doing is writing down some definitions and terms, which the learners are going to meet from time to time (**CS; LP**). The first is to define a *pulse* (**CS**). He asks the learners what a pulse is and allows the learners to answer. He then states that it’s a single disturbance and writes it on the board (**CS**; TS). He adds that it is a single disturbance in a medium. He explains that if one has a medium and there is a disturbance, one is generating a pulse. He then asks the learners the definition of a medium (**CS**; **TS**). He leaves the question unanswered but the learners do not comprehend, so he explains that it is a substance where a wave or pulse moves and writes it on the board(**TS**). He asks the learners to give him an example and a learner responds with the word ‘water’. The teacher asks the class for further examples (**LP**; **TS**). Another learner gives the word ‘air’. Another learner answers with the word ‘string’. The teacher refers to the textbook and asks the learners for the definition of a *wave* (**CS**). No one answers, so he states that it is a succession of pulses and writes the definition on the board. A learner asks the teacher what the word succession means. The teacher explains that when one is making a disturbance, a pulse is formed. Then, when one keeps making disturbances, there will be more pulses, so when there is a succession of these pulses, one is forming a wave. The teacher goes back to the textbook and asks the learners the next definition of the word *oscillations* (**CS**). He leaves the question for the moment but no learner responds (**TS**). He asks the question again and then answers it by stating that it is a ‘vibration’ (**TS**). The teacher then writes the word *frequency* (**CS**) on the board and asks the learners to give the definition (**TS**). A learner answers that it is the number of cycles of waves per second, which is the definition from the textbook. The teacher reiterates that it is the number of cycles, oscillations or wave per second and writes it on the board. The teacher then asks the learners what frequency is measured in and soon after writes down that it is in Hertz, also giving its symbol (**TS**). A learner is heard asking the teacher for the meaning of frequency and the teacher reiterates that it is the number of waves per second. The teacher points out that another term that needs to be understood is called *period* (**CS**). He asks the learners what they believe to be a ‘period’ (**TS**). A learner responds by saying that it is the time taken for one complete wave cycle or oscillation, again believed to be read from the textbook. The teacher writes it on the board. The teacher explains that because *period* is time, it is measured in seconds (**LP**; **TS**).

Figure 6.17: The lesson narrative for Section 1 of Craig's lesson

Relevant segments from Section 7: start of Lesson 3a – re-teaching the concepts of transverse waves using demonstration (ripple tank)

Start of lesson 3a: The teacher is observed constructing the ripple tank apparatus for the first seven minutes and fifty-one seconds. At seven minutes and fifty-one seconds, the teacher begins the lesson. The teacher reminds the learners that they have been learning about pulses, which then make waves (**CS; LP**). He introduces the learners to the ripple tank and reveals that the ripple tank is used to generate waves and to show how waves behave (**RPRT**). The teacher points out that in front of them there is a motor and inside the tank is water. He indicates that he has put a small amount of dishwasher liquid into the water to make the water "soft", so that it responds to the things that he wants to do. The teacher reveals that they want to determine what happens to water when one produces a disturbance (**CS**). He reminds the learners that there is going to be a movement of waves if there is a disturbance (**LP**). The teacher touches the surface of the water with his finger and says, "Do you see what happens?" (**RPRT**; **TS**). The learners answer yes. The teacher does it again and describes that there is a movement of water and that the pulse is moving outward. He further says, 'That is what we call a disturbance, causing water to move". The teacher points out that the motor is going to cause vibrations and that vibrations are a continuous supply of pulses that form waves (**CS**). He connects the ripple bar to the controller and asks the learners if they can see what is happening (**RPRT**; **TS**). He asks the learners what they are seeing (**LP; TS**). The teacher asks the learners to describe what they are seeing on the white paper that is placed underneath the ripple tank (**LP; TS**). Soon after, the teacher states that they must say what it is they see and not what it is they think they should see (**TS**; **LP**). A learner answers that he is observing multiple pulses. He asks again what the learners are seeing and moves onto explaining that there are lines that are moving across the water (**TS**). He further explains that from these lines, one observes light lines and dark lines (**RPRT**; **TS**; **CS**). He asks the learners if they are observing these lines he speaks of, and the learners indicate that they are (**LP; TS**). The teacher now asks the learners what the lines represent (**TS**). A learner answers that they are pulses. The teacher explains that when there is a continuous movement of pulses, a wave is formed (**CS**). He further explains that when there is a light line, it represents the crest of a wave and when there is a dark line, it represents the trough of a wave (**CS; LP; TS**). He reveals that the "highest thing" is the crest and the "lowest thing" is the trough (**CS**). He reiterates that the two important terms are known as the crest and the trough and that the crests are represented as the light line and the troughs are represented as the dark lines (**CS; TS**). He asks the learners what else they are seeing and allows the learners to answer (**LP; TS**). No one answers and then the teacher asks if they are realising that the lines are not changing their size (**RPRT**). The learners agree. He reveals that as long as the disturbance stays the same, the pulses will remain the same, and that the successions will be the same. He further adds that the pulse length is not changing, which also means that the wavelength (**CS**) is not changing. He asks the learners if "we are together?" (**LP; TS**). He reveals that it is for that reason that the lines are staying the same. The teacher then indicates that he wants to increase the speed of that "thing" while pointing to the ripple tank bar and motor and tells the learners that they need to tell him what they think is happening (**TS**). While turning the controller knob, there is silence and he asks again: "What are you seeing?" (**RPRT**; **LP; TS**). A learner answers that the crests and troughs look smaller. The teacher repeats after the learner stating, "So the crests and troughs look smaller as I increase?" (**TS**). The learner answers "yes" and continues to say, "That means that wavelength is smaller", using his fingers to illustrate. The teacher agrees and says that the wavelength (**CS**) is decreasing. The teacher then reduces the frequency by putting the controller back to the original frequency. The same learner answers by saying that "they" look bigger. The teacher then asks the same learner what he could say about the relationship between the two, specifically mentioning wavelength (**CS; LP**; **TS**). The learner starts answering by saying "the more…" and then stops. The teacher says, "okay let us answer the first question, the first question is: If I increase the vibration what is it that I am increasing?"(**LP; TS**). The learner replies that the teacher is increasing the number of pulses per second (**CS**). The teacher says "good" and asks again, "What am I increasing?" The learner responds with the same answer and the teacher says, "Don't you think it is frequency, which is the number of waves per second which is being increased" (**CS; LP TS**). The learner agrees. The teacher then asks the second question which is,"Explain the relationship regarding frequency and wavelength"(**CS**; **LP; TS**).No one answers.The teacher then specifies that a low frequency causes…while pointing to the demonstration using the tank (**RPRT**)... no one answers. The teacher, using the controller, changes the frequency again and says, "This is higher frequency which causes what?" and the learners answer that it causes smaller wavelengths(**RPRT**; **LP**; **TS**). The teacher reduces the frequency and the learner states, "It is a bigger wave". The teacher repeats what the learner said but using the correct term of "bigger wavelength" (**CS; LP**; **TS**). The teacher then re-asks the class for the relationship between frequency and wavelength (**TS**). A number of learners are heard answering, but the clearest voice is heard saying, "The higher the frequency the lower the wavelength". The teacher repeats after the learner and points out that the higher the frequency, the shorter the wavelength, or the lower the frequency the shorter the wavelength (the learners are heard repeating after the teacher). The teacher reminds learners that if they are talking about wavelength, it is either "shorter" or "longer" (**WDT**; **LP; TS**). The teacher concludes that frequency is inversely proportional to wavelength (**CS; TS**). He asks the learners what the statement means and what inverse means (**TS**). A learner answers, "The opposite". The teacher explains further that it means that as one increases, another decreases or if one decreases, the other one increases and that it explains the relationship between frequency and wavelength.

Figure 6.18: The lesson narrative for Section 7 of Craig's lesson

Relevant segments from Section 11: review about transverse waves and terminology using a wave diagram

The teacher is then observed to draw a diagram of a transverse wave on the board (**CS; RP**). A learner asks the teacher if what is drawn on the board is a transverse wave. The teacher answers "yes" and then the learner proceeds to ask, "Where are the right angles?" The teacher replies by saying, "I will get to that". The teacher is seen to label the diagram by putting in the labels of *rest position*, *crest*, *trough*, and *wavelength* from trough to trough, from crest to crest, and from one point in phase to the next point in phase(**CS; RP**).He writes Lambda as its symbol in brackets after the word wavelength (**CS**). The learners are given time to copy the diagram and labels from the board (**TS**). Before the teacher explains the diagram, the learners are heard saying the word *Lambda*. The teacher then asks if the learners are done drawing (**TS**). A learner asks what the funny symbol represents, seen on the board. The teacher answers by saying that it is *Lambda* and that it is the symbol for wavelength. The teacher reveals that what the learners see drawn on the board is an example of a transverse wave. The teacher continues talking about the transverse wave. He indicates that the highest point or maximum point on a transverse wave is the crest and the lowest point on the transverse wave is the trough (**TS**). He shows that the distance between two crests is the wavelength. Furthermore, that the distance between two troughs is also termed the wavelength or even where a wave starts, to where it starts to repeat itself, is also known as a wavelength (**WDT**). He points out that the learners must look for the crests or the troughs or where it repeats itself to measure the wavelength (**WDT**). The teacher then shows the rest position and asks the learners, "What is the rest position?" (**CS; TS**). A learner answers saying that it is where the wave is before a disturbance. The teacher specifies that the rest position is where the particles (**CS**) will stop when there is no disturbance. The teacher illustrates using the diagram on the board where rest position is and that when a disturbance occurs, it is at that point that a wave starts to form (moving his finger over a crest) (**RP**). The teacher shows, using the diagram, the particle movement from the start of the wave and how the particles would move. He also illustrates using his finger on the diagram the meaning of *one complete wave* (**CS**; **RP**). A learner asks, "Will the particle rest for like a second?" The teacher responds by saying that the particle does not rest as long as there is a disturbance. He reminds the learner that a disturbance is a succession of waves (**CS**) and that there is a continuation (**LP**). Using the diagram and his finger, he moves along a complete wave and then the next complete wave and the next, but which is only half a wave (**CS; RP**). The teacher then says that if he has to ask the learners how many waves there are in the diagram what would the learners answer? (**TS**). He allows the learners to answer (**TS**). They respond by saying: two-and-a-half waves. The teacher repeats the phrase of two-and-a-half. It can be heard that some learners are confused. The teacher

[30]allows the learners to argue and discuss before showing again on the board using his finger why the answer to his question is *two-and-a-half* (**LP; TS**). The teacher reveals that the reason why he is showing the learners [32]how to determine the number of waves is because there are going to be calculations where they will be required to calculate frequency. (**CS**) The number of oscillations is required for such questions.

Figure 6.19: The lesson narrative for Section 11 of Craig's lesson

Curriculum saliency

The teacher began Section 1 (Figure 6.17) with his textbook open in front of him and would often refer to it (line 1). The teacher revealed to the learners what it is he intended to address during the new topic of waves. He discussed relevant concepts in their respective order: pulse (line 9), medium (line 11), a wave (line 16), oscillation (line 21), vibration (line 22), frequency (line 23) and then period (line 29). He included the units of frequency and period (lines 26-32). A logical sequence was evident as he discussed relevant terms and their definitions and displayed an awareness of learners' knowledge that should be in place before further concepts were taught (Figure 6.20). However, he omitted to address the concept of wavelength and the pre-concepts of a crest and trough. However, I cannot be certain if this was the sequence that the textbook (which he was very reliant upon) followed for the introduction of waves. He seemed nervous to veer away from the textbook and what the textbook stipulated in terms of content and order.

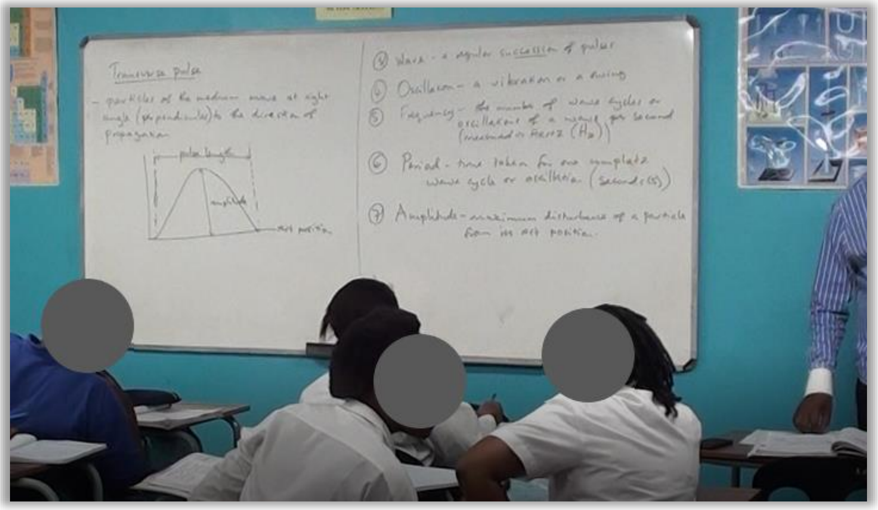


Figure 6.20: Terms and definitions covered by Craig written on the board while referring to the textbook

Section 7 (Figure 6.18) was the only section for which the participant was not reliant on the textbook. In this section, the participant used the ripple tank to demonstrate the concept of waves (lines 1 -60). During Section 7, the teacher displayed logical sequencing by addressing, in order: the ripple tank use, a pulse (line 3), a disturbance (line 8-12), the observation of light and dark lines (lines 19-25), crests and troughs (lines 19-25), wavelength, frequency, and the relationship between wavelength and frequency (lines 29-60) (Figure 6.21(a) and (b)). However, knowing that the concept of wavelength was not addressed together with the pre-concepts of crest and trough before the demonstration, his chosen sequence seems questionable.

In Section 11 (Figure 6.19), Craig was observed to revise all the necessary terms relating to a transverse wave through an annotated wave diagram (line 1) (Figure 6.22). This was carried out in a logical manner. The discussion included wavelength, its unit, and the different ways of determining wavelength, i.e. using different successive points (lines 13-16). Furthermore, he explained the importance of determining the number of wave cycles because of its use to determine frequency in calculations that they were yet to discuss (lines 22-33).

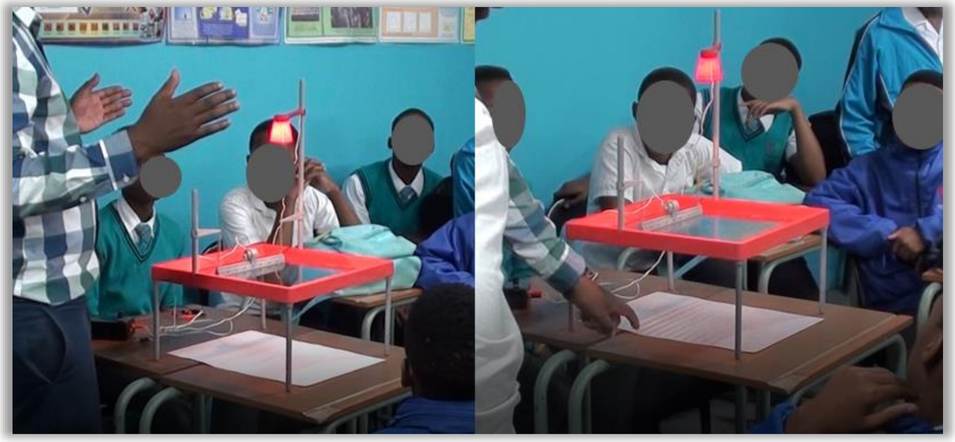


Figure 6.21: (a) Craig using the ripple tank to illustrate wavelength and frequency; and (b) The relationship between wavelength and frequency

Due to the omission of wavelength and the subordinate ideas in Section 1, I scored his *knowledge of curricular saliency* for the concept of *wavelength* as **limited** but for the concept of *frequency*, I scored his knowledge as **adequate**.

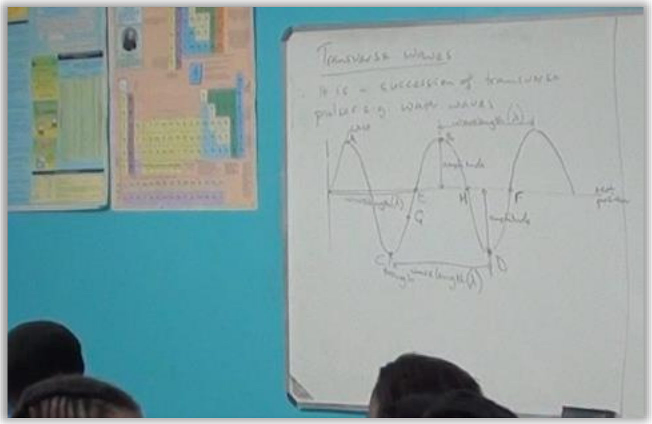


Figure 6.22: Wave diagram drawn by Craig

During the VSR interview, when I indicated to the participant that I had noticed that he often referred to his textbook, he made the following statement:

> *The reason for that is… in the textbook, that is where I was checking which terms… we normally use when… explaining those terms. That was the main reason I was checking… the textbook.*

I further asked whether he believed that having the textbook in front of the learners was a positive or a negative thing, considering that they just read the definitions out to the teacher when he asked for them. The participant explained:

> *…to me it is either way… For them to have it in front of them, because in this case when I am asking definitions, normally they will rush to go and check what is the meaning of… the definition. But in some circumstances, it will be very important for them to have the textbooks in front of them.*

The questions asked and the responses above further motivates my observation about how reliant he was on his textbook. His responses also highlight that he identified that having the textbook in front of the learners when addressing definitions was possibly not always beneficial knowing that the learners would generally state a definition without understanding it. He did not make the lesson his own.

Learners' prior knowledge

During Section 1 (Figure 6.17), it was evident that the lesson followed the approach of writing down definitions, even those written in the textbook and already available to the learners (Figure 6.20). No further extension was done to explain the terms and definitions, unless asked by a learner. The definitions were merely written down on the board as per the textbook (line 7). However, this was very different to the approach used in Section 7 (Figure 6.18). The participant interacted a lot more with the learners, encouraging discovery through questions and by asking the learners what it was that they observed during the lesson using the apparatus (lines 10, 14, 15, 17, 27 are examples). Even though the concept of wavelength was not addressed in the previous lessons, once the teacher made the learners aware of the concept through the illustration using the ripple tank, a learner was seen to explain what he observed using the term wavelength and described correctly what he observed when the frequency of the wave was increased (lines 37-38). However, the teacher misused the term 'speed' and I believe he should have used the term 'frequency' to explain what the change in the controller was accomplishing, especially in this context where learners may develop confusion between the term speed and the frequency of a wave. During Section 7 using the ripple tank, Craig followed a sequence with awareness regarding what he knew the learners knew at that point. He broke down the questions that he asked in order for the learners to better understand the questions, which were related to the relationship between wavelength and frequency (lines 42-48) (Figure 6.21 (a) and (b)). Back at the writing board, in Section 11 (Figure 6.19), the participant addressed the common misconception about the number of cycles that appear in a wave diagram (lines 26-33). After indicating to the learners how many wave cycles were present, he allowed the learners to discuss and disagree before illustrating through the wave diagram why they had concluded the answer to be two-and-a-half waves (lines 26-33). As a result, I scored the participant's knowledge regarding learners' prior knowledge as **adequate** for the concept of *wavelength* and *frequency.*

During Section 1 (Fig.6.17), a learner asked the teacher for the meaning of succession, which was a word the teacher had just written on the board. During his VSR interview, I asked Craig whether there was often a language barrier that he faced during his lessons. He explained that, "English at times…it is a bit tricky to them". He also stated that when writing an exam, they often answered incorrectly due to not understanding the question.

I further asked the participant whether he found that English was a barrier to better understanding the subject in general, to which he replied:

> *English is quite the barrier… you have to check the words which you use, to simplify them…. in Physical Sciences… we have to use the exam guideline… some… words which are used in the exam guideline, the learners don't understand… So, you go back to simple English, then take them to the words which are being used...*

Lastly, I was intrigued to know whether he felt that the language barrier would have something to do with the misconceptions that his learners had in class. His reply was as follows:

> *Yes…[at] times… the misconceptions is because of the language barrier. It is because they don't understand what is...[or] what would be the meaning. So, at the end they will have…other conceptions [ideas]…*

Although the above questions were generic, not topic-specific, and not linked to specific examples, his responses indicate an alternative aspect of teaching and learning that may affect learners' understanding and could be a topic for future studies.

Representations

It was during Sections 7 and 11 (Figure 6.18 and 6.19 respectively) that the participant made use of representations. He made use of two different representations: the ripple tank apparatus (Figure 6.21 (a) and (b)) in Section 7 (lines 1-62); and a wave diagram (Figure 6.22) in Section 11 (line 1). During Section 7, he stimulated conceptual development through discovery and questioning to understand wavelength, frequency and the relationship between the two. He made the learners aware of the light and dark lines that they were observing. Due to the reason for this phenomenon being based on the refraction of light, a Grade 11 concept, he chose to state which lines represented the crests and which represented the troughs (lines 19-27). This addressed the pre-concepts needed to understand what was being observed using the ripple tank regarding the relationship of wavelength and frequency (lines 40-62). Section 11 cemented the concepts of waves as discussed in Section 7, but through the use of the wave diagram. Craig was the only participant to use the ripple tank apparatus to illustrate *wavelength* and *frequency*. As such, I considered the *knowledge revealed about representations* as **rich**.

During the VSR interview, I played a clip where the participant could hear himself saying to the learners "what do you see?", "what do you observe?" I asked if it was a technique that he learnt from the teacher training. He answered:

> *Yes, it is a technique which I learnt from the training… initially you don't have to tell the learners what is happening. Let them think and then try to come up with ideas of what is happening and that way, they are building up their confidence… in... themselves.*

My next question was related to the same clip where he heard himself telling the learners that the crests were the bright lines and the trough were the dark lines. I asked him if it was something he had taught before or if it was something that he had learnt from the training. He replied that it was something he learned from the training.

Both responses given by the participant indicated that he used methodology and content relevant to the ripple tank as a representation in the lessons that I observed that had been taught during the in-service training. This further motivates the **rich** score given to the participant for his enacted TSPCK regarding representations.

Conceptual teaching strategies

I considered the participant's conceptual teaching strategy as **limited to adequate** because although he had the teaching style of 'lecturer' in Sections 1 (Figure 6.17) and 11 (Figure 6.19), he changed his teaching style to that of a demonstrator and facilitator in Section 7 (Figure 6.18). The curricular saliency followed was not very logical at times, but as mentioned, this could have been due to the sequence in which the textbook addressed the concepts. The participant tended to answer his own questions after only one or two attempts by learners and did not rephrase the questions asked during Sections 1 and 11 (lines 9, 17, 21, 26 in Section 1; and line 18 in Section 11). During Section 7, he asked questions to elicit the learners' thinking and to develop conceptual reasoning (lines 28, 31, 40). There was a lack in knowledge about common misconceptions, i.e. the common confusion learners have between frequency and period and frequency and speed. The learners were disruptive at times, which hindered them from hearing particular questions and responses (refer to the full narrative account in Electronic Appendix M). I asked the participant, when reflecting back on the lessons, whether he felt that his learners were engaged in Lesson 1 where he discussed the terms and definitions while writing them on the board. The participant responded, saying:

> *…in this lesson they were not that engaged… one or two who [were] participating… this normally happens, especially when you are introducing… a new topic to them… some of them will be puzzled on what… is actually happening.*

Furthermore, when I asked the participant which lesson he believed the learners were most engaged in, he indicated the following:

> *It was the one which we were using the ripple tank. I think it was lesson 3… the double… they were engaged because we talked a lot, and they were asking a lot of questions and [they] were telling me what they were seeing, correcting them and getting a lot of ideas from… them.*

The participant acknowledged that his learners were not fully engaged during the lessons in which he worked from the textbook while introducing waves, the terms and their definitions. He further acknowledged that the learners were more engaged when the representations were used. Craig's responses prove that the learners were not always fully engaged, which further motivates why a **limited to adequate** score was given for *wavelength* and *frequency* and an **adequate** score for *superposition* for the TSPCK component of *conceptual teaching strategies*.

Integration of PCK components

There was little emphasis on what learners find difficult and on the common learner misconceptions and learner thinking during the lessons where he employed the lecture-based teaching style. However, the participant showed emphasis on the TSPCK component of *representations* and used it to his benefit in order to stimulate questions during Section 7 (Figure 6.18). Sections 1 and 11 (Figures 6.17 and 6.19 respectively) showed that the participant did not really adapt the lesson despite evidence that the learners required the teacher to change his teaching strategy during the lesson. As a result, his competence in integrating the components is considered **limited to adequate** for both the concepts of *wavelength* and *frequency*.

Pedagogical reasoning

When I recognised that the teacher had a different curricular sequence, i.e. covering knowledge about a pulse and amplitude before wavelength and frequency, I asked Craig if he would make any changes after reflecting back over the lessons. He answered as follows:

> *The changes… which I might make before I even use the ripple tank, [is to] also introduce the wave on its own. Showing the crest and the trough and the rest position before doing demonstration… on the ripple tank. I think that way they will understand even more when you are doing the demonstrations.*

During his VSR interview, Craig explained in full regarding the rationale behind the decisions and actions undertaken. He recognised how best to adjust his teaching strategy to benefit the understanding of the learners and gave concrete examples, i.e. showing the crest. He showed sensitivity and responsiveness towards the context by indicating, such as the excerpt above, where he could improve his actions once reflecting on the actions taken. For this reason, I considered his *pedagogical reasoning* **rich**.

6.2.3.2 Sections 5, 6 and 8, 10 of Craig's lesson and discussion of the components

Sections 5 (Figure 6.23), 6 (Figure 6.24), 8 (Figure 6.25) and 10 (Figure 6.26) and their full narrative accounts can be seen in Electronic Appendix M. In all of the above-mentioned sections, the participant was observed to teach about the key idea of *superposition*.

Relevant segments from Section 5: teaching the new key idea: superposition with the use of diagrams – constructive interference

The teacher writes on the board the heading *superposition of pulses* (**CS**). He reminds the learners that a pulse is a single disturbance (**CS**). If one continues producing these pulses in succession, it will then be termed a wave (**CS**; **LP**; **TS**). The teacher then explains that if two pulses meet at the same point at the same time, they will interfere with each other. He asks the learners "if the waves interfere; what does it mean?" (**LP**; **TS**). A number of learners are heard answering at the same time. One learner says, "They will meet each other". The teacher re-words the question and says that if the waves are interfering with him, what does it mean (**LP**; **TS**). Another learner says that they are disturbing each other. The teacher explains that it can be a positive or negative interference (**CS**) and that if one mixes with people there can be a positive or negative interference (**LP**; **TS**). He implies that this effect is what also happens when pulses meet each other. The teacher expresses that the first thing they need to do is define 'interference' (**CS**). He allows the class to define it and then soon after states, while writing on the board, that interference is when two or more pulses meet or interact with each other at the same space and time (**TS**). He reminds the learners that the class discussed that interference can be positive and negative and this brings them to the principle of superposition (**LP**; **CS**). He tells the learners to write the following while reading from the textbook: "It is said that when pulses cross, their combined disturbance at any point, is equal to the sum of their disturbances". The teacher then explains that if two pulses meet at the same point, the effect is the sum of the disturbance (**CS**). The teacher asks the learners what is meant by the term *disturbance* (**CS; TS**). The teacher then states soon after that it is the amplitude, which means that when they meet in superposition, one is saying that when the pulses meet it will be the sum of their amplitudes (**TS**). He further adds that it is an addition of the amplitudes of the pulses occupying the same space at the same time. He reminds the learners that interference can be positive or negative so interference can be constructive and destructive (**LP**). Constructive interference implies building up. Destructive interference means that one is bringing down (**LP**). The teacher then starts defining and discussing constructive interference and writes the heading on the board (**CS**). He reiterates that when constructive interference happens, it is when two pulses meet and the amplitude increases. He writes this on the board (**TS**). He points out that the amplitude which is formed is bigger than the amplitude of the pulses. He starts to draw a diagram (**RP**) to illustrate two pulses (A) and (B) before interference, both having different amplitudes. He illustrates that B is moving to the left and that A is moving to the right. He draws the resultant wave and its amplitude at the point of interference, illustrating that it is building and forming a greater amplitude. He then substitutes in mathematical values for A, which is 7cm and B, which is 3cm then the resultant wave would be A+B = 10cm, thus there is a combination of the two amplitudes to form one (**CS**; **LP**; **TS**). The teacher explains that it is constructive interference because the pulses are both approaching each other on the same side (meaning above the plane). He explains that it is like interacting with someone nicely, it is a positive interaction. He asks if the learners are clear with what has been described (**TS**).

The teacher then asks the learners what will happen after the waves meet and reminds the learners that they are approaching each other from different directions (**WDT**). The teacher states soon after that after interference the one (pointing to B) will go to the left and the other (pointing to A) will go to the right and that they will then retain their amplitudes (**WDT**). He further elaborates what he has just said by drawing the diagram (**RP**) to show what the pulses would look like after interference, showing B as 3cm on the left and A as 7cm on the right still going in their original directions, indicated by arrows. He asks if the learners are "fine" (**TS**).

Figure 6.23: The lesson narrative for Section 5 of Craig's lesson

Relevant segments from Section 6: the continuation of the key idea of superposition – destructive interference

The teacher writes on the board the heading of *destructive interference* (**CS**). He asks the learners, "Who can explain what destructive interference is?" (**TS**) He leaves the question for the learners to answer. A learner answers by saying that it is when two pulses interfere and their amplitude, A and B subtract. The teacher then says, "They cancel each other" (**TS**). The learner agrees. The teacher asks if anyone else has another definition(**TS**). Another learner answers, "One negative, one positive coming from opposite sides and then coming together they combine..." then the teacher adds that their amplitudes become smaller. The teacher writes the definition of destructive interference on the board (**CS; TS**). He explains that when they meet their amplitudes become smaller because they are cancelling each other. The teacher starts to draw destructive interference, showing two pulses before they interfere up on the board (**RP**). The two pulses are of different sizes with different amplitudes. He also draws the resultant pulse during interference (**CS**). After drawing the diagram, he asks the learners what the differences are between constructive and destructive interference (**CS; TS**). He then states soon after that with constructive interference, the waves are approaching each other and are both on the same side, but in the case of destructive interference, they are approaching each other from different sides. As a result of being on different sides, they are going to cancel each other, hence your amplitude gets smaller. He points out that if they take the first wave as positive, then the second wave will be negative. “What it means is that if the first wave has an amplitude of 7cm, then it is +7cm and the second wave will have an amplitude of -3cm because they are on different sides”(**TS**).He describes the resultant wave (**CS**) and writes 7 – 3 = 4cm and further explains that they are thus seen to be cancelling each other out.

He revises that constructive interference is “on one side and are building each other up” and with destructive interference, “They are on opposite sides, so they are cancelling each other out”(**LP**). He further adds that with constructive interference,“It is increasing the amplitude” but with destructive interference, “It is reducing the amplitude” (**LP**). The teacher then reiterates again what happens to the pulses once they have met and draws a diagram of it on the board (**RP**). He states that once they pass each other, they maintain their amplitudes (**CS; WDT**). He asks the learners if there are any questions (**TS**). A learner asks, "For A and B for destructive interference, if A were to be 7cm, and B were to be 10cm, would you get a negative?" and "How would you then represent it?" The teacher answers by saying that the final amplitude will be negative and below the rest position because upwards is positive and below is negative. The answer will determine whether it is negative or positive and will show you which side the amplitude is. The teacher asks if it makes sense and if there are any more questions (**TS**). Another learner asks if it is possible for more than two pulses to interact at the same time. The teacher affirms that it is possible but it is "not for their level". He explains that it is the same principle because even if they meet and there are three or four of them, and are on one side, they will go up. If two of them are up and one is down, then the one down is negative and the ones up are positive, then the same principle applies (**CS**; **LP**). He asks if there are any further questions (**TS**).

Figure 6.24: The lesson narrative for Section 6 of Craig's lesson

Relevant segments from Section 8: re-teaching the concept of superposition using demonstration (ripple tank)

The teacher asks the learners if they are able to identify the shape of the waves (**TS**). Soon after, he reveals that they are linear because the vibrations are produced, using a linear object (**CS**). The teacher places the two circular balls into the ripple bar (**CS; RPRT**). At the same time, a learner asks, “What happens if you put another wave 2m away?” The teacher misinterprets the question and says that it is when one changes the vibrations. The learner makes his question clearer by asking if one puts another wave on the other side (the learner illustrates what he is asking by using his hands which are seen to move towards each other. He then claps his hands together while moving them up as a sign of the waves then meeting and hitting each other). The teacher implies that that is when one would see superposition (**CS**). The teacher places the two circular balls onto the surface of the water making sure that the ripple tank is nicely setup (**RPRT**). He starts the vibrations. He then asks the learners what they are seeing (**TS**). A learner answers that he is seeing circular waves, while another learner uses her finger to illustrate a circular pattern. The teacher then further states that there are two different waves (**CS**). The learners agree, and that they are circular. The teacher asks the learners if they can see the pattern (**TS**). The teacher also points out that the waves are meeting, while the learners are seen indicating this by pushing their hands together. The teacher is observed trying to see the effects of superposition using the stroboscope in front of the learners (**RPRT**). A learner asks if the two waves are linked to each other. It is observed that the teacher is battling to see the phenomenon through the stroboscope. The teacher then asks the learners if the learners are seeing the pattern down on the white paper. The learners indicate that they are. He asks the learners if they can see where the waves are meeting (**TS**).

Figure 6.25: The lesson narrative for Section 8 of Craig's lesson

Relevant segments from Section 10: start of Lesson 3b – re-teaching the concept of superposition using demonstration (ripple tank)

Start of lesson 3b: The teacher starts the lesson by illustrating the phenomenon of superposition, constructive and destructive interference again, using the ripple tank apparatus (**RPRT**).This time around, the classroom lights are switched off. The teacher suggests from which angle he believes the phenomenon is best seen, which is in front of the ripple tank on the other side of the ripple bar. The teacher shows the learners the lines that are coming out from the circular balls, seen on the white paper under the tank (**RPRT**). A learner responds by saying that what he is seeing in the tank is also being observed and projected on the roof. The teacher focuses on the white pieces of paper underneath the tank and shows the learners the lines which he terms as "empty" and that at those lines there is "nothing there" (**RPRT**). The teacher reiterates where it is best seen. The teacher explains to the learners that where they are observing lines, constructive interference (**CS**) is occurring and where they are observing the "empty lines" it is where destructive interference is occurring (**CS; RPRT**). A learner is heard confusing the two and asks the teacher to repeat himself, which he does. The teacher points out that the waves are moving and spreading. A learner is heard saying that it is "beautiful". The teacher reveals that he wants to do something else, which is to discuss the transverse wave. The learners resettle, while the teacher sets up his textbook to start teaching from the board.

Figure 6.26: The lesson narrative for Section 10 of Craig's lesson

Curriculum saliency

Section 5 (Figure 6.23) and Section 6 (Figure 6.24) address the theory about the concept of superposition. Thereafter, Section 8 (Figure 6.25) and Section 10 (Figure 6.26) cover the illustration of superposition using the ripple tank apparatus. I scored the participant's *knowledge about curricular saliency* on the concept of *superposition* as **adequate**. The participant chose to address the concept of superposition after covering the pre-concepts discussed in Section 1. In addition, he also covered the concepts of amplitude, transverse pulse and pulse length, addressed in Sections 2, 3 and 4 respectively. Craig chose to address the theory about this more complicated concept before covering the pre-concepts of crest, trough and wavelength. Again, this could be due to following the sequencing in the textbook. However, once he began teaching the concept, the teacher had an awareness of the knowledge that should be in place to understand superposition, examples thereof being: interference (from line 3 in Section 5), two types of interference (from lines 7 of Section 5 through to Section 6), their diagrammatic representations with mathematical values, and the difference between the two types of interference (end of Section 5 through to Section 6) (Figure 6.27 (a) and (b)). The teacher then chose to illustrate the concept using the ripple tank apparatus (Sections 8 and 9 of the narrative account of his lessons). The consecutive order in which he chose to address the subordinate ideas with the use of representation from Section 5 through to Section 10 further illustrates his *knowledge about curricular saliency*.

Learners' prior knowledge

During Section 5 (Figure 6.23) and Section 6 (Figure 6.24), the teacher facilitated conceptual development using analogies from the learners' world and using the learners' existing knowledge to explain the idea of 'interference' by relating it to 'positive' and 'negative' interference (lines 5-8 and 32 of Section 5). The teacher also addressed the two main misconceptions about interference. He ensured that learners understood that pulses continue along their path after interfering, and that pulses retain their original amplitude after interfering (lines 34-37 of Section 5). Craig also addressed a number of the learners' questions (lines 24, 29 of Section 6). However, during Section 8 (Figure 6.25) and Section 10 (Figure 6.26), the teacher illustrated the concept very briefly, not linking the previously learnt ideas to the illustration and did not initiate questions in the pursuit of conceptual development. The lesson was therefore carried out in more of a 'show and tell' manner. As a result, I considered his knowledge as **adequate** rather than rich.

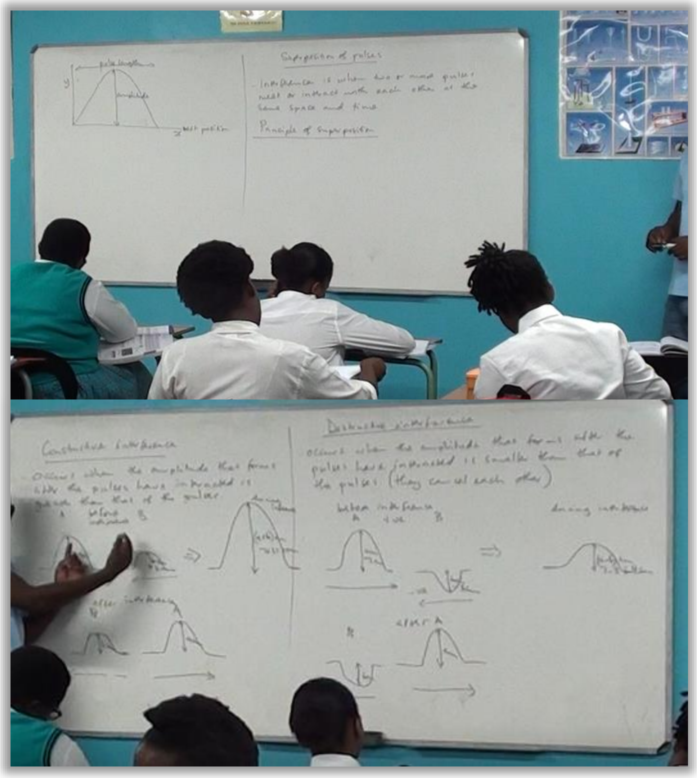


Figure 6.27: Curricular order followed while (a) Teaching the superposition of pulses; and (b) Constructive and destructive interference

Representations

The participant made use of a combination of representations to teach the concept of superposition. He illustrated constructive and destructive interference through the use of a diagram, which was split into before, during and after interference (lines 26 and 38 of Section 5 and lines 8 and 23 of Section 6). He also introduced mathematical values into the diagrams (Figure 6.27). He then illustrated superposition using the ripple tank apparatus. He illustrated the concept first in Section 8, which was not observed effectively (lines 3, 9 and 15), and therefore he chose to illustrate it again during Section 10 (lines 2, 5, 8 and 10) (Figure 6.28 (a) and (b)). The representations were used in a logical sequence to support the explanation of the concept of *superposition*, and because the participant first tried to illustrate the concept in Section 8, which proved to not be effective, and did not give up and illustrated it again in Section 10, he obtained a **rich** score for this component.

During the VSR interview with Craig, I asked him whether it was his first time using the ripple tank in his lessons. He answered:

> *It was my first time after the… training. It was my first time to, to use it in the class. Even in my teaching years, it was my first time, to use the ripple tank.*

Despite never having used the ripple tank before as part of his teaching strategy, he adapted his teaching strategy to incorporate the ripple tank into his lessons after receiving the apparatus and after attending the in-service teacher training. This response further supports his **rich** score for the TSPCK component of *representations*.

Figure 6.28: (a) Illustrating superposition using the ripple tank during Section 8; and (b) during Section 10

Conceptual teaching strategies

Craig's teaching strategy is considered **adequate**. In Section 5 (Figure 6.23) and Section 6 (Figure 6.24), he used the learners' understanding of interference to facilitate conceptual development (lines 5-8, 32 of Section 5). He also asked the learners whether they understood the previously discussed theory before he continued with the lesson (lines 33 and 40 of Section 5 and lines 24, 28 and 33 of Section 6). During the use of the ripple tank, he asked learners what they observed (line 1, 10, 13 and 17 of Section 8). However, during Section 8, he himself did not observe the concept being illustrated effectively while using the apparatus. As a result, he started the next half of the double lesson, Section 10, by illustrating the concept again. Had he not tried to illustrate the concept again, I would have had to assume that he was not aware of what he was meant to observe, however, during the second attempt, he pointed out aspects of which he wanted his learners to be aware. However, he used the term 'empty' (lines 8 and 10) to explain what was observed at the points of completely destructive interference, which was not correct terminology.

Integration of PCK components

The participant showed evidence of knowledge about the components and the logical sequencing of the five TSPCK components within the classroom context. He made use of diagrams and the apparatus to explain the concept. However, he followed a unique approach to curricular saliency in terms of when he covered the concept in relation to the rest of the topic of waves. He addressed the common learner misconceptions but did not link all the theory addressed about the concept to the representation of the concept using the ripple tank. He acknowledged that the first illustration was not effective and therefore changed his planned lesson, but approached this illustration as more of a show and tell rather than allowing discovery or facilitating learning. As a result, his competence in integrating the components is considered **adequate**.

Pedagogical reasoning

During the VSR interview with the participant, I indicated to him that I found it interesting that he introduced superposition, which included constructive and destructive interference, straight after addressing the definitions of amplitude and pulse but before introducing frequency and wavelength. When I asked him for his thinking behind this decision, he had the following response:

> *…to me superposition is more to do with the… amplitude and the pulse… as soon as they know what is an amplitude, then I wanted them to see how… the amplitude[s] interact when two pulses approach each other or when they in-phase…. that is how… I saw it easier for the learners to understand. That after knowing the amplitude, after knowing the pulse… how is the interaction between the waves, before I go [on] to the wavelength and... the frequency.*

The participant explained his reasons for following the particular curricular saliency. As mentioned, his conceptual teaching strategies were very dependent on the textbook and what it stipulated. However, a teacher still needs to have knowledge and an understanding of the reasons as to why an order is followed, even if it is stipulated by a book or document. The teacher illustrated that he possessed knowledge about why he carried out what he did and in the order in which he did it, and therefore accounted for his actions. As a result, his *pedagogical reasoning* was considered **rich**.

6.2.3.3 Other evidence concerning the use of the ripple tank as a representation

During Section 9, the participant used the ripple tank to illustrate diffraction as shown in the intervention (Figure 6.29). During the VSR interview, when the participant was asked why he decided to show his Grade 10's the phenomenon of diffraction, he gave the following response:

> *…because I know it is… a concept which comes from what they are doing now, which comes in…Grade 11… I just got a chance for them to… open their minds to see what other situations… can happen. What are the other characteristics of waves, which we will be doing next year.*

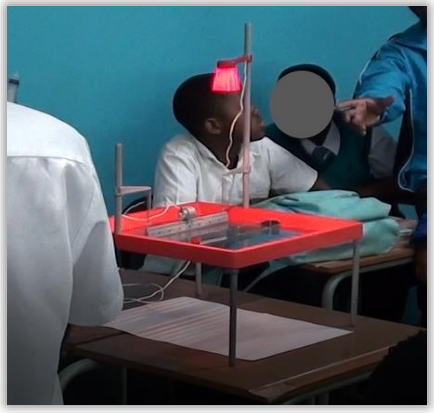


Figure 6.29: Illustrating diffraction using the ripple tank

It was important for me to ask the participant because diffraction is not part of the Grade 10 curriculum. I wanted to reveal whether carrying out this demonstration was due to a lack of curricular knowledge or if he had other reasons for carrying it out. His response indicated that he understood curricular saliency because he was aware that the concept is addressed in Grade

11. The reason for demonstrating the concept was because he had the chance to show his learners and took the opportunity to extend their perspective on the topic.

During Section 7, the participant spent a part of the lesson setting up the ripple tank. During this time, the learners were observed to congregate around the apparatus. I asked the participant if he believed it indicated anything particular, and he responded as follows:

> *It indicates that there was this excitement of, wanting to have this hands-on… they were saying… can we help you set it up. Just show us how to set it up and why. We will help you and we also want to, to be part of the setting up… which means there was an excitement… and… they wanted to really see what was going to happen.*

This response is in line with what I observed and I wanted the participant to comment on this observation thus to eliminate researcher bias. This response further proves that the learners were more engaged when representations were used, as already mentioned regarding Section 1, 7 and 11 of conceptual teaching strategies.

I asked the participant whether he would have felt as comfortable using the ripple tank had he not had training on how to use the apparatus, to which he replied:

> *No, I was not going to be comfortable, because even checking the manual, I later realise[d] no, if there was no training, I was not going to be able to use the ripple tank. So, the training… is very essential. If you get apparatus, I think the person, people who are going to use it, there should be some training of some sort… for me it was easy, because there was training… I was seeing everything being done… for me, it was easy.*

This response further illustrates the value the participant saw in having the teacher in-service training on the use of the apparatus.

6.2.3.4 Other evidence from the VSR interview not relevant to the sections chosen.

Other relevant evidence taken from the VSR interview related to Craig can be found in Appendix XIII.

6.2.3.5 Semi-structured post-interview

In the semi-structured post-interview, the participant stated that the training was clear and that it was not difficult for him to follow. He indicated that there were things that he had learnt and that he used in explaining to the learners. When he was asked what else he had learnt from the training, he stated:

> *…when introducing the topic, not telling the learners what you know. Getting the details from them, what they know. What do they think is going to happen?*

When asked what he liked best about the training he indicated the following:

> *…this thing of getting more information…There were some things which I had problems in explaining, now I got a way to explain those things.*

The teacher explained during this interview that previously he had the perception that the ripple tank was something that was not that necessary, however, after the training and after using it in class, he realised its benefits. When I asked Craig whether the training helped him and his learners to do the required activities and illustrations related to waves in Grade 10, his response was as follows:

> *It helps quite a lot… on my side and… the learner's side… this test which they wrote… the end of term test, the way they approach[ed] the questions which has to do with waves… I could see that this is because of how they got those demonstrations which we did in class... the way that they answered it was a bit different to years before… from seeing and doing, it is very essential it's easy to explain something which you have seen live than something which you just have a perception.*

The teacher further added that he would continue to use the apparatus, even for his Grade 11 class to address the concept of diffraction. He stated that he chose to use the apparatus during the observations because it was very easy to use and helpful to explain the section on waves rather than just using the textbook, the way he used to do it before. As a closing remark, the participant stated that he experienced the training as helpful and essential.

6.3 CHAPTER SUMMARY

In Chapter 6, I reported on my search for evidence to indicate how teachers employ this science equipment and enact the knowledge and skills taught during the in-service training. This, therefore, answered the third sub-question. I discussed the evidence obtained from the classroom observations, VSR interviews and semi-structured post-interview. I further explain the scores given and the reasons for assigning each score, with reference to the enacted TSPCK rubric (Appendix VI). Table 6.5 below, presents a summary of the enacted scores across the TSPCK components and the three key ideas for each participant. It was not possible to obtain a pre-intervention enacted PCK score since the teachers taught the topic only once. The pre-intervention CoRe was the only way in which I could get access to the participants' PCK about the topic before the intervention.

Table 6.5: Summary of the enacted scores across the TSPCK components and the three key ideas for each participant

		Knowledge and skills related to curriculum saliency (Prompts 1-4)	Knowledge and skills related to learners' understanding (Prompts 5-7)	Knowledge and skills related to conceptual teaching strategies		Integration of PCK components	Pedagogical reasoning
				Representations (Prompt 8)	Conceptual teaching strategies (Prompts 9-10)		
Participant	Idea taught	Enacted	Enacted	Enacted	Enacted	Enacted	VSR interview
Jessica	Wavelength	R	A	A	R	R	L
	Frequency	R	A	A	A/R	A	L
	Superposition	R	R	R	R	R	R
Tshuma	Wavelength	R	R	L	A	A	L
	Frequency	R	R	L	A	A	L
	Superposition	-	-	-	-	-	-
Craig	Wavelength	L	A	R	L/A	L/A	R
	Frequency	A	A	R	L/A	L/A	R
	Superposition	A	A	R	A	A	R

*L = Limited; A = Adequate; R = Rich; (-) = not observed
***Enacted scores**

Table 6.6: Difficulties and misconceptions mentioned by the participant in the observed lessons (enacted PCK)

Ideas that learner finds difficult & misconceptions	Participant		
	Jessica	Tshuma	Craig
Light and dark lines seen in the ripple tank projection.	✔	✕	✔
Relationship between *f* and *λ* in $v = f \times \lambda$	✕	✕	✔
Confusion between speed of a wave and frequency.	✔	✕	✔
Wave speed during refraction (constant *f*).	✔	-	-
Confusion regarding frequency and period.	✔	✔	✕

✔ = mentioned; ✕ = not mentioned; (-) not applicable.

I discuss the findings per component including the aspect of *pedagogical reasoning*. The summary is based on the scores and observations recorded in Table 6.5 and Table 6.6.

Knowledge and skills related to curriculum saliency

When teaching the wave concept after in-service training, Jessica was observed to have **rich** enacted *knowledge and skills related to curriculum saliency* for all three key ideas. She was aware of the scaffolding of concepts and made an effort to build on the learners' knowledge using the terminology that they themselves used. In addition, she often allowed the learners to reach the correct terminology and/or idea of the given concept on their own through guided questioning.

Tshuma was also observed to have **rich** enacted *knowledge and skills related to curriculum saliency* when teaching the wave concept regarding *wavelength* and *frequency*. The participant showed evidence of knowledge about the scaffolding of ideas, particularly the application of equations. However, this could also be due to the sequence of the past paper and its sequence of questions that lead him to follow a logical sequence.

Craig predominantly had **adequate** enacted *knowledge and skills related to curricular saliency* with one **limited** score related to *wavelength*. The limited score is because he omitted to teach about wavelength, crests and troughs before teaching pulse length, and constructive and destructive interference. For the concepts of frequency and superposition, his sequencing was more logical and included the relevant subordinate ideas.

Knowledge and skills related to learners' understanding

The participants' enacted PCK levels can be seen in Table 6.5 and observations can be seen in Table 6.6. In summary, Jessica was observed to discuss the idea of light and dark lines seen in the ripple tank projection. She failed to address the idea of the relationship between frequency and wavelength in the wave equation, and was the only participant not to make any mention of this relationship. However, the confusion between the speed of a wave and frequency was addressed. Jessica was the only participant that mentioned the idea of how the speed of a wave changes during refraction while frequency remains constant. This is because Jessica was following the IEB curriculum where the concept of refraction is covered in Grade 10, unlike the curricular sequence of the CAPS document (Appendix I), which addresses refraction in Grade 11 which is followed by the other two participants. The difficulty learners had between frequency and period was addressed during the lessons.

Tshuma only addressed the confusion between frequency and period during the lessons. The misconception about refraction and the speed of the wave had no relevance to this participant.

Craig, similar to Jessica mentioned the explanation of light and dark lines seen in the ripple tank projection during the observed lessons. This was also true for the idea of the relationship between frequency and wavelength in the wave equation and the confusion between the speed of a wave and frequency. However, he stated that the number of vibrations in a second determines the speed of a particular wave, which reveals poor conceptual understanding. Similarly, the participant spoke about speed during his lessons (see Section 7, Electronic Appendix M), but the term 'speed' was used incorrectly to explain frequency. A discussion on the difficulty learners have between frequency and period was not addressed in the lessons.

Knowledge and skills related to representations

Jessica employed the science equipment and enacted the knowledge and skills taught during the in-service training in the conceptual teaching strategies used in her classroom. The aspects that indicated evidence of this was through her use of the ripple tank to demonstrate the concepts of reflection, refraction, diffraction. She also used the two longer single barriers, which are components of the ripple tank, to illustrate interference and related that to the understanding of the wave nature of matter. This was despite not using the apparatus to show the direct relationship between wavelength and frequency and being one of two participants who did not illustrate this relationship to the learners using the equipment. Jessica made the statement that the learners drew wave fronts "better or clearer" when compared to the learners from the previous year who were not exposed to the illustration of wave fronts using the ripple tank apparatus.

Tshuma did not employ the science equipment that was introduced during the in-service training in his teaching strategies in his classroom. His reason for this decision was due to a lack of time during the lessons.

Craig employed the ripple tank to demonstrate the relationship between wavelength and frequency and the concept of superposition. He was the only participant to use the ripple tank apparatus to demonstrate the concepts of wavelength and frequency and their relationship. Craig made a similar remark to Jessica as he stated that he believed that the use of the ripple tank as a representation improved learners' understanding, which was evident through the test his learners wrote after the representation was used.

Knowledge and skills related to conceptual teaching strategies

For this component, Jessica had a **rich** enacted score for the key ideas of *wavelength* and *superposition* and an **adequate to rich** score for the key idea of *frequency*. She followed logical sequencing, strategically thinking about content. She used several representations, including the ripple tank apparatus, in her teaching and provided evidence that she was aware of common learner misconceptions. Her overall teaching strategy was creative and included learner involvement.

Tshuma had an **adequate** score for the key ideas of *wavelength* and *frequency*. The teaching of *superposition* was not observed. Although he interacted well with the learners, he lacked variation in representations, despite having the ripple tank apparatus at his disposal, being the only participant choosing not to use the equipment provided. In addition, he did not address all the misconceptions and difficulties learners are known to experience and that were discussed during the intervention.

Craig had a **limited to adequate** score for the key ideas of *wavelength* and *frequency* and **adequate** for the key idea of *superposition*. For the concepts of wavelength and frequency, the lessons were more lecture-based predominantly using the textbook, but for demonstration purposes he made use of the ripple tank apparatus. For the key idea of superposition, the participant facilitated learning and used a variety of representations, including the ripple tank apparatus, to demonstrate the concept. He repeated the demonstration of superposition when he realised that the first demonstration was not clear to the learners, thus making an effort to improve his conceptual teaching.

Pedagogical reasoning

Jessica's *pedagogical reasoning* was scored **limited** for the concept of *wavelength* and *frequency* due to her inability to fully substantiate why she did not use the ripple tank to demonstrate these two key ideas even though it was readily available. However, this differed for the concept of *superposition* for which she was scored **rich**. Upon reflection, she explained that superposition was the easiest section to teach and for the learners to understand, which was evident while observing the lessons.

Tshuma had **limited** *pedagogical reasoning*. As mentioned, he indicated the lack of lesson time for not using the ripple tank apparatus despite his written and verbal intentions of using the apparatus and after acknowledging its value in aiding learners' understanding.

Craig was the participant that was most able to reflect on his practices, explaining his reasoning for the questions asked and was aware of adaptions that would be required to improve his teaching. He indicated that it was the first time he made use of the ripple tank during his lessons, revealing that he was willing to change his previous teaching strategy to include the apparatus.

In conclusion, Jessica, Tshuma and Craig enacted the knowledge and skills attained during the in-service training in their classrooms, although not at the same levels or in the same manner as one another. Chapter 7 presents a discussion of the results as obtained from and discussed in Chapters 5 and 6.

CHAPTER 7 - DISCUSSION OF RESULTS

7.1 INTRODUCTION

Chapter 7 presents an overview of the reasoning behind the study and the methodology that was followed. The findings of the study are summarised, which leads into how these findings answer the formulated research questions. In this chapter, I discuss the limitations of the study and how these were addressed. Recommendations for future studies are given, after which the way in which this study has contributed to the body of TSPCK knowledge development of in-service teachers is discussed.

7.2 OVERVIEW AND DISCUSSION OF THE FINDINGS AND ANSWERING THE RESEARCH QUESTIONS

7.2.1 Overview

The purpose of this study was to investigate the development of Physical Sciences teachers' PCK about the topic of waves through in-service teacher training in the use of the ripple tank apparatus. In this study, the development of PCK in the teaching of waves was explored within the classroom environment.

In the world of teaching, teachers use knowledge, specifically subject matter content knowledge, PCK, and curricular knowledge while planning and teaching (Shulman, 1986). Shulman's Theory of PCK includes two key elements of knowledge, namely, the representations of subject matter and the understanding of specific learner difficulties and learners' conceptions (Van Driel, Verloop & de Vos, 1998). Since the initial conceptualisation of PCK by Shulman (1986), the construct of PCK has continued to evolve. As a result, over time, different models have been developed that show the relationship between the domains of teacher knowledge. The earlier work of Grossman (1990) and Tamir (1988) paved the way for the developments made by Magnusson et al. (1999), who describe PCK as the transformation of a number of types of knowledge for teaching, which include SMK. The model of PCK described by Rollnick et al. (2008) gives insight into the nature of PCK by presenting a model that helps in understanding the role and amalgamation of teachers' SMK with other knowledge domains while in practice within the classroom.

As such, the model includes four manifestations of PCK, namely, representations, curricular saliency, assessments, and topic-specific instructional strategies. The model also includes domains of teacher knowledge, viz. knowledge of subject matter, students, context, and general pedagogical knowledge. Davidowitz and Rollnick (2011) argue that the four domains of teacher knowledge are influenced by the beliefs of a teacher, and vice versa. The authors further indicate that these would, therefore, influence with what a teacher enacts within the classroom environment. Mavhunga (2014) drew from the model developed by Davidowitz and Rollnick (2011) and considered the broader PCK domains of teacher knowledge. The author, however, took into account the quality of PCK at a topic-specific level, considering the TSPCK components as suggested by Mavhunga and Rollnick (2013). At the 2016 PCK summit, a group of PCK researchers developed the first consensus model of PCK, which defines PCK as having two bases: the knowledge used in the planning and delivery of topic-specific instruction in a specific classroom context; and the skill displayed when involved in the act of teaching. This model paved the way to the recent Refined Consensus Model (RCM) (see Figure 2.1).

The above literature and their respective findings illustrate the multidimensional nature of PCK and, as stated by Mavhunga (2019), these are all different perspectives of the same theoretical construct. Over the years, the challenge has been around the ambiguity of how to refer to or relate each of these PCK constructs and models to a teacher’s PCK and to its development. This is the basis on which the RCM was developed. The RCM considers how a teacher draws from the shared knowledge within the profession of teaching, known as the collective PCK (cPCK). It also considers that teachers personalise their teaching, which may be influenced by their beliefs and other factors, which is known as their personal PCK (pPCK). The pPCK in turn personalises the teachers' understanding and informs their *pedagogical reasoning* involved when teaching in the classroom environment and when their knowledge is enacted (ePCK) (Mavhunga, 2019). The RCM also considers the TSPCK nature of PCK, as described by Mavhunga and Rollnick (2013). The RCM (see Figure 2.1) describes the collective PCK as being at a discipline, topic or concept level, and distinctly shows the knowledge exchange of cPCK with a teacher’s broader professional knowledge bases, namely: content knowledge, pedagogical knowledge, curricular knowledge, assessment knowledge and knowledge of students (Carlson & Daehler, 2019). As such, the framework of this study was based on the idea that the knowledge required for teaching is at a topic and concept level and considers that the value of PCK lies in its topic-specific nature. Although the model (Figure 2.5) refers to PCK, this study explored PCK at a topic level with each realm of PCK; cPCK, pPCK and ePCK being underpinned by the TSPCK components suggested by Mavhunga and Rollnick (2013). These are: knowledge about the curricular saliency of the topic, representations, learners' prior knowledge, and what is difficult and/or easy relating to the topic and the conceptual teaching strategies.

It has been suggested that PCK can be derived from a teacher's own practice and developed through activities such as in-service training (Van Driel et al., 1998), and that teachers can transfer PCK from one topic to another (Mavhunga et al., 2016). With this evidence, it can be said that improving the quality of teaching can be done through teacher professional support programmes focusing on a particular topic. As such, this study investigated whether, and to what extent, in-service teacher training in equipment affected the five components of TSPCK of the teachers in terms of the wave concept. Furthermore, the study investigated whether the teachers would incorporate the knowledge taught during the in-service training while teaching the topic of waves in their classrooms. Based on the above-mentioned aim, the following research questions were developed.

Primary research question:

How does in-service training in the use of Physical Sciences equipment affect teachers' PCK about the teaching of the wave concept?

Secondary research questions:

a) What are the levels of the teachers' reported PCK about teaching the wave concept before the in-service training?
b) What are the levels of the teachers' reported PCK about teaching the wave concept after the in-service training?
c) How do the teachers enact PCK when teaching the wave concept after in-service training?

The study investigated the participants' PCK about the topic of waves due to a lack of previous research in the field pertaining to the topic of waves. Although it is a small component within the South African curriculum, it forms the basis of phenomena experienced in daily life through aspects of sound and light. In addition, due to its theoretical nature, learners have difficulty in understanding the topic, which leads to learners' having misconceptions about a variety of concepts related to this topic (Caleon & Subramaniam, 2010; Sadler & Sonnert, 2016; Wittmann et al., 2002).

The in-service training conducted with the participants was the intervention of this study. It was assumed that the intervention drew from the collective PCK about teaching waves, belonging to the profession, which intended to develop the personal and enacted PCK of the teachers.

The in-service training was carried out in Term 1 because it was the allocated term in which the topic of waves was to be covered according to the South African curriculum document (see Appendix I). The five TSPCK components informed the intervention based on teaching the wave concept. The CoRe-prompts, each associated with one of the TSPCK components, were used to access and determine the level of the personally reported PCK of each teacher. An expert CoRe about waves (Appendix IV) was developed and considered as a representation of the collective PCK about the teaching of waves. The participants' personal PCK, as recorded in their CoRe responses, were gauged against the expert CoRe and scored using the rubric (Appendix V). The comparison in the pre- and post-CoRe scores was used to determine whether the in-service teacher training affected the PCK of the teachers. Table 7.1 below displays the pre-and post-CoRe scores and the enacted scores across the TSPCK components, as well as the three key ideas for each participant.

Table 7.1: Summary of the pre-and post-CoRe and enacted scores across the TSPCK components, as well as the three key ideas for each participant

		Knowledge and skills related to curriculum saliency (Prompts 1-4)			Knowledge and skills related to learners' understanding (Prompts 5-7)			Knowledge and skills related to conceptual teaching strategies						Integration of PCK components	Pedagogical reasoning
								Representations (Prompt 8)			Conceptual teaching strategies (Prompts 9-10)				
Participant	**Idea taught**	**Pre**	**Post**	**Enacted**	**Pre**	**Post**	**Enacted**	**Pre**	**Post**	**Enacted**	**Pre**	**Post**	**Enacted**	**Enacted**	**VSR interview**
Jessica	**Wavelength**	R	R	**R**	R	R	**A**	L	**A**	**A**	L/A	**A/R**	**R**	**R**	**L**
	Frequency	A	**A/R**	**R**	A	A	**A**	A	**R**	**A**	A	**A/R**	**A/R**	**A**	**L**
	Superposition	A	**A/R**	**R**	R	R	**R**	A	A	**R**	A	**A/R**	**R**	**R**	**R**
Tshuma	**Wavelength**	A	A	**R**	A	A	**R**	L	**A**	**L**	L	**A**	**A**	**A**	**L**
	Frequency	A	**R**	**R**	A	A	**R**	L	L	**L**	L	**A/R**	**A**	**A**	**L**
	Superposition	L/A	**A**	**-**	L	**A/R**	**-**	A	A	**-**	L	**A/R**	**-**	**-**	**-**
Craig	**Wavelength**	L	**L/A**	**L**	A	A	**A**	L	L	**R**	A	A	**L/A**	**L/A**	**R**
	Frequency	L	L	**A**	A	A	**A**	L	L	**R**	L/A	L/A	**L/A**	**L/A**	**R**
	Superposition	L/A	L/A	**A**	A	A	**A**	L	L	**R**	A	A	**A**	**A**	**R**

*L = Limited; A = Adequate; R = Rich; (-) = not observed

***Improved scores after comparing the pre-Core and post-CoRe**

***Enacted scores**

7.2.2 Answering Research Question 1

The TSPCK levels for the pre-CoRe, per prompt, are presented in Table 5.4 and are discussed in detail in Section 5.2. Table 7.1 presents the final pre-CoRe TSPCK level for each key idea and participant. These were determined by considering the scores for individual responses to the prompts (see Table 5.4) and employing the principles presented in Table 5.1 when scoring the CoRes. The levels of the teachers' reported PCK about teaching the wave concept *before* the in-service training is summarised below for each TSPCK component.

7.2.2.1 Knowledge and skills related to curriculum saliency

Jessica had **rich** knowledge for the key idea of *wavelength* as she related the concept to other concepts in the curriculum. She had **adequate** knowledge for the key ideas of *frequency* and *superposition*. Her response regarding the key idea of frequency was mainly definition-based and did not include other relevant information such as the symbol or unit of measurement. For the key idea of superposition, she mentioned the important concepts to be taught before superposition but left out common ideas that the learners need to know about the concept.

Tshuma had **adequate** knowledge for the key ideas of *wavelength* and *frequency*. His responses were limited to the idea of pulses; however, he related the concept of wavelength to everyday examples, i.e. the spectrum. He did not relate the concept of frequency to the subordinate idea of period, but displayed knowledge in relation to future concepts in the curriculum. He had **limited to adequate** knowledge for the key idea of *superposition*. He mentioned only the two main subordinate ideas of superposition and provided no reference to a real life application, such as sound.

Craig had **limited** knowledge for the key ideas of *wavelength* and *frequency* because he failed to mention the name, unit and symbol of the physical quantity referred to in the key ideas, with no reference to real life applications. He revealed his own misconceptions that in-phase points also undergo destructive interference and that the number of vibrations per second determines the speed of the wave. He had **limited to adequate** knowledge for the key idea of *superposition*. He related the idea to the important subordinate ideas of constructive and destructive interference and the effect of interference on amplitude. He mentioned the pre-concepts that are required to understand superposition, but did not relate the concept to other relevant ideas of sound or light. During his pre-interview, Craig mentioned that an extensive amount of content makes up the Physical Sciences curriculum, which had an impact on the number of practical lessons he was able to conduct and the depth in which he carried them out.

7.2.2.2 Knowledge and Skills related to Learner Understanding

Jessica had **rich** knowledge for the key ideas of *wavelength* and *superposition*. She mentioned appropriate difficulties and the most common misconceptions. She had **adequate** knowledge for the key idea of *frequency* as she mentioned the difficulty of teaching frequency and period. However, she did not mention the common misconception of learners believing frequency to be the same as the speed of a wave and that the one determines the other.

Tshuma had **adequate** knowledge for the key ideas of *wavelength* and *frequency*. He mentioned appropriate learner difficulties but failed to mention common misconceptions for the idea of wavelength. For the idea of frequency, he mentioned the misconception of frequency and period, but did not mention other common misconceptions of frequency, such as frequency being thought to be the same as the speed of a wave and that the one determines the other. He had **limited** knowledge for the key idea of *superposition* because he omitted to include common misconceptions.

Craig had **adequate** knowledge for *all three key ideas*. He mentioned concepts that learners find difficult and what he found difficult to teach and listed common learner misconceptions, however, as mentioned, he had his own misconceptions about the key idea of frequency.

7.2.2.3 Knowledge and skills related to representations

Jessica had **limited** knowledge for the key idea of *wavelength* because she gave nonspecific examples of representations such as not stipulating which diagram she would use. This was the same for the key ideas of *frequency* and *superposition*, however, other representations were mentioned over and above a slinky spring and simulations, thus resulting in a score of **adequate** knowledge for these two key ideas. In her pre-interview, she illustrated her belief in incorporating hands-on activities during lessons, based on the availability of equipment and how dangerous the experiment may be. The participant highlighted her concerns regarding the ripple tank and its use.

Tshuma had **limited** knowledge for the key ideas of *wavelength* and *frequency* because he did not specify what equipment he would use or elaborate on how he would make use of simulations and demonstrations. He had **adequate** knowledge for the key idea of *superposition* because he stated the ripple tank as an apparatus that he planned to use but was not specific on how he would use the apparatus nor what simulations he would utilise. His pre-interview responses further revealed that he was aware that he did not carry out practical lessons often in class due to a lack of equipment and time. This was despite knowing that science teaching is carried out more effectively using a variety of resources.

Craig had **limited** knowledge for all three key ideas. The participant simply listed the representations and was non-specific about their use. His pre-interview indicated that he believed in using visualisations to aid learners' understanding, but had not made use of such visualisations. He also mentioned that because of the demanding CAPS curriculum, he was unable to make time for a hands-on approach in his lessons.

7.2.2.4 Knowledge and skills related to conceptual teaching strategies

Jessica revealed **limited to adequate** knowledge of the key idea of *wavelength* because there was little evidence of logical scaffolding. She also did not mention the use of higher-order thinking questions in her response. She revealed **adequate** knowledge of the key ideas of *frequency* and *superposition* because, again, she did not show evidence of logical sequencing in her strategies. However, she illustrated good knowledge in formulating important questions to stimulate conceptual understanding, which require higher-order thinking skills.

Tshuma revealed **limited** knowledge of *all three key ideas*. For the key idea of wavelength, he mentioned using a rope, which is not the best item to use to represent waves due to the friction it experiences along the ground. For the key ideas of frequency and superposition, he mentioned demonstration but did not indicate further strategies that could be used. For all three key ideas, his chosen questions were more related to instruction rather than conceptual development. His pre-interview revealed that despite discussing the idea of allowing learners to explore to stimulate conceptual understanding, he admitted to not carrying out many practicals.

Craig revealed **adequate** knowledge of the key ideas of *wavelength* and *superposition*. He mentioned making use of different strategies such as: discussion, simulations and the use of past exam questions. The questions he considered important to ask for the concept of wavelength would develop conceptual understanding, but would not aid in understanding the key idea of superposition. However, the subordinate ideas given for superposition were relevant. He revealed **limited to adequate** knowledge of the key idea of *frequency* because, again, he mentioned different strategies and included the subordinate idea of period, but did not state questions that would develop conceptual understanding of frequency. During the pre-interview, he acknowledged the need for equipment and resources to allow learners' conceptual understanding through practical work; however, he revealed his lack of using such equipment.

7.2.3 Answering Research Question 2

The TSPCK levels for the post-CoRe, per prompt, are presented in Table 5.5 and are discussed in detail in Section 5.3. Table 7.1 presents the final post-CoRe TSPCK level for each key idea and participant, which were determined in the same manner as the pre-CoRe, as mentioned above, but using Table 5.5. The levels of the teachers' reported PCK about teaching the wave concept after the in-service training and the most important differences and/or improvements regarding each participants' PCK that could be linked to the intervention are summarised below.

7.2.3.1 Knowledge and skills related to curriculum saliency

Jessica and Tshuma improved their knowledge and skills for the key ideas of *frequency* and *superposition*, while Craig showed an improvement for the key idea of *wavelength*. For the key idea of frequency, Jessica and Tshuma included its unit and symbol in their post-CoRe responses. The symbols and unit of frequency were discussed during the intervention while discussing the formula that shows the relationship between the speed of a wave, frequency and wavelength (see Figure 4.9).The improvement for Craig can also be linked to the intervention because he mentioned the idea of how the light lines observed in the projection of the ripple tank are the crests and the darker lines are the troughs. This idea was discussed in the intervention (see Figure 4.6), and is an idea that was not mentioned by the participant in any of his pre-intervention responses.

7.2.3.2 Knowledge and skills related to learners' understanding

After the intervention, the only improvement in PCK for any key idea was shown by Tshuma, who revealed improved knowledge about the key idea of *superposition*. His post-CoRe response to Prompt 6 gave an example of how explaining constructive interference is made easy through the use of diagrams. A diagram of superposition (see Figure 4.15) was discussed and drawn during the intervention so he may have obtained the idea of using a diagram from the intervention, but there is not enough evidence to confirm this.

7.2.3.3 Knowledge and skills related to representations

Both Jessica and Tshuma had an improvement in scores for the key idea of *wavelength*. Jessica was more specific in her post-CoRe response about how she would use the ripple tank to illustrate wave fronts. Jessica's improvement can be directly linked to the intervention, knowing that the concept of wave fronts was discussed and illustrated using the ripple tank. Jessica showed an additional improvement for the key idea of *frequency*. She elaborated how she would use the ripple tank, i.e. changing the source's oscillations, therefore being more specific as to how she would use the given apparatus. This, again, can be linked to what was discussed in the intervention while the ripple tank was in use (see Section 4.3.2).

7.2.3.4 Knowledge and skills related to conceptual teaching strategies

Effective interaction of the TSPCK components demonstrates rich conceptual teaching strategies (Coetzee, 2018). The participants had to illustrate that they possessed knowledge about the other four TSPCK components and their integration into *conceptual teaching strategies* that would allow for learners' conceptual understanding. Jessica and Tshuma displayed improved levels for all three key ideas for this component. In the post-CoRe, the participants had a better understanding of curricular sequencing, the use of appropriate questions to address common learner misconceptions, and how to develop conceptual understanding. They also mentioned the use of demonstrations and representations. The participants therefore illustrated knowledge about the integration of the TSPCK components into their teaching strategy. Despite Craig's scores remaining the same, he alluded to the idea of incorporating the ripple tank apparatus, which was now available to him, into his teaching strategy.

As such, one can conclude that the reported PCK of the participants was enhanced after being provided the ripple tank apparatus and the in-service teacher training.

7.2.4 Answering Research Question 3

The study went further and assessed the enacted PCK of the teachers by observing them in their classrooms while they taught the three key ideas, namely, wavelength, frequency and superposition and their respective subordinate ideas. The observations were video recorded. Using the video recordings, the lessons were broken up into sections and a narrative account was given for each section. The sections that were rich in information relevant to the study and to the key ideas, and which revealed evidence of the enactment of one or more of the TSPCK components, were chosen and discussed (see Chapter 6). After which, I evaluated the participants' PCK using the rubric for enacted topic-specific PCK (Appendix VI). The participants were evaluated per TSPCK component and per key idea, and were scored as having either **restricted**, **adequate** or **rich** knowledge.

The recorded observations allowed for the enacted PCK to be further explored through eliciting the teachers' *pedagogical reasoning* during the VSR interview. The teachers' thinking and general views about the training were revealed through the semi-structured post-interview. The lesson observations and recorded interviews were used to search for evidence that the intervention contributed to and had become part of the participants' pPCK and ePCK. The section below gives a summary of the findings that answer the third sub-question: How do the teachers enact PCK when teaching the wave concept after the in-service training?

7.2.4.1 Knowledge and skills related to curriculum saliency

Jessica and Tshuma had **rich** scores for all three key ideas. Both participants had workable sequential development and an understanding of the importance of the key ideas in relation to other ideas in the curriculum. However, Tshuma's curricular sequence was determined by the past paper questions that he used during the lesson. Despite this observation, Tshuma had knowledge of the topic and the relevant subordinate ideas and made an effort to incorporate his content knowledge into the questions he asked.

Craig had a **limited** score for the key idea of *wavelength* due to his inappropriate sequencing of ideas. He did not address the concept of wavelength and the pre-concepts of a crest and trough, and taught superposition before these pre-concepts. This may have been due to his reliance on the textbook and therefore the curricular sequence of the textbook. Craig showed more evidence of appropriate curriculum sequencing and illustrated his awareness of what knowledge should have been in place before the concepts of *frequency* and *superposition* were taught. This resulted in an **adequate** score for both key ideas.

7.2.4.2 Knowledge and skills related to learner understanding

The summary below is based on the information given in Table 6.6 and Table 7.2 regarding which difficulties and misconceptions, as addressed during the intervention, were mentioned by the participants in the different data capturing techniques that took place pre- and post-intervention and enacted in the classroom.

Jessica was given an **adequate** score for the key idea of *wavelength* and *frequency*. She made an effort to facilitate learners' understanding and discussed most of the common misconceptions that were addressed during the intervention, for example: the troughs and crests seen as light and dark lines respectively in the ripple tank projection (see Table 6.6 and Table 7.2). However, she had a misunderstanding about the pre-concept of a pulse. In addition, she misused the term 'speed' to ask, "How to determine the *speed* of one pulse" and used the words, "How long each pulse or wave cycle **is**" when referring to the time interval, which the verb 'takes' would have referred to (see Section 6.2.1). However, she had **rich** *knowledge and skills related to learners' understanding* for *superposition* because she was aware of the way in which learners were thinking and adjusted her teaching strategy when the learners were not seeing what they were meant to while using the slinky spring as a representation. Furthermore, she allowed learners to develop understanding through exploration.

Table 7.2: Difficulties and misconceptions addressed during the intervention that were mentioned by the participant in the different data capturing techniques

Ideas that learner finds difficult & misconceptions	Participant											
	Jessica				Tshuma				Craig			
	Interview	Pre-CoRe	Post-CoRe	Enacted	Interview	Pre-CoRe	Post-CoRe	Enacted	Interview	Pre-CoRe	Post-CoRe	Enacted
Light and dark lines seen in the ripple tank projection	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	✓
Relationship between *f* and λ in $v = f \times \lambda$	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✓	✓
Confusion between speed of a wave and frequency	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	✗	✓
Wave speed during refraction (constant *f*)	✗	✗	✗	✓	-	-	-	-	-	-	-	-
Confusion between frequency & period	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗

✓ = mentioned; ✗ = not mentioned; (-) not applicable

pre intervention; post intervention.

Tshuma had **rich** *knowledge and skills related to learners' understanding* for the concepts of *wavelength* and *frequency*. He pinpointed the appropriate aspects that learners would find difficult relevant to the key ideas. He also mentioned an example of such difficulties, i.e. determining the number of wave cycles. However, he did not discuss the misconceptions that learners have which were relevant to the ripple tank apparatus and which were discussed during the intervention; this was mainly due to not using the apparatus during his lessons. The confusion between frequency and period was one misconception that was addressed during the observed lessons (see Table 6.6 and Table 7.2). However, he already possessed this knowledge, having mentioned it in his pre-intervention data. He engaged well with the learners and assessed their understanding through continuous questioning. As mentioned, the participant was not observed teaching the concept of superposition.

Craig had **adequate** *knowledge and skills related to learners' understanding* for *all three key ideas*. The participant displayed two different teaching strategies: lecturing and demonstration. However, despite initially using the lecture-based teaching style, he changed his teaching style to demonstration when using the ripple tank. This change in teaching style facilitated conceptual development using representations and analogies. Even during the lecture based lessons, the participant addressed the misconceptions discussed during the intervention, except the confusion between frequency and period (see Table 6.6 and Table 7.2).

7.2.4.3 Knowledge and skills related to representations

Jessica made use of a slinky spring and a wave diagram to discuss the concepts of *wavelength* and *frequency*, but did not support learners' understanding through the use of the ripple tank apparatus, as illustrated during the in-service training. Consequently, her knowledge and skill was scored as **adequate** for both concepts. For the concept of *superposition*, a variety of representations were used, including the ripple tank apparatus. This facilitated learners' understanding, linked the representations to aspects of the concept of superposition, and stimulated conceptual understanding through questioning. As a result, she was scored as having **rich** *knowledge about representations* for this key idea. Jessica also stated that the rest of her department began using the ripple tank apparatus after it was provided and that she had trained a new colleague on the use of the same apparatus after the in-service training.

Tshuma decided to use the time available to work through past paper questions and not to demonstrate or represent the concepts of *wavelength* and *frequency* through forms of physical demonstration. This was despite having the ripple tank apparatus available to him and after receiving the in-service training. Consequently, he was scored as having **limited** *knowledge about representations*. The participant was not observed teaching *superposition*.

Craig was the only participant to use the ripple tank apparatus to demonstrate the concepts of wavelength and frequency to enforce concept development, as shown in the in-service training. In addition, the participant stimulated conceptual understanding through questioning when the ripple tank apparatus was being used. For the concept of superposition, Craig used a variety of representations to discuss and demonstrate the concept. He used the apparatus as shown during the intervention, and repeated the demonstration when the first illustration was unclear. As such, the participant was scored **rich** for *all three concepts*. It is important to make note of the fact that his *knowledge and skills related to representations* was recorded as **limited** in the CoRes. However, his enacted PCK indicated richer knowledge for this same component. This concurs with Mazibe et al. (2018), who find that there is a variation between the level of reported PCK and the level of enacted PCK, and that the one manifestation of PCK would not necessarily be a true reflection of the other. A reason for Craig having higher enacted scores could be that through previous experience while teaching the topic of waves, he was more confident in the classroom rather than writing down his knowledge during the CoRe, which was an aspect that was new to him.

7.2.4.4 Knowledge and skills related to conceptual teaching strategies

Jessica revealed **rich** knowledge of the key ideas of *wavelength* and *superposition* and an **adequate to rich** knowledge for *frequency*. She followed a logical curricular sequence and facilitated understanding through exploration and discovery to develop and reconstruct learners' ideas. She integrated different teaching approaches to support learners' understanding and addressed their common misconceptions. She used representations, although not physical demonstrations, to teach wavelength and frequency, but then incorporated the ripple tank apparatus to teach superposition. Her conceptual teaching strategy was creative and learner-centred, which supported conceptual understanding and, as such, illustrated knowledge of the other four TSPCK components.

Tshuma revealed **adequate** knowledge of the key ideas of *wavelength* and *frequency*. He engaged well with the learners and facilitated learning through questions. He continuously asked the learners if they understood the concepts before moving on to the other ideas/concepts. He did not address all the common misconceptions; however, his strategy encouraged learner involvement. Tshuma emphasised the application of concepts in calculations rather than the understanding of the concepts. As mentioned, the participant was not observed teaching the concept of *superposition*. Tshuma illustrated *knowledge of curricular saliency*, *learner thinking* and *what is difficult to understand and teach*, but not so much about *representations* in terms of their integration within his conceptual teaching strategy.

Craig revealed **limited to adequate** knowledge of the key ideas of *wavelength* and *frequency* because much of his lessons were based around the lecture teaching style. The participant approached wave theory through definitions written on the board, despite the definitions being present in the textbook. In addition, the concept sequence followed was not very logical. However, despite his lack of confidence about the apparatus and his teaching strategy, which was evident through his reliance on the textbook and through his procedural teaching approach, he made an effort to integrate representations using the ripple tank apparatus. This is also true for his conceptual teaching strategy for the key idea of *superposition*, but, in addition, while using the apparatus, he asked questions to ascertain the learners' understanding as part of his conceptual teaching strategy. As such, he was scored **adequate** for this key idea. Through this integration of TSPCK components, the participant showed to have better knowledge of *representations* and *learners' thinking* than about *curricular saliency*.

7.2.4.5 Integration of PCK components

Jessica's competence in integrating the components was considered **rich** for the key ideas of *wavelength* and *superposition*. With both concepts, she showed evidence of logical curricular sequencing and it was evident that she understood the learners, their thinking, and their prior knowledge because she addressed four of the five difficulties and misconceptions discussed during the intervention (see Table 7.2). She used a variety of representations, including the ripple tank apparatus, for the concept of superposition. Her competence was scored as **adequate** for the key idea of *frequency* because no representations were utilised and no further learner difficulties were discussed based on this key idea.

Tshuma's competence in integrating the components was considered **adequate** for the key ideas of *wavelength* and *frequency*. He followed a logical curricular sequence, but this may have been based on the fact that he was using a past paper during the lessons and was therefore following the question paper's sequence. As discussed above, under learners' understanding, Tshuma only addressed the confusion regarding frequency and period during his lessons (see Table 7.2). He left out the other three difficulties and misconceptions. He lacked creative components in his strategy and did not include the use of the ripple tank apparatus to assist in conceptual development, despite being provided with the apparatus and in-service teacher training. As mentioned, the participant was not observed teaching the concept of *superposition*. Craig's competence in integrating the components was considered **limited to adequate** for the key ideas of *wavelength* and *frequency*. The curricular sequence may have been a consequence of the fact that he was following the textbook sequencing. Although he addressed three difficulties and misconceptions that learners have (see Table 7.2), it was approached through a chalk and tell method rather than discussion. He made use of representations in the form of the ripple tank to demonstrate both key ideas. He was scored **adequate** for his *knowledge of curricular saliency* for the concept of *superposition* because his curricular sequence was more logical. In addition, he used diagrams and physical demonstration to develop learners' understanding through questioning.

7.2.4.6 Pedagogical reasoning

Jessica's *pedagogical reasoning* was scored **limited** for the concepts of *wavelength* and *frequency* because she did not substantiate fully why she chose not to use the ripple tank available to her to demonstrate the key ideas of wavelength and frequency. Upon reflection, she gave sufficient explanation about her teaching strategy but failed to reflect on the difficulties the learners had in understanding. As such, her score for the key idea of *superposition* was **adequate**.

When ascertaining Tshuma's *pedagogical reasoning* regarding his decision not to use the ripple tank apparatus in his lessons but rather using the lesson time to focus on past paper questions, he revealed that it was due to a lack of lesson time. This is despite the participant indicating his intentions to use the apparatus in his pre- and post-CoRe. As such, the participants' *pedagogical reasoning* was considered **limited** for the key ideas of *wavelength* and *frequency*. No score for *superposition* could be given.

Craig gave full accounts for his actions and stated areas in which he believed he needed to improve his teaching. As discussed in section 6.2.3, when the participant was asked if he would change anything when looking back at his lessons, he gave concrete examples as to how he would change his lesson plan. His response accounts for the curriculum sequencing that he followed and revealed his awareness of curricular sequencing outside the textbook.

Craig, who generally had the least improved reported PCK and enacted PCK scores, had the highest *pedagogical reasoning* scores (see Table 7.1). As already mentioned, Craig had limited *knowledge and skills related to representations* in the CoRes, however, his enacted PCK indicated richer knowledge for this same component. This finding is in line with a finding from Mazibe et al.'s (2018) study, as explained above. In having previous experience while teaching the topic of waves, Craig was more confident in the classroom than in writing down his knowledge during the CoRe, which was an aspect new to him. The results for Tshuma are also in line Mazibe et al.'s (2018) findings. Tshuma gave written (reported PCK) and verbal intentions of using the apparatus, however, did not use the apparatus during his enacted PCK and, as such, he did not a give satisfactory pedagogical reason for not using the equipment. This shows the variation between the level of reported PCK and the level of enacted PCK and that the one manifestation of PCK would not necessarily be a true reflection of the other.

Another reason for Craig's higher scores for *pedagogical reasoning* may have been brought about by the type of questions and the way in which I asked the questions during his VSR interview (see Section 6.2.3). The first question I asked was regarding the idea that I had recognised that he followed a different curricular sequence, i.e. addressing knowledge about a pulse and an amplitude before wavelength and frequency. The second question was based on the idea that I found it interesting that he introduced superposition straight after addressing the definitions of amplitude and pulse, but before introducing frequency and wavelength. These questions may have brought about a sense of guilt in the participant and therefore he may have felt led to amend his teaching strategy, thinking that what he had done in class was incorrect.

During their post-interviews (Electronic Appendices Q, R and S), all three participants stated that they found the training to be helpful and, as recalled by the trainer (Electronic Appendix U), the teachers were receptive to the idea of receiving further in-service training. It was apparent that the teachers were enthusiastic about the intervention and that their perception of the ripple tank apparatus was positively changed after participating in the in-service teacher training. The openness with which the teachers accepted the in-service training is in line with the findings of Johnson et al. (2013), which ascertained that teachers are receptive to receiving more materials and training because they acknowledge what could be achieved.

7.2.5 Conclusion: Answering the main research question

The following discussion, with reference to Table 7.1 and Table 7.2, sets out to answer the primary research question of how in-service training in the use of Physical Sciences equipment affects teachers' PCK about the teaching of the wave concept.

7.2.5.1 Knowledge and skills related to curricular saliency

Collectively, the participants' reported PCK for this component was the second-best improved component (see Table 7.1). After the in-service training, Jessica's reported PCK level improved from **adequate** to **adequate to rich** for the key idea of *frequency* and *superposition*. In addition, she had **rich** enacted PCK scores for all three components.

Tshuma's reported PCK level improved from **adequate to rich** for the key idea of *frequency* and from **limited/adequate** to **adequate** for the key idea of *superposition*. In addition, he had **rich** enacted PCK scores for the components of *wavelength* and *frequency*. The key idea of *superposition* was not observed during the lessons.

Craig's reported PCK level improved from **limited** to **limited/adequate** for the key idea of *wavelength*. In terms of his enacted PCK, he had a **limited** knowledge for the key idea of *wavelength* and an **adequate** knowledge for *frequency* and *superposition*.

7.2.5.2 Knowledge and skills related to learners' understanding

After the in-service training, the only improvement for any key idea was Tshuma's about the key idea of *superposition*. Even though learners' thinking was extensively discussed in the intervention, the teachers did not seem to realise the importance of knowing about the difficulties and misconceptions learners have with conceptual understanding.

In summary, and with reference to Table 7.2, Jessica was observed to discuss the idea of light and dark lines seen in the ripple tank projection, which was not previously recorded in the pre-interview, pre-CoRe or post-CoRe. She failed to address the relationship between frequency and wavelength in the wave equation during her lessons, and made no mention of this idea in her interview or CoRes. She was the only participant not to make any mention of this relationship. However, the confusion between the speed of a wave and frequency, which was not mentioned in her pre-interview or in her pre-CoRe, was mentioned in her post-CoRe and discussed during her lessons. This indicates that this may be an idea obtained from the intervention. Jessica was the only participant that mentioned the idea of how the speed of a wave changes during refraction while frequency remains constant. The difficulty learners have regarding frequency and period was recorded in her post-CoRe and was addressed during the observed lessons, however, it was also recorded in her pre-interview and pre-CoRe. This indicates that the participant had knowledge of this idea before the intervention. She, therefore, addressed four of the five difficulties and misconceptions discussed during the intervention, three of which were not recorded as knowledge in her pre-interview and pre-CoRe (see Table 7.2). This suggests that there was an improvement in her pPCK, and therefore ePCK after the intervention.

Tshuma mentioned the idea of the light and dark lines seen in the ripple tank projection. He covered the confusion between the speed of a wave and frequency in his post-CoRe, which was not mentioned in the pre-interview or pre-CoRe. This indicates that this may have been an idea obtained through the intervention. However, neither ideas were covered during the observed lessons and he was the only participant to not address the confusion regarding frequency and period during the lessons. The participant mentioned the relationship regarding frequency and wavelength in the wave equation both in his pre- and post-CoRe. Despite this, he was not observed to have addressed this idea during the observed lessons. The difficulty learners have regarding frequency and period was recorded in the post-CoRe and was taught during the observed lessons, however, it was also recorded in his pre-interview and pre-CoRe. This indicates that the participant had knowledge of this idea before the intervention. He therefore was observed to leave out three difficulties and misconceptions during his lessons, despite having been mentioned in his post-CoRe, two of which were not recorded as knowledge in his pre-interview or pre-CoRe (see Table 7.2). This indicates that despite an improved pPCK through the intervention, he did not transfer his pPCK into ePCK.

Craig did not enter into an explanation regarding the light and dark lines seen in the ripple tank projection in his pre-interview or pre-CoRe, but mentioned it in his post-CoRe and observed lessons. This indicates that this may have been learnt during the intervention. This is also true for the idea about the relationship between frequency and wavelength in the wave equation. In terms of the confusion between the speed of a wave and frequency, the participant mentioned it in his pre-CoRe but stated that the number of vibrations in a second determines the speed of a particular wave, which reveals poor conceptual understanding. Similarly, Craig spoke about speed during his lessons (see Section 7, Electronic Appendix M), but the term 'speed' was used incorrectly to explain frequency. A discussion on the difficulty learners have regarding frequency and period was also recorded in his pre-interview, pre-CoRe and post-CoRe, but was not covered in the lessons. However, because it was mentioned in his pre-interview and pre-

CoRe, it indicates that the participant knew of this idea before the intervention. He therefore discussed three difficulties and misconceptions that learners have during the lessons, two of which were not recorded as knowledge in his pre-interview or pre-CoRe (Table 7.2). This suggests that there was an improvement in his pPCK and ePCK after the intervention, and thus he transferred his pPCK into ePCK.

7.2.5.3 Knowledge and skills related to representations

Jessica employed the science equipment to demonstrate the concepts of reflection, refraction, diffraction and superposition, as illustrated in the training. She was one of two participants who did not illustrate the direct relationship between wavelength and frequency to the learners using the equipment. Jessica used the ripple tank apparatus after being supplied with it and with in-service training. Thereafter, Jessica stated during her post-interview that the rest of her department had begun using the ripple tank that was provided. She also stated that she trained a new colleague on the use of the same apparatus.

Tshuma did not employ the science equipment that was introduced during the in-service training in the teaching strategies used in his classroom. He stated that the lack of time during lessons was the reason for this decision. In his pre-CoRe under the prompt of ‘*What representations would you use in your teaching strategies?’* he wrote, "Given the right equipment, one would teach the topic easier." In his post-CoRe, he made reference to using the ripple tank. Furthermore, in his pre-interview, he alluded to the fact that the reasons for not carrying out hands-on lessons, despite knowing their value and emphasising that science is learnt best through "exploring", was due to the lack of equipment and due to time constraints. His pre-interview also alluded to the fact that he had been relying on charts and textbook activities in his lessons to teach waves, which is what I observed him using during the lesson observations. His written and verbal responses illustrated his intention to use the ripple tank apparatus, especially knowing its value in teaching the concept of waves. However, he did not carry out this intention, even though the ripple tank apparatus was now available to him and he was trained to use it.

Craig employed the ripple tank in his lessons. He was the only participant to use the ripple tank apparatus to demonstrate the concepts of wavelength and frequency and their relationship, as shown in the training. He further made use of the apparatus to teach the key idea of superposition, again, as illustrated in the training.

In addition to the above, Jessica and Craig made similar observations. Jessica indicated that the learners drew wave fronts "better or clearer" after being exposed to the illustration of wave fronts using the ripple tank apparatus when compared to the learners from the previous year who were not exposed to the ripple tank apparatus. Craig stated that he believed that the use of the ripple tank as a representation improved learners' understanding, which was evident through the test that his learners wrote after the representation was used. This suggests the effect that improved ePCK has on learner performance.

7.2.5.4 Knowledge and skills related to conceptual teaching strategies

Collectively, the participants' reported PCK showed the most improvement for the *knowledge and skills related to conceptual teaching strategies*. Rollnick and Mavhunga (2016) allude to the idea that rich conceptual teaching strategies necessitate the integration and effective interaction of the other components. Therefore, the improvements for this component may be due to the participants' individual improvements in the other TSPCK components, impacting the final score for each of the participants' *knowledge and skills related to conceptual teaching strategies.*

7.2.5.5 Integration of PCK components

Table 6.5 and 7.2 reveal the close link between the scores for *knowledge and skills related to conceptual teaching strategies* and the scores for the teachers' *integration of PCK* components, yet both components were scored separately using the Rubric for enacted PCK (Appendix VI). Carlson and Daehler (2019) suggest that teachers need to have an understanding of all the components to make concepts understandable to all learners during their teaching strategy. In addition, Mavhunga (2018, p. 21) states:

> *The components of TSPCK were found to interact among one another in distinguishable, completely interwoven arrangements, in some cases in a combination of a linear and interwoven structural arrangement.*

More about this finding and suggestions for future studies are discussed in Section 7.5.

7.2.5.6 Pedagogical reasoning

Jessica did not substantiate fully why she chose not to use the ripple tank to demonstrate the key ideas and relationship between wavelength and frequency. This differed for the key idea of superposition.

Tshuma indicated his intension to use the ripple tank apparatus during his pre-and post-CoRe. However, he made the decision not to use the ripple tank apparatus in his lessons and rather to use the provided lesson time to focus on past paper questions. He indicated that it was due to the shortage of lesson time.

Craig gave a full account for his actions and stated areas in which he believed he needed to improve his teaching. As already discussed, he generally had the least improved reported PCK and enacted PCK scores, but had the 3highest scores (see Table 7.1). This is discussed in detail in Section 7.2.4.

Although this study did not focus on comparing the participants' reported PCK to their enacted PCK, Jessica's reported PCK for this topic was similar to what was enacted. Her lesson plan revealed in her semi-structured pre-interview regarding the three key ideas of wavelength, frequency and superposition (Appendix XI) correlated with her CoRe responses and, in turn, correlated to what was enacted in the classroom. The misconceptions mentioned and discussed in her semi-structured pre-interview corresponded with what was recorded in her CoRe responses and which were addressed in her lessons.

Looking at Table 6.5 and Table 7.1, and comparing Tshuma's reported PCK to his enacted PCK, Tshuma's post-CoRe scores, like Jessica's, were similar to his enacted PCK scores.

Craig's strategy, as taken from his pre-interview (Appendix XI) and compared to what he enacted in the lessons, followed a similar approach. However, he included the use of the ripple tank which was now available to him.

Through the analysis and scoring of the pre-and post-CoRes and the above overview and discussion of the findings, it was evident that the participants' reported PCK improved after receiving the ripple tank apparatus and the in-service training on the use of the ripple tank, focusing on Grade 10 topic of waves (see Table 7.1). However, the improved reported PCK was not at the same level across each TSPCK component or for each of the different concepts. This highlights the importance of assessing a teacher's PCK for each TSPCK component and per concept. Furthermore, through the analysis of the classroom observations and the scoring of the enacted PCK (see Table 7.1), it is evident that enacting the skills learnt during the intervention contributed to developing the teachers' understanding of what the topic entails and how it can be taught. The participants drew from the cPCK of science teaching through the intervention to develop and improve their pPCK, as seen in their reported PCK. As such, this developed and improved their ePCK in the topic of waves.

7.3 A SUPPLEMENTARY FINDING

A supplementary finding from the study is the time constraints felt by the teachers in the classroom environment, causing the lack of practical lessons. Although it is not linked specifically to the TSPCK components relevant to the study, it still revealed the pedagogical reasoning of the teachers while teaching the topic of waves. This also supports findings from other studies, as discussed below.

Tshuma gave the scarcity of lesson time as his primary reason for using the available time to cover past paper questions as opposed to using the ripple tank apparatus in his lessons to teach the key ideas of wavelength, frequency and superposition (Electronic Appendix O and R). This finding is similar to the results obtained from Rollnick et al. (2008), which revealed that because numerical values are easily substituted into equations, teachers often spend more time on the calculations rather than the understanding of the concept. This is especially true if exam results take priority. Craig made it apparent in his pre-interview (Electronic Appendix D and discussed in Section 5.2.3) that the curriculum is "loaded" and that "the time to do practical work is very limited and that it is a cause for concern". This is in line with what was revealed by Ramatlapana and Makonye (2012), who set out to investigate teacher autonomy and curriculum implementation. They explain that the prescriptive nature of the CAPS curriculum demands uniformity and impacts and restricts the professional autonomy of teachers, effecting the quality of education. In addition, Green and Condy (2016, p. 7) state, "Teachers in schools today experience severe time constraints and are under extreme pressure to produce results in the national assessments, leaving little time for active learning." It is therefore evident that these two participants are not the only teachers that feel the tension and constraints of the CAPS curriculum.

An additional finding is one that suggests the effect that improved ePCK has on learner performance. This was evident through the statements made by Jessica and Craig that the use of the ripple tank apparatus improved learners' conceptual understanding in drawing wave fronts. This was further shown by their improved performance through a written test.

7.4 LIMITATIONS AND RESTRICTIONS OF THE STUDY

It must be acknowledged that the results of the study cannot be generalised and taken as a norm for the wider population of in-service teachers. The study only involved three case studies, but included participants that were of different ages, genders and races (see Table 3.1), but who were all teaching Grade 10 Physical Sciences. Further limitations to this study that need to be considered are as follows:

a) Although the lesson observations occurred in the teachers' natural context and took place after the intervention, I had to consider that the teachers would not enact their entire personal PCK in a given moment in front of a given group of learners. As a result, I could merely look for links between the intervention and what was provided in their pre- and post-CoRe, and what was observed during their lesson observations.
b) The third sub-question investigated how the teachers employed the use of the equipment and enacted the knowledge taught during the in-service training in their conceptual teaching strategies used in the classrooms. As explained previously, I could only report on events and findings that illustrated the similarities between what was covered in the intervention and the knowledge employed and revealed during teaching. I could therefore not assume that the teachers obtained the knowledge during the intervention. This is because it was not possible to obtain a pre-intervention enacted PCK score since the teachers taught the topic only once.
c) Other limitations due to observer effects are discussed in detail in Appendix XI.

7.5 RECOMMENDATIONS FOR FUTURE STUDIES

As this study has revealed, Tshuma's reported PCK was less than his enacted PCK. As such, it shows the importance of having several different data collection techniques that obtain as much data as possible about both the reported and enacted PCK of a teacher to ensure a reliable overall reflection of a teacher's TSPCK. This is in line with the findings of Mazibe et al. (2018), which indicate that there is sometimes a variation between the level of reported PCK and the level of enacted PCK, and that the one manifestation of PCK would not necessarily be a true reflection of the other. As such, like Mazibe et al. (2018) state, there is still a paucity of information about the comparison between reported and enacted PCK. What is evident, however, is that both forms of PCK should be explored as it involves both understanding and enactment (Park & Oliver, 2008).

As mentioned, at times Craig did not maintain discipline in the classroom. As much as content knowledge is a prerequisite of PCK, general PK may be a prerequisite for PCK. If a teacher has the CK and an acceptable level of PCK, but cannot engage learners and maintain discipline, the teaching strategy will be less effective. This may therefore indicate the scope for future research in order to determine the link between PK and PCK.

The results of this study, in relation to the research questions, show that the TSPCK of the participating teachers improved after the in-service teacher training. However, to maximise the positive effects of in-service training, it could be worthwhile to carry out a study to determine how teachers perceive teacher training to gain insight into their likes, dislikes and requests during such in-service training.

While analysing and scoring the CoRes, I became aware that the participants did not interpret specific prompts in a manner that resulted in well-rounded responses. This was not only due to their interpretation, but also due to the current wording of the specific prompts. It is for this reason that, in addition to the amendments suggested by Coetzee (2018), one can consider further amendments, as presented in Appendix XIV, to the CoRe prompts for further studies. Rollnick and Mavhunga (2016) stipulate that rich conceptual teaching strategies necessitate the integration and effective interaction of the other components. The Grand Rubric (see Figure 2.3) consists of five PCK components with the component of *knowledge and skills related to* *conceptual teaching strategies* and *integration between PCK* components as two separate components. It may be superfluous to assess both the components separately and thus one can consider, different to the Grand rubric, that both components could be combined when capturing and assessing PCK.

Essentially, further studies into PCK build on previous research. I envisage that this study may contribute to the current information about PCK and how to use this knowledge to support teacher education.

7.6 CONTRIBUTION OF THE STUDY

Research on the development of in-service teachers' TSPCK on the wave concept has not been a topic of previous research and is the contribution of this study. In addition, this study includes an expert CoRe (Appendix IV) about waves, which was specifically developed for this study. The expert CoRe, which is extensive but not exhaustive, was composed to portray the PCK about the three key ideas pertaining to the study and is relevant to the South African curriculum. Any person within the Physical Sciences field who wants to assess TSPCK based on the topic of waves can use the expert CoRe. A further contribution includes the TSPCK rubric (Appendix V) and the rubric for enacted PCK (Appendix VI), which were adapted from Coetzee (2018) to pertain to the topic of waves. This study revealed that one needs to be aware of and explicitly address the five TSPCK components during teacher training. This also therefore revealed the importance of looking into and possibly revising the way in which teachers are trained.

This study contributes to theory about the development of the TSPCK of in-service teachers and therefore complements previous studies by O'Brien (2017) and Rollnick and Mavhunga (2014a) regarding in-service teachers. In addition, this study complements a recent study by Mavhunga (2019) that considered the RCM and illustrated PCK at a topic level, which the current study also incorporated. Mavhunga (2019) has shown that pre-service teachers can improve the quality of their pPCK and ePCK in the topic of electrochemistry after an intervention. The current study also found an improvement in the teachers' quality of pPCK and, in turn, ePCK after an intervention, although for in-service teachers about the topic of waves. In addition, this study accessed the teachers ePCK through classroom teaching and lesson observations, as well as through teachers' reflections after the lessons.

With this study having been based on the wave concept, it is an addition to research that has previously been carried out within Physical Sciences education, adding to the previously researched topics of electric circuits, mechanics, heat and temperature (Wittmann, 2002), magnetism (Caleon & Subramaniam, 2010), electromagnetism (Coetzee, 2018) and equations of motion (Mazibe et al., 2018).

The findings of this study have indicated that the in-service training, in line with the framework of this study, had a positive influence on the participating teachers' knowledge, although at different levels for different teachers, and for different TSPCK components. This finding contributes to the idea that teacher training should be considered with any event that involves the supply of Physical Sciences equipment, despite the concern over its monetary implications. As a result, I envisage that this study will influence public and private school administrators, teachers, the DOE, and the private sector when making resource decisions about professional learning opportunities for Physical Sciences teachers.

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APPENDICES

APPENDIX I: CAPS CURRICULUM FOR PHYSICAL SCIENCES PERTAINING TO THE TOPIC OF WAVES

Waves, Sound & Light	Grade 10	**Transverse pulses on a string or spring** (pulse, amplitude superposition of pulses), **Transverse waves** (wavelength, frequency, amplitude, period, wave speed, **Longitudinal waves** (on a spring, wavelength, frequency, amplitude, period, wave speed, sound waves), **Sound** (pitch, loudness, quality (tone), ultrasound), **Electromagnetic radiation** (dual (particle/ wave) nature of electromagnetic (EM) radiation, nature of EM radiation, EM spectrum, nature of EM as particle - energy of a photon related to frequency and wavelength) **16 hours**
	Grade 11	**Geometrical Optics** (Refraction, Snell's Law, Critical angles and total internal reflection), **2D & 3D Wave fronts** (Diffraction) **13 hours**
	Grade 12	**Doppler Effect (either moving source or moving observer)** (with sound and ultrasound, with light - red shifts in the universe.) **6 hours**

PHYSICAL SCIENCES GRADES 10-12

Grade	Term	Prescribed Practical Activities Formal Assessment	Recommended Practical Activities Informal Assessment
10	Term 1	Experiment 1 (Chemistry): Heating and cooling curve of water.	Practical Demonstration (Physics) Use a ripple tank to demonstrate constructive and destructive interference of two pulses **OR** Experiment (Chemistry) Flame tests to identify some metal cations and metals.
	Term 2	Experiment 2 (Physics): Electric circuits with resistors in series and parallel - measuring potential difference and current.	Investigation (Physics) Pattern and direction of the magnetic field around a bar magnet. **OR** Experiment (Chemistry) Prove the Conservation of matter experimentally.
	Term 3	Project: You may do any of these topics or any other topic based on the Grade 10 content. Chemistry: Purification and quality of water. **OR** Physics: Acceleration. Example: Roll a ball down an inclined plane and using measurements of time and position obtain a velocity+time graph and hence determine the acceleration of the ball. The following variations could be added to the investigation: i. Vary the angle of inclination and determine how the inclination impacts on the acceleration ii. Keep the angle fixed and use inclined planes made of different materials to determine how the different surfaces impact on the acceleration. One could also compare smooth and rough surface etc.	Experiment (Physics) Roll a trolley down an inclined plane with a ticker tape attached to it and use the data to plot a position vs. time graph. **OR** Experiment (Chemistry) Reaction types: precipitation, gas forming, acid-base and redox reactions.
	Term 4		Experiment (Chemistry) Test water samples for carbonates, chlorides, nitrates, nitrites, pH and look at water samples under the microscope. Experiment (Physics) Conservation of Energy (qualitative)

GRADE 10 PHYSICS *(WAVES, SOUND & LIGHT)* TERM 1

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
4 HOURS	**Transverse pulses on a string or spring**				
2 hours	Pulse, amplitude	• Define a pulse • Define a transverse pulse • Amplitude • Define amplitude as maximum disturbance of a particle from its rest (equilibrium) position • Know that for a transverse pulse the particles of the medium move at right angles to the direction of propagation of the pulse	Practical Demonstration: Let learners observe the motion of a single pulse travelling along a long, soft spring or a heavy rope	**Materials:** Slinky spring, rope	Sometimes learners are taught about waves without ever learning about pulses. A pulse is a single disturbance. It has an amplitude and pulse length, but no frequency, since it only happens once.
2 hours	Superposition of Pulses	• Explain that superposition is the addition of the disturbances of the two pulses that occupy the same space at the same time • Define constructive interference • Define destructive interference • Explain (using diagrams) how two pulses that reach the same point in the same medium superpose constructively and destructively and then continue in the original direction of motion • Apply the principle of superposition to pulses	**Recommended experiment for informal assessment:** Use a ripple tank to demonstrate constructive and destructive interference of two pulses	**Materials:** Ripple tank apparatus.	

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
2 HOURS	**Transverse waves**				
2 hours	Wavelength, frequency, amplitude, period, wave speed;	• Define a transverse wave as a succession of transverse pulses • Define wavelength, frequency, period, crest and trough of a wave • Explain the wave concepts: in phase and out of phase • Identify the wavelength, amplitude, crests, troughs, points in phase and points out of phase on a drawing of a transverse wave • Know the relationship between frequency and period, i.e. f = 1/T and T = 1/f • Define wave speed as the product of the frequency and wavelength of a wave: $v = f\lambda$ • Use the speed equation, $v = f\lambda$, to solve problems involving waves	**Practical Demostration** Generate a transverse wave in a slinky spring	slinky spring	For a wave the distance travelled in one period is one wavelength, and frequency is 1/period.
2 HOURS	**Longitudinal waves:**				
1 hour	On a spring	• Generate a longitudinal wave in a spring • Draw a diagram to represent a longitudinal wave in a spring, showing the direction of motion of the wave relative to the direction in which the particles move	**Practical Demonstration:** Generate a longitudinal wave in a spring	**Materials:** Slinky spring	

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
1 hours	Wavelength, frequency, amplitude, period, wave speed.	• Define the wavelength and amplitude of a longitudinal wave • Define compression and rarefaction • Differentiate between longitudinal and transverse waves • Define the period and frequency of a longitudinal wave and the relationship between the two quantities $f = \frac{1}{T}$ • Use the equation for wave speed, $v = f\lambda$ to solve problems involving longitudinal waves			

APPENDIX II: INTERVENTION PLAN

TSPCK component key to explicitly indicate where each component featured in the intervention:

CS - Curricular saliency
WDT - What is difficult to teach
LP - Learner prior knowledge
RP - Representations
RPRT - Representations using the ripple tank
TS - Conceptual Teaching strategy

Items needed to carry out the intervention

- Ripple tank apparatus kit
- Battery (1 x D cell)
- Power supply
- Copy of the ripple tank teacher manual
- Sunlight liquid
- Syringe without needle
- 10Ω resistor with a red croc to croc lead

Introduction

a) The importance of the apparatus to assist in teaching the topic of waves:
   Waves is a theoretical topic (WDT). The apparatus makes the definitions tangible and understandable (WDT) & the drawings seen in textbooks real and life like (RP). It allows learners to visually see and conceptualize the concepts and thus address certain misconceptions and reconstructing conceptual understanding (WDT; LP).
b) The topic of waves is covered in schools following the CAPS curriculum and in private schools following the IEB syllabus and SAG document (CS).
c) Practical work needs PRACTICE even by a teacher (TS).

Action plan:

- Introduction to the different components of the kit (RPRT; TS)
- How to assemble the kit with and without the access of electricity (RPRT; TS)
- Further items to discuss while assembling the apparatus (RPRT; TS)
  a) The level of the apparatus while on the surface it is placed.
  b) The importance of having a white working surface or having white paper placed underneath the unit to observe the projected effects effectively.
  c) The ripple tank light should be moved/rotated so that it is central, in relation to the tank.
  d) The use of the sunlight liquid in the water of the tank to reduce the surface tension of the water allowing better waves to be produced and clearer projections to be observed. This is particularly important when demonstrating refraction using the Perspex prism.
  e) If the frequency of the waves is observed to be too high, even at the minimum setting of the controller, connect a 10Ω resistor to the controller using a connecting lead. This will reduce the frequency.
  f) General knowledge: Raised bumps/ A bollard (a short vertical post) on the side of the apparatus is based upon the concept of a dolos (plural: dolosse) to reduce the effects of reflection of the waves when they hit the side of the tank. Based upon a South African invention.

- Concepts to cover during the intervention in the respective order (CS)
  a) Pulse / wave fronts (straight line crests – dark and light lines observed)
  b) Wavelength, frequency and period
  c) Reflection
  d) Refraction
  e) Diffraction
  f) Interference including superposition

Intervention

1. **Pulse and wave fronts**
   - Using the ripple bar to generate horizontal pulses (RPRT).
   - Using the dropper or the tip of a finger to generate circular pulses (RPRT).

- Discuss the idea of wave fronts (CS).
- Discuss the misconception about how learners believe that the light lines observed on the white paper below the ripple tank are the troughs of a wave and the dark lines are the crests. Address this misconception through a diagram drawn on the board (WDT; LP; RP).

2. Wavelength, frequency and period.

- Place the ripple bar onto the surface of the water and attach the speed controller. (RPRT)
- Illustrate the continuous wave fronts, wavelength and frequency using the waves being produced. (RPRT)
- Adjust the speed controller to illustrate the relationship between wavelength and frequency i.e. increase the frequency to reduce the wavelength. (RPRT)
- Address the concept of period and its differences to frequency to ensure learner understanding regarding the two concepts. (CS; WDT; LP)
- Address the misconception that the speed of a wave can change even when the medium of the tank is unchanged with the use of the formula $v = f \times \lambda$. (CS; WDT; LP)

3. Reflection

- Use the longest of the metal barriers to place into the water at a +-45-degree angle to the ripple bar. Connect the speed controller and allow the teacher to observe what will happen when the waves hit the barrier and reflect off of it. (RPRT)

  *A grid like/square like pattern should be observed when the waves reflect off the barrier. The pattern is produced due to the interference of the waves that are being reflected off the barrier and the waves that are approaching the barrier that are moving parallel to the ripple bar.

4. Refraction

- Place the rectangular prism into the water and ensure that it pushed under the surface of the water. If the water is not covering the Perspex prism use some sunlight liquid to reduce the surface tension of the water. Try to avoid creating bubbles. Alternatively, if that still does not assist add additional water. (RPRT)

- Adding the prism is to reduce the depth of the water in the area where the prism sits with deeper water surrounding it.
- Attach the controller and allow the teachers to observe the effect. If the effect is not being seen clearly, use the syringe to remove some water from the tank.

  *The waves/wave fronts moving parallel to the ripple bar should hit the prism and should be observed to slow down, have a shorter wavelength and seen to 'lag' behind the wave fronts that are on the edge of the. Be sure to indicate to the teacher that the frequency of the waves is being kept constant (WDT; LP).

5. Diffraction

- *Illustration 1* (RPRT)

  Place the small silver barrier in the centre of the tank. Connect the controller and let the wave fronts hit the barrier.

  *one should observe that the waves move around the obstacle, diffracting around the edges.

- *Illustration 2* (RPRT)

  Use the two longer metal barriers and place them in the centre of the tank. Make a small slit/gap using the two barriers. Connect the controller and allow the teachers to observe the effect.

  *one should observe that the waves pass through the slit and diffract a lot, allowing waves to be observed behind each barrier. The pattern should resemble a rainbow.

- *Illustration 3* (RPRT)

  Repeat illustration 2 however, this time around make a bigger slit/gap using the two metal barriers. Connect the controller and allow the teachers to observe the effect.

  *one should observe that the waves again, pass through the slit and diffract, allowing waves to be observed behind each barrier. However, in comparison to illustration 2, the waves diffract less and the pattern less resembles a rainbow and illustrates lines that are more flat in nature.

6. **Interference including superposition**

- Attach two balls to the ripple bar and place the ripple bar down into the water allowing the balls to just touch the surface of the water. Connect the controller and allow the teachers to observe the effect. (RPRT)

  *one should observe two sets of circular waves. The effect is best seen, when looking at the ripple tank head on, with the ripple bar furthest from you.

  *one will be able to observe even brighter "spots" and even "darker" spots, representing constructive interference of crests with crests and troughs with troughs.

  *one should also observe areas of total destructive interference which appear like sun rays originating from the ripple bar. This is observed because these are areas of total destructive interference and thus undisturbed water.

- Draw the interference pattern on the white board to further illustrate what is happening during the illustration in the ripple tank. Diagram will show areas of constructive and destructive interference. (WDT; LP; RP).

7. Allow the teachers to ask any further questions or to express any further thoughts before concluding the in-service training.

APPENDIX III: CORE TEMPLATE

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	 **Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea?		
Why is it important for learners to know this?		

What concepts needs to be taught before teaching this big idea?		
What else do you know about this idea (that you do not intend learners to know yet)?		
What is difficult to understand?		

What do you consider easy or difficult in teaching this big idea?		
Learner misconceptions		
What are the typical learner misconceptions on this big idea?		
Representations		
What representations would you use in your teaching strategies?		

Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea?		
What questions would you consider important to ask in your teaching strategies?		

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea?		
Why is it important for learners to know this?		

What concepts needs to be taught before teaching this big idea?		
What else do you know about this idea (that you do not intend learners to know yet)?		
What is difficult to understand?		

What do you consider easy or difficult in teaching this big idea?		
Learner misconceptions		
What are the typical learner misconceptions on this big idea?		
Representations		
What representations would you use in your teaching strategies?		

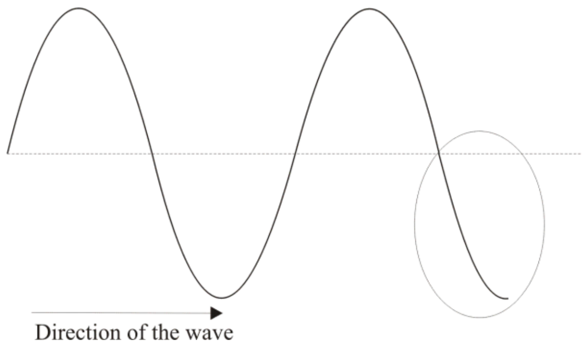
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea?		
What questions would you consider important to ask in your teaching strategies?		

APPENDIX IV: EXPERT CORE FOR GRADE 10 WAVES

CAPS curriculum FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea A** Distance between two successive points in phase.	**Key Idea B** The number of cycles/oscillations/vibrations in 1 second.
Curriculum saliency		
What do you intend the learners to learn about this idea?	• The definition of wavelength. • To identify successive points that are in-phase and out of phase for a transvers wave and a longitudinal wave. • That wavelength is the total distance between *any* two successive points in-phase. • To learn its symbol (λ) and unit of measurement (metre). • How to read off a wave diagram and determine the wavelength. • To identify the difference between wavelength and the number of wave cycles. When asked about the wavelength of a given wave using a diagram, to identify that the given wave diagram may be made up of many wave cycles but each with the same wavelength. • How to determine wavelength using the wave equation of $v = f \times \lambda$.	• The definition of frequency. • That the frequency is determined by the source. • To learn its symbol (f) and the unit of measurement -Hertz (Hz). • How to determine frequency from a diagram using information given about the number of vibrations/wavelengths over a given time. f = no. of vibrations/ time. • That it is inversely proportional to wavelength at constant speed. • How to determine frequency using the equation $v = f \times \lambda$. Subordinate idea of period. • The definition of period being the time taken for one complete cycle. • That the concept of frequency is different to the concept of period. • To learn its symbol (T) and unit of measurement (seconds)

		• How to calculate period using frequency: $T = \frac{1}{f}$ and to calculate frequency using period $f = \frac{1}{T}$.
Why is it important for learners to know this?	• To be able to identify wave phenomena in nature and everyday life e.g. light, microwaves, sun UV rays, music. • To understand later in the curriculum that wavelength determines the colour of a light wave (Electromagnetic spectrum) • To understand the more complicated phenomena of wave speed, diffraction, refraction, superposition and the Doppler Effect.	• To be able to identify wave phenomena in nature and everyday life e.g. Sound. • To understand the effect of frequency on the pitch of sound. I.e. Higher the frequency, higher the pitch. • To understand later in the curriculum that the frequency determines the colour of light (EM spectrum); penetrating ability (higher the frequency the more harmful the wave). • To understand the more complicated concepts and phenomena of wave speed, refraction, diffraction, the EM spectrum, the dual nature of light and the Doppler Effect.
What concepts need to be taught before teaching this big idea?	• The subordinate ideas of: A pulse Rest position Peak/Crest Trough In- phase Out of phase Medium Source Wave fronts Direction of waves Propagation of the wave (Right angles vs parallel to the disturbance of particles in the medium).	• The subordinate ideas of: A pulse Rest position Peak/Crest Trough Amplitude In- phase Out of phase Medium Source Wave fronts Direction of waves Wavelength

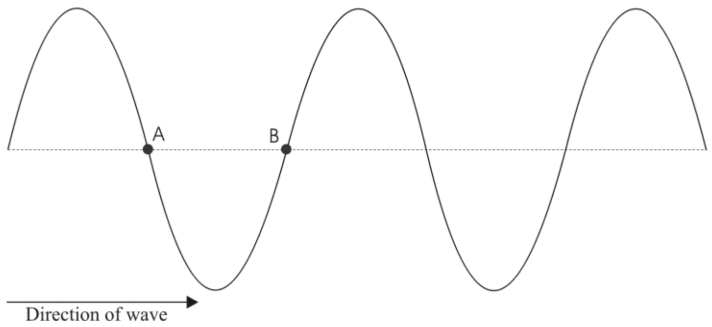
	The diagrammatic representations with labels for both transverse and longitudinal. • The conversion of measurement units nm, mm, cm, m and the use of scientific notation.	Propagation of the wave (Right angles vs parallel to the disturbance of particles in the medium). The diagrammatic representations with labels for both transverse and longitudinal waves. • The conversion of time units seconds, minutes and the use of scientific notation. • Possible extension work in terms of general knowledge related to the history of Hertz.
What else do you know about this idea (that you do not intend learners to know yet)?	• That the wavelength determines a wave property i.e. Light colour (EM spectrum). • Wavelength changes with the phenomenon of refraction. • The degree of diffraction is greater when the wavelength is longer. • Waves undergo interference when they are superimposed causing a change in amplitude (using examples with the same wavelength and frequency). • The Doppler Effect – how a perceived increase/decrease in frequency of a wave occurs because of the decrease/increase in wavelength as the source or observer move towards or away from each other. The Doppler Effect causes a perceived change in the pitch of a sound e.g.: heard when an ambulance drives past. The Doppler Effect can also be observed with light through the red or blue shift seen by astronomers.	• That frequency remains constant for the phenomenon of refraction. • Identical waves interfere and superimpose changing the size of the amplitude (using examples with the same wavelength and frequency). • Frequency determines the pitch of the sound heard. • The higher the frequency the higher penetrative ability of the wave for waves along the EM spectrum. • The energy of a photon depends on its frequency and the application in photo electric effect such as the threshold frequency. • The Doppler Effect – how a perceived increase/decrease in frequency of a wave occurs because of the decrease/increase in wavelength as the source or observer move towards or away from each other. The Doppler Effect causes a perceived change in the pitch of a sound e.g. heard when an ambulance drives past. The Doppler Effect can also be observed with light

		through the red or blue shift seen by astronomers.
What is difficult to understand?	• Learners find it difficult to identify points that are in – phase and out of phase. If understood it would allow for other points to be used to measure wavelength. • Learners have difficulty in identifying parts of a wave from a diagram that need to still be considered (circled below) i.e.: $1\frac{3}{4}$ waves  • Learners find two or three step problems challenging. E.g.: In one question they are required to calculate several aspects (a) Find the wavelength using the diagram, (b) Determine the speed of the wave, (c) How would the speed change if the wavelength increased? E.g.: Determining speed using $S = \frac{D}{t}$ then using this value to determine either f or λ • Determination of the wavelength of a longitudinal wave and a transverse wave from wave diagrams. • Learners find mathematical calculations difficult when scientific notation and conversion of units are involved	• Learners often find it difficult to distinguish between frequency and period and the calculation of $T = \frac{1}{f}$ and $f = \frac{1}{T}$. • How to determine the number of cycles or vibrations as it is given in a diagram when time is given. This causes incorrect answers when calculating the frequency from this information. • Learners cannot relate Hz with the meaning of $\frac{1}{s}$ or s^{-1}. • Learners find mathematical calculations difficult when scientific notation or prefixes are involved i.e. for calculations involving light with a value in kHz. • Learners want to use an equation instead of applying basic definitions to determine period or frequency when interpreting wave diagrams or displacement / time graphs or information given in text.

	e.g. for calculations involving light with a value in nanometres and conversion of units e.g. cm to mm or km to m. • Learners find it difficult to determine the direction in which a particle in the medium is moving at a particular point in time.	
What do you consider easy or difficult in teaching this big idea?	• Explanations about waves are easier to teach using diagrams. • Teaching about wavelength for longitudinal waves is more challenging compared to teaching wavelength for transverse waves. • It is difficult to teach the mathematical conversions of units and the prefixes which results in their misuse during wave calculations. • Learners find points that are out of phase easier to identify than points that are in-phase making in-phase points difficult to teach.	• Questions given that involve determining the number of waves or oscillations when time is given to determine frequency is often more difficult to teach than the equation $v = f \times \lambda$. • Learners often confuse frequency and period making anything regarding both frequency and period challenging to teach. • It is difficult to teach about the mathematical conversions and the prefixes which results in the misuse during wave calculations. • Learners tend to think wavelength and frequency are directly proportional making the equation of $v = f \times \lambda$. difficult to teach.

<table>
<tr><th>Learner misconceptions</th><th></th><th></th></tr>
<tr>
<td>What are the typical learner misconceptions on this big idea?</td>
<td>

Learners assume that if points in a diagram are on the same level they are then deemed to being in-phase. E.g. Point A and Point B are assumed to be in-phase.



Learners believe that wavelength is only measured from a crest to crest or trough to trough forgetting that they can measure it between any two successive points in-phase.
Learners are often unaware that the number of waves may include a fraction, indicating a part of a wave that is present at the end of a diagram. E.g. $1\frac{1}{4}$; $1\frac{1}{2}$; $1\frac{3}{4}$ waves. Learners believe that because it is not a full wave, it may be excluded (seen circled below)

</td>
<td>

Learners think that 1 wave cycle always takes place in 1 second.
Learners confuse the definitions, units and symbols of frequency and period. This directly affects the relevant calculations involving frequency and period.
Learners believe that wavelength remains constant in $v = f \times \lambda$ and when f changes v will change.
Learners assume that the higher the frequency of a wave the longer the wavelengths of the wave i.e. direct proportion is confused with their inversely proportional relationship.
Learners think that it is the frequency that changes during the phenomenon of refraction.
Learners assume that the higher the frequency the more the wave diffracts.
Learners take frequency to be the same as the speed of a wave and that frequency is not determined by the source of the wave.

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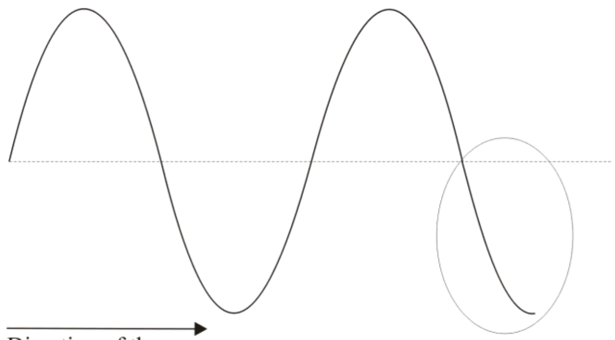
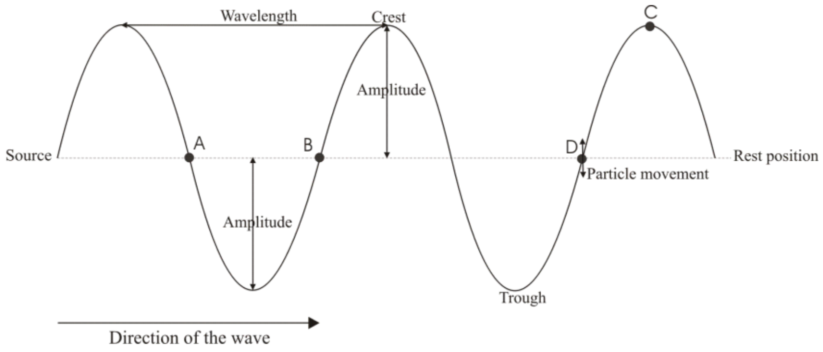
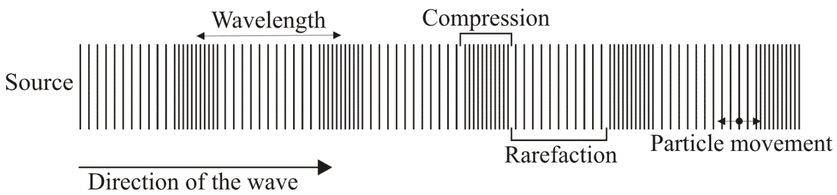


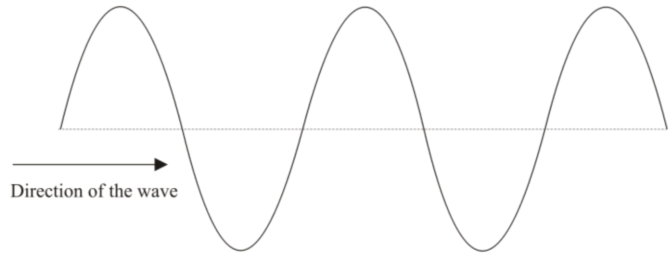
	- Learners tend to believe that amplitude is related to wavelength i.e. if the wavelength increases the amplitude also increase. - Learners misunderstand that it is the speed of the wave that remains constant in the equation $v = f \times \lambda$ in a rope/slinky of constant tension/ EM wave/ Sound wave in air at a constant temperature and that it is not the wavelength that remains constant. - In a ripple tank the wavelength is illustrated by the distance between the dark and light bands produced below the tank. Learners believe that the dark bands are the crest of the waves and the light band are the troughs of the waves. - Learners do not realise particles in a medium move vertically up and down but maintain the same mean position when a transverse wave moves forward horizontally.	

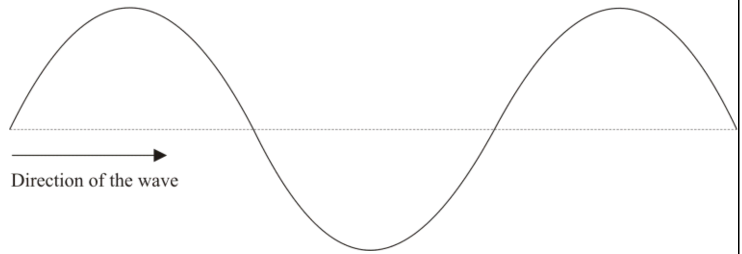
Representations		
What representations would you use in your teaching strategies?	• Diagrammatic representations of waves drawn and annotated on the board. Transverse wave:  Longitudinal wave:  • A slinky spring placed on the floor to illustrate the wave pattern and to point out wavelength and the subordinate ideas of source, crest, trough, in and out of phase etc. • Textbook pictures of a wave, an annotated wave and pictures of real-life examples of waves.	• Diagrammatic waves drawn and annotated on the board (As seen alongside under the key idea of wavelength). However, frequency does not have an annotation therefore rather colour could be used to indicate the number of waves to show the concept of frequency. • A slinky spring placed on the floor to illustrate the wave pattern and to point out wavelength and the subordinate ideas of source, crest, trough, in and out of phase.

- Posters/charts with information about the two different types of waves, their definitions, their wavelengths, their particle direction and the other subordinate ideas and the wave properties.
- The use of the learners to simulate a Mexican wave to illustrate particle movement in a wave and wave fronts.
- The use of the ripple tank to illustrate waves through the medium of water with the use of the stroboscope to view the waves as if they were stationary to identify different lengths of a wave when the frequency changes.
- Computer phET Simulations to illustrate waves, the particle movement and the wavelength for both types of waves.
- Real life photographs.

*Rope has high resistance when on the ground and thus one cannot really use a rope to illustrate a wave effectively. The friction dampens the wave almost immediately. The only aspects that can be shown using a rope is a pulse that travels less than a metre in distance.

Furthermore, if two Slinky's are available, simultaneously produce a wave on one slinky and another wave on the other slinky that has a higher frequency than the first – Frequency does not have a label on a wave diagram. Seeing a higher frequency being illustrated allows conceptual understanding about the meaning of 'frequency'. If no slinky is available a diagrammatic illustration will suffice, as seen below.





- Textbook pictures of a wave, an annotated wave, real life examples of waves.
- Posters/charts with information about the two different types of waves, their definitions, their wavelengths, the other subordinate ideas and the wave properties.
- The use of the learners to simulate a Mexican wave to illustrate particle movement in a wave

		but now including how often they stand up to illustrate the frequency of their movement. • The use of the ripple tank to illustrate waves through the medium of water with the use of the stroboscope to view the waves as if they were stationary to identify the frequency produced by the source and the ripple tank controller. Ripple tank can also show the relationship between frequency and wavelength while observing the projection and changing the controller from min to max setting. Best viewed using the stroboscope. • Computer phET Simulations to illustrate waves, their particle movement and the wavelength for both types of waves. • Tuning fork that is hit and then placed on to the surface of the water producing a small splash indicating that the fork is vibrating. Different tuning forks can be used to listen for different pitched sounds. • A ticker timer and tape (if motion has been covered). The subordinate idea of period can be calculated using the ticker timer frequency and the formula $T = 1/f$. * Rope has high resistance when on the ground and thus one cannot really use a rope to illustrate a wave effectively. The friction dampens the wave almost immediately. The only aspects that can be shown using a rope is a pulse that travels less than a metre in distance.

Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea?	• Identify real life examples of waves that learners can relate to e.g. water waves; Mexican wave, dropping a pebble in water. • Illustrating waves using a slinky spring using one source. During the illustration allowing the learners to discuss what it is they observe while using the slinky spring. • After underlying concepts are discussed using the demonstrations mentioned above, a diagram drawn on the board to label and annotate the relevant subordinate ideas will assist in the understanding of wavelength. • Identify wavelength using the diagram while discussing its symbol and unit of measurement. • Learner involvement which may include: learner, teacher discussions; allowing learners to develop other pictorial illustrations such as charts or drawings that can be placed up onto the board. • Illustrate waves, wave fronts and wavelength making use of ripple tank and stroboscope to see the light and dark line that are projected on the white paper below the ripple tank.	• Identify real life examples of waves that learners can relate to i.e. Sound, pitch, colour of light, sirens. • Illustrating waves using a slinky spring using one source. During the illustration allowing the learners to discuss what it is they observe while using the slinky spring. • After some subordinate ideas are discussed using the demonstration mentioned above, draw a diagram on the board to label and annotate the relevant subordinate ideas that require an understanding of frequency. • After defining frequency introduce the learners to its symbol and unit as well as the formulae used to calculate it. This includes the use of a diagram to obtain the number of waves present over a given time. • Introduce the subordinate idea of period, its definition, symbol and unit. • Introduce the formula used to calculate frequency that requires period and the formula of period which relies on knowing the frequency. • Illustrate the relationship between frequency and wavelength using the ripple tank and stroboscope. • Introduce the formula $v = f \times \lambda$ and using it to further explain the relationship between frequency and wavelength.

		• Include calculations using the formulae taught starting with simple calculations that use information given in a word problem. Move to higher order questions that involve a diagram and/or conversions with scientific notation – Testing different levels of cognitive and critical thinking.
What questions would you consider important to ask in your teaching strategies?	• When demonstrating the transverse wave using the slinky spring ask: If I move my hand up and down in this manner (i.e. the motion should be slow, but don't indicated this) what do you observe? If I move my hand up and down in this manner (i.e. the motion should be a little faster than the previously illustrated, but don't indicated this) what do you observe? Explain what you see using your own words. • When drawing a wave diagram on the board ask: What do you think is meant by a pulse? What do you think is meant by a wave cycle? Where does a wave cycle begin and end? If we take one particle along the wave, explain its movement. Identify points that are moving in the same direction i.e. introducing in-phase. • What term do we use when we measure the distance from the one point that is in-phase to the next? • When demonstrating wavelength using the ripple tank ask: What would you expect to observe using the ripple tank? Would there be a way to measure the wavelength using the projection from the water in ripple tank? – by choosing successive points in the middle of the light and dark lines it	• When illustrating the transverse wave using the slinky spring ask: If I move my hand up and down slowly what do you observe? If I move my hand up and down a little faster what do you observe? What did you observe? Explain what you see/saw using your own words. When taking the term 'frequency' what do you understand by that term? After illustrating two different frequencies again using the slinky spring ask the following: If you observed the number of wave cycles increasing, what happened to their wavelength - relating the relationship between frequency and wavelength. • When drawing a wave diagram on the board ask: How did you previously identify a wave cycle? How many wave cycles do you see in the diagram? If it took 2 seconds to generate the total wave (say one drawn with 4 cycles), how do you think we would calculate the frequency if I remind you that frequency is the number of waves per second? – this would be used to introduce the first formula of *f = no. of vibrations/time*

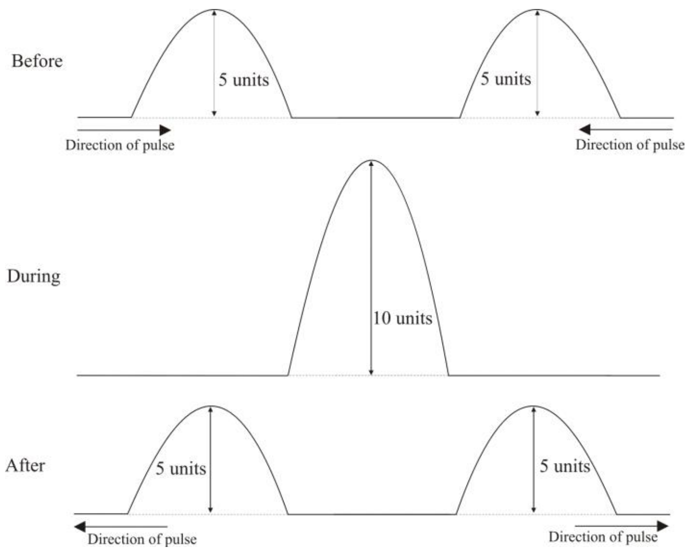
	would identify points in phase that can be used to determine the wavelength. • Once the concept is understood, higher order questions would evolve: If there were two different waves produced using two different slinky springs, would they have the same wavelength if the source vibrates at the same frequency?	What happens if you wanted to now know the time taken for 1 cycle? – this would introduce period and the formulae involving frequency and period. After which, ask: How are the two concepts different in terms of their unit, their definitions and their formulae? • Using the ripple tank ask: What relationship do you see between wavelength and frequency? – while the frequency controller is adjusted. Has the medium in the tank changed during the illustration? – this would be used to introduce the speed of the wave and the formula $v = f \times \lambda$ • Introduce inverse proportion if v is constant.

FET Level: **Grade 10** Content area: **Waves**	**Important science ideas/concepts** **Key Idea C** The phenomenon when two or more waves pass the same point in space simultaneously	
Curriculum saliency		
What do you intend the learners to learn about this idea?	• Superposition takes place when two or more waves meet at the same place at the same time in the same medium and interference takes place. • Identify that the net displacement at any point in the medium, is the sum of the individual wave displacements when the waves meet. • That there can be a positive or negative displacement from the rest position (NB: for when mathematical values used).	

	• That waves travelling in opposite directions along a medium, meet, combine and then continue in their original directions and with their original amplitudes. • That there are two types of interference: *Constructive interference* – when a crest and crest overlap or when a trough and trough overlap to make a bigger crest or trough. *Destructive interference* – when a crest and a trough overlap to make a smaller crest or trough or when total destructive interference causes extinction of a trough and crest. • For the learners to be able to complete examples involving superposition using numerical values.	
Why is it important for learners to know this?	• To be able to identify and understand the phenomenon of the superposition of waves during everyday life. i.e. Musical instruments, wind instruments. Sound from speakers that are facing each other playing the same music at the same time can cause constructive or destructive interference. Light experiencing interference through single and double slit interference observed by seeing light and dark bands.	
What concepts need to be taught before teaching this big idea?	• The subordinate ideas of: Amplitude as well as amplitude using numerical values Source Medium Direction of the wave Propagation of a wave. Particle motion being at right angles to the direction of propagation. In phase Crest Trough Speed of a wave	

What else do you know about this idea (that you do not intend learners to know yet)?	• The interference pattern – areas and points of total destructive interference (seen by flat water in a ripple tank or in a diagram) and areas of constructive interference (seen by even brighter and darker areas while observed in a ripple tank). • As extended work but not essential are the terms of nodes and antinodes. • The principle of sonic booms and the clarity of sound. •	
What is difficult to understand?	• Learners have difficulty in understanding that the waves continue in their original directions and return to their original amplitudes after superposition. • That there is a negative and positive amplitude. (Crest of amplitude 5 interferes with a trough of amplitude 3. Thus (+5) + (-3) = 2, causing the resultant wave to have an amplitude of +2 during destructive interference). This could also occur in a similar manner to have a resulting amplitude of -2 which indicates that the wave must be drawn below the rest position.	
What do you consider easy or difficult in teaching this big idea?	• Generally, the section is not difficult to teach when broken up into before, during and after superposition with the use of diagrams. • The phenomenon of constructive and destructive interference is not easily observed when using a slinky spring especially if it is demonstrated before the learners know what it is they should observe making the introduction to the concept difficult. • That there are areas of superposition taking place at positions other than the highest points of each peak and trough.	

	• Learners have difficulty with the mathematical idea of the term 'sum' and considering the negative value when destructive interference occurs. • Constructive interference and diagrammatic representations are easier than destructive interference and its diagrammatic representations.	
Learner misconceptions		
What are the typical learner misconceptions on this big idea?	• Learners believe that waves act independently and therefore do not have an effect on each other. • Learners think that once superposition has taken place that the wave continues at its new amplitude in the direction of which the biggest amplitude came from. • Learners assume that waves will not retain their amplitudes and directions after superposition has taken place. • Learners have difficulties when they are asked to draw the concept of superposition. • Learners misunderstand that waves will continue and retain their previous amplitude and direction even if total destructive interference occurs. • Learners believe that it only applies to one pulse and not a whole wave cycle– this is because it is taught and illustrated normally using one pulse. • Learners tend to think that waves approach each other and then bounce off one another changing direction themselves rather than interfering and continuing in the same direction as they came from.	
Representations		

What representations would you use in your teaching strategies?	• Diagrammatic waves drawn and annotated on the board showing before, during and after interference for both constructive and destructive interference. I.e. an example of constructive interference with mathematical values seen below.  • Computer phET Simulations that have two waves moving in motion concurrently but above and below one another with a third wave showing the result of what happens when the two waves interfere. The simulation is best when it utilises gridlines to help learners identify the size of the amplitudes. • A slinky spring stretched out on the floor with two learners on either side to create a pulse in opposite directions that would meet and superimpose. • Ripple tank first to illustrate circular waves and then with two balls attached to illustrate the superposition of waves.	

	• Textbook images that have the diagrammatic images of constructive and destructive interference. These may show a comparison. Photographic real like examples of two speakers facing each other with drawn in waves that show daily application of superposition. • Rotate a vibrating tuning fork near the ear to hear loud and soft sounds •	
Conceptual teaching strategies		
What effective teaching strategies would you use to teach this idea?	• Recall prior knowledge and the terms based upon the concept of waves, using the wave diagram previously taught to introduce the concept of superposition (constructive and destructive interference). • Introduce real life examples of superposition to make the theory relevant to the learners i.e. sound • Using the slinky spring to generate two pulses from either side that would illustrate constructive interference. Destructive interference would be difficult to illustrate. • Diagrammatically represent a pulse before, during and after constructive and destructive interference using numerical values. • Demonstrate superposition using the ripple tank with two circular balls attached to the ripple bar to generate two waves that would interfere to show the principle of superposition. • Cement the idea through the use of a simulation which has two waves interfering and the third wave showing the result of the interference. • Work through textbook examples relevant to the concept of superposition.	

What questions would you consider important to ask in your teaching strategies?	• Before showing the slinky spring, demonstration ask the learners: What does the term *constructive* mean to you? What does the term *destructive* mean to you? • Once illustrated on the slinky spring using a source each side of the slinky spring preferably generating a pulse of same amplitude and as a crest or trough ask: What is the direction of each wave? What do you notice about the waves explained as a timeline of events i.e. before, during, after? • After drawing the diagram of two pulse before interfering, ask the learners: What do you predict the next diagram will look like? What will the amplitude of the wave be? • After drawing the resulting wave during superposition ask: What will occur after the waves have interfered? Which direction will they move? What will now be their amplitudes? Do you think that superposition only applies at the maximum point of a crest and the minimum point of a trough? Standing waves in musical string instruments. • Before demonstrating the principle using the ripple tank and a circular ball attached to the ripple bar ask: What shape of waves will be seen? What do you predict will be observed in the water and on the paper below the tank? How will we observe that interference is occurring? At which points is constructive interference occurring? At which points is destructive interference occurring?	

APPENDIX V: TSPCK RUBRIC FOR TEACHING WAVES AS REVEALED THROUGH CORES

Component prompts	Limited (1)	Adequate (2)	Rich (3)
Knowledge and Skills related to Curricular Saliency			
What do you intend learners to know about each key idea? **4. Wavelength** **5. Frequency (period)** **3. Superposition**	- Knowledge of key idea limited to being aware of the definitions, equations and/or terms. - No links to key ideas - Subordinate ideas are limited i.e. Pulse, trough, peak, time etc. - No evidence of appropriate sequencing of ideas.	- Knowledge of key idea is identified and aware of however with a lack of understanding of definition, equations and/or terms. - Shows links to key ideas i.e. Frequency & wavelength. - The list of subordinate ideas is not extensive	- Knowledge of key idea identified and understood being aware of the definitions, equations and/or terms. - Explanation links to key ideas. - Subordinate ideas constitute an exhaustive list of concepts to be taught. - Identified subordinate ideas that focus on understanding of the concepts. - Relationship of the concept to real life application.
Why is it important for learners to know this key idea?	- Reasons provided are limited to the general benefit of education - Restate the key idea - Reasons provided have no logical link between the key / subordinate idea(s) and its importance for key ideas that follow sequentially (lack of the bigger picture).	- Reasons provided exclude considerations such as scaffolding / sequential development. - Reasons include reference to the selected key and subordinate ideas rather than topics that follow sequentially on the key-idea.	- Reasons provided include conceptual scaffolding / sequential development of understanding of specified subsequent topics in the subject. - Understanding in the learners' understanding of the world around is evident. - Understanding of the importance of the key idea in relation to other

Component prompts	Limited (1)	Adequate (2)	Rich (3)
	- No link to real life application.		ideas in the curriculum (bigger picture is understood)
What concepts need to be taught before teaching this key idea?	- Inadequate understanding of the curriculum is evident - The mentioned pre-concepts are not appropriate for the key idea. - Inadequate evidence of knowledge about sequencing.	- Identified concepts refer to elementary concepts generally regarded as basic for the subject or topic. - Identified pre-concepts consist of those required to understand the current key idea.	- Understanding of the curriculum is evident - Identified pre-concepts include those needed in discussing the introductory definitions and those sequentially needed in the key ideas of the current topic. I.e. Pulse, source of wave, - Include concepts from other topics having logical links with the key idea i.e. History of Hertz; scientific notation.
What else do you know about this idea-(that you don't intend learners to know yet?)	- No evidence of knowledge about sequencing or scaffolding. - Illogical placing of concepts	- Some evidence of knowledge about sequencing or scaffolding. - Select ideas that are unlikely to be discussed at school level; does not show knowledge of curriculum. - Include key ideas following the current key idea	- Evidence of knowledge about the logical scaffolding and sequencing of ideas in the topic and subject. use of formula with the key ideas involved; linking frequency and pitch. - Selected ideas indicate strategically thinking about content. - Rich content knowledge evident.

Component prompts	Limited (1)	Adequate (2)	Rich (3)
Knowledge and Skills related to Learner Understanding of Science.			
What do learners find difficult to understand?	- Unable to identify aspects of this component. - Knowledge of key idea repeated	- Briefly explains what learners find difficult without concrete examples.	- Pinpoints appropriate aspects that learners find difficult relevant to the key ideas. I.e. Identifying points in-phase. Identifying parts of a wave. - Gives defined examples of such difficulties.
What do you consider difficult about teaching this idea?	- Knowledge about this component not evident - Knowledge of key idea/s are rephrased or restated. - Identifies broad topics without specifying the actual sub-concepts that are problematic.	- Identifies and clearly formulates appropriate difficulties for one or two of the key ideas.	- Identifies and clearly formulates appropriate difficulties for all three selected key ideas. - Mentions gate keeping concepts that when not fully understood add to the difficulty of key idea.
What are typical learners' misconceptions when teaching this idea?	- Fails to identify any misconceptions - Selects inappropriate misconceptions not related to the topic - Reveals own misconceptions - Not well formulated	- Identifies at least one misconception - Identifies gaps in pre-concepts or problems with mathematical concepts. - Leaves out important well documented misconceptions that are related to the conceptual understanding of the key idea.	- Identifies and describes a number of misconceptions or gaps in pre-concepts. - An indication of knowledge about misconceptions and their origin is evident i.e. confusion in the definition of frequency and period. - Identifies most common misconceptions. I.e. Learners believe that wavelength is only

Component prompts	Limited (1)	Adequate (2)	Rich (3)
			measured from a crest to crest or trough to trough.
Knowledge and Skills related to Representations.			
What representations would you use in your teaching strategy?	- The representations mentioned are vague and not specific to the key idea. - Suggested representations are not feasible.	- An adequate selection of representations (visual and / or symbolic) sufficient to support explanation of concepts. - Mentioned representations with no explanation of specific links to the concepts considered.	- Extensive use of representations (visual and symbolic / graphical / pictorial / diagrammatic/2D and 3D examples, basic representations to electronic representations) to enforce specific aspect(s) of concepts being developed. - Presence of explanatory notes linking the different kinds of representations to aspect(s) of the concepts being explained i.e. slinky spring sufficient to explain the basic concepts but not something like superposition; tuning fork to show vibrations and hear difference in frequency.
Knowledge and Skills related to Conceptual Teaching Strategies.			
What teaching strategies would you use to teach this idea?	- List of general strategies without indications of how they will be employed. - Suggested strategies are not conceptually connected to the key-idea.	- Overall strategy workable. - Considers at least one aspect related to curriculum saliency or sequencing. - Uses at least two different levels of representation to	- Overall excellent and creative strategy to teach required concept. - Uses macroscopic, visual and symbolic representations to enforce aspect(s) of a concept with explanatory notes.

Component prompts	Limited (1)	Adequate (2)	Rich (3)
	- No evidence of acknowledgement of student prior knowledge and misconceptions. - Insufficient conceptual development - Lack aspects of curriculum saliency. - Limited involvement of learners	enforce an aspect or concept with explanatory notes - There is evidence of encouraged learner involvement.	- Considers confirmation / confrontation of student prior knowledge and / or misconceptions and aspects related to sequencing. - Highly learner centered lesson. - Evidence that strategy will support conceptual understanding.
What questions would you consider important to ask in your teaching strategy?	- List concepts without relating them to the key idea. - No evidence of questions that will support conceptual understanding. - No evidence of sequential development of concepts.	- Basic questions with some rote learning questions are posed. - Questions do not require higher order thinking skills. - Knowledge of sequencing towards conceptual development not evident or slightly evident.	- Questions require higher order thinking skills - Questions lead to constructive development of concepts - Knowledge of sequencing is evident.

APPENDIX VI: RUBRIC FOR ENACTED PCK

Components	Lowest level: Restricted	Middle level: Adequate	Highest level: Rich
Knowledge and Skills related to Curricular Saliency	• Never elicits learner's knowledge of pre-concepts • Does not show evidence of knowledge of scaffolding of concepts • No logical sequencing of concepts evident – "jumping around" • Does not link the concepts to real life situations nor to future concepts/sections.	• Elicits knowledge of some of the pre-concepts, but assumes knowledge of others • Sequencing of concepts is somewhat logical but leaves out important ideas. • Either links the concepts to real life examples or to future concepts/sections	• Elicits knowledge of all applicable pre-concepts at appropriate phases in the lesson • Shows awareness of the scaffolding of concepts in the topic by referring to pre- or forthcoming ideas. • Reminds learners of pre-concepts when they are applicable in the conceptualization of new ideas. • Teaches key-ideas and subordinate ideas with logical sequencing • Links the concepts to real life examples/situations and to future concepts/sections.
Knowledge and Skills related to Learner Understanding of Science.	• Knowledge of learner thinking not evident • Does not pay attention to typical difficulties that can arise.	• Mainly uses repetition (without changing the approach) to address learner difficulties. • Misses some indications that learners find a concept difficult to understand.	• Knowledge of learner thinking evident. • Responds to and addresses gaps in knowledge of pre-concepts.

	• Shows no evidence of techniques to address difficulties. • Does not pay attention to possible existing misconceptions • Own misinterpretations and misconceptions are evident • Little evidence of eliciting learners' thoughts through assessment like questions. • Eliciting yes and no type response questions.	• Pays attention to some known difficulties and misconceptions. • Misses some opportunities to address possible misconceptions. • Uses one or two assessment like questions that are based mainly upon rote learning responses.	• Breaks down difficult ideas into understandable units which are sequenced logically • Pays attention to possible misinterpretations such as destructive and constructive interference. Difference between Period and Frequency. • Uses techniques such as "going slower", repetition and a different approach to address learner difficulties. • Pays attention to all (or most) known misconceptions. • Uses analogies from learners world to explain ideas • Continuously assess learners through questions based towards problem solving inquiry.
Knowledge and Skills related to Representations	• The use of representations is restricted to drawings also available in textbooks. • Does not make an effort to incorporate representations to support conceptual understanding.	• Use of representations restricted to one type of representation. • Uses objects as illustrations or artefacts. • Uses a representation with no apparent conceptual development in learners.	• Makes extensive use of representations in combination with the ripple tank. • Uses representations to support understanding of concepts. • Uses representations effectively to stimulate conceptual reasoning.

			• Uses a variety of representations with logical sequencing in combination with appropriate questions.
Knowledge and Skills related to Conceptual Teaching Strategies.	• Relies mostly on explaining and telling. • Portrays a teaching style aimed towards – *Lecturer* • Questions elicits chorus or yes/no responses. • Answers own questions before learners make an attempt. • Ignores learners' answers when not in line with the expected answer. • Does not show awareness when learners reveal the existence of misconceptions	• Portrays a teaching style aimed towards – *Demonstrator or Hybrid* • Questions asked mostly requires rote learning • Answers own questions after only one or two attempts by learners – does not rephrase questions. • Address misconceptions through procedural teaching. • Uses representations in combination with direct instruction – telling learners what they are supposed to see or as confirmation of theory only.	• Portrays a teaching style aimed towards – *Facilitator or delegator* • Shows an attempt to work towards problem solving and inquiry. • Asks questions to elicit learner thinking and that requires conceptual reasoning. • Shows effective integration of pre-concepts. • Shows awareness of typical learner errors and misconceptions and works towards conceptual change. • Wait for responses and do not answer own questions; rephrase questions.
Integration of PCK Components	• Lacks evidence of knowledge about the components and the logical sequencing of the five TSPCK components within the classroom context. • No link made between components within the lessons	• Shows understanding and the link of only two or three of the five TSPCK components. • Planned lesson with some evidence in adjusting the lesson if required.	• Evidence of knowledge about the components and the logical sequencing of the five TSPCK components and is seen in use within the classroom context. I.e.: Identifies the link between understanding the curriculum followed by what is difficult to understand and thus

	i.e.: a) Teaching incorrect content (no understanding of curriculum). b) No talk and tell, just talk (no use of representations) c) No appropriate instructions or eliciting of questions to address learner thinking and misconceptions. • Planned lesson remains unchanged despite the findings while teaching i.e.: does not adapt the lesson despite evidence that learners require a shift in the teaching of the lesson.		common learner misconceptions that then drive the representations and teaching strategies to be used. • Planned lesson is flexible and the teacher shifts the lesson based upon the needs of the learner.
Pedagogical Reasoning ***(determined during VSR interview)***	• Pays no attention to the decisions and actions chosen. • Actions chosen are not relevant to the classroom context. • No correlation between the static PCK and the dynamic PCK	• Able to identify their actions and decisions but fails to explain or provide a rationale for the decisions made and actions taken.	• Explains in full and with depth the rationale, decisions and actions chosen. The strategy is fully accounted for. • Actions chosen are relevant to the classroom context and why the actions were chosen are explained. • Knowledge and reasoning (static PCK) correlated to the implementation

			knowledge/skills and reasoning (dynamic PCK). • Sensitivity and responsiveness seen towards the context.

APPENDIX VII: SEMI-STRUCTURED PRE-INTERVIEW QUESTIONS

Teacher information

1. Age: 18-25 26-35 36-45 45-60
2. Gender Male Female
3. What are your qualifications?

Qualification	Majors	Institution	Year obtained

4. Are you currently registered for any science studies? If yes:

a) Which studies are you registered for?

___

b) At which institution are you registered?

___

5. Have you participated in any previous Physical Sciences training? If yes, elaborate.

___

6. How long ago was the training?

___

7. Who carried it out?

___

8. Was it hands on based or lecture based?

___

9. Did you find it helpful? Elaborate

___

10. How many years have you been employed as a teacher, as of the end of 2018?

___

11. How many years have you been teaching Physical Sciences, as of the end of 2018?

___

12. Can you identify what your teaching style involves and which one you relate to the most? Mark with an X.

a)	Telling/Lecture	*Teacher-centred involving lengthy period of teacher lectures. Students absorb and take notes.*
b)	Demonstration	*Similar to lecturer style but includes some multimedia presentations, demonstrations and activities that are done by the teacher only.*
c)	Hybrid/blended	*Tailor teaching styles to the learners needs. Trying to please every type of learner and their different learning styles.*
d)	Facilitator	*Initiates student self-learning and helps learners to develop critical thinking. Allows learners to ask to questions & find own answers through exploration.*
e)	Delegator	*Guided discovery. Inspires students to reach a common goal. Works with the learners.*

13. What do you see as your teaching strengths?

____

____

14. What areas do you feel are relatively weak in your teaching?

____

____

15. Currently, what do you do to increase your general Content Knowledge?

____

____

16. What type of activity or support events would help your growth in science knowledge?

____

____

17. In what ways would you define science teaching?

____

____

18. How do you think learners learn science?

____

____

19. What do you see as important to do or have to teach Physical sciences effectively?

____

____

20. When do your learners learn science best?

____

____

21. Do you believe in using hands on apparatus during the lesson? If so, elaborate on how often within a week you conduct such lessons?

____

____

22. During allocated practical time what percentage is spent on the following:

Use of simulation____________________________

Use of hands on apparatus____________________

Use of textbook images ______________________

23. What challenges do you have in the classroom teaching physical sciences?

____

____

24. Do you conduct all the experiments specified by the curriculum? Do you rearrange the curriculum?

____

____

25. Have you felt that you have always had the correct resources to teach science?

____

____

26. Do you see waves as an important topic within the Physical Sciences curriculum?

____

____

27. What resources do you usually use to teach and illustrate the topic of waves?

____

____

28. What sub-topics or concepts do you consider to be key in the topic of waves in Grade 10? List them.

____

____

29. Would you tell me about your usual lesson plan and tell me how you would carry out the lesson to teach wavelength, frequency and period to Grade 10 learners.

___

___

___

30. Would you tell me about your usual lesson plan and tell me how you would carry out the lesson to teach superposition to Grade 10 learners.

___

___

___

31. What do you expect students would have difficulties with in learning about?

a) Wavelength:

___

b) Frequency:

___

c) Period:

___

d) Superposition:

___

32. What kinds of students' misconceptions are associated with a lesson teaching about?

a) Wavelength:

___

b) Frequency:

___

c) Period:

___

d) Superposition:

___

APPENDIX VIII: SEMI-STRUCTURED POST-INTERVIEW QUESTIONS

1. Were the explanations on the equipment and activities clear and helpful?

   ____

   ____

2. In what ways did the in-service training affect your attitude towards practical work?

   ____

   ____

3. In what ways did the in-service training affect your confidence?

   ____

   ____

4. In what ways did the in-service training affect your Science Content Knowledge?

   ____

   ____

5. Did you benefit from the in-service training? What did you like best about the training?

   ____

   ____

6. Did your perception of the ripple tank change after the training?

   ____

   ____

7. Would you recommend the in-service training to other teachers?

   ____

   ____

8. Will this training help you and your learners to do the required activities and illustrations related to waves?

   ____

   ____

9. Did the training using hands-on equipment change your perceptions about how you teach waves?

   ____

   ____

10. If you use PhET simulations to teach waves how is the use of physical equipment different?

11. How has the in-service training that you attended helped you prepare for your lesson on the foundational concepts of waves?

12. Would you continue to use the hands-on equipment in your lesson to teach waves?

13. Would you continue to use the ripple tank in your lesson to teach Grade 11 and 12?

14. Is there anything that you will do now after the training that you did not do before?

15. Any other comments? (As a statement)

APPENDIX IX: GENERAL OUTLINE ON THE VIDEO STIMULATED RECALL INTERVIEW

1. What teaching methods and activities did you use during the lesson? (Evidence of Curriculum order?)

---

2. What were your reasons for using the teaching methods and activities?

---

3. Explain the reasoning in the order of events used here (Evidence of Curriculum order?).

---

4. How did you address learners learning difficulties, if at all, during the lesson? (Learner prior Knowledge and what is difficult to learn)

---

5. What changes would you make the next time you teach the same concept? (Learner prior Knowledge and what is difficult to learn)

---

6. Was your lesson effective? How do you know?

---

7. What made the lesson effective?

---

8. What were your successes during the lesson?

---

9. Do you think the learners learnt what you intended them to learn in the lesson? (Learner prior Knowledge and what is difficult to learn)

---

10. Did your learners enjoy the lesson? What were the indicators? (Learner prior Knowledge and what is difficult to learn)

---

11. What was the level of learner's participation during the lesson? (Learner prior Knowledge and what is difficult to learn)

---

12. How will you be able to know whether your students understand the concepts you try to teach? (Learner prior Knowledge and what is difficult to learn)

13. How do you feel about the lesson you taught? (What is difficult to teach)

14. Did you feel confident in the lesson using the ripple tank? (Representations)

15. Would you have felt as comfortable using the ripple tank had you not had training on the apparatus? (Representations)

16. Did you make any changes in the class that I observed compared to previous years and other classes or lesson plans? Why? (Conceptual teaching strategies)

17. Do you believe what you planned out to achieve was achieved when actually coming to carry out the lesson or did you deviate from your planned lesson? (Conceptual teaching strategies)

APPENDIX X: LETTERS OF CONSENT/ASSENT

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

7 January 2019

Dear Parent,

Re: Request for your child to be present in lessons that will be observed and video recorded.

I am an Education specialist stationed at Lasec SA. Currently I am enrolled for a MEd study at the University of Pretoria. In order to fulfil the requirements of the degree, I have to carry out a research project. I am currently conducting a study titled "*Teaching the wave concept: How training in the use of equipment affects teachers' PCK*. I will investigate the impact in-service teacher training on the use of the ripple tank apparatus has on the development of the pedagogical content knowledge (PCK) of teachers who teach the wave-concept in the Grade 10 Physical Science curriculum. To accomplish this research, it is required that I observe and video record three lessons during which the Physical Sciences teacher teaches the topic of waves to the Grade 10 learners. These lesson observations and video recordings will take place during normal school hours in normal scheduled Physical Science lessons. Ethical clearance has been given to conduct this study and thus I will adhere to all the requirements, policies and procedures for responsible research drawn up as the Code of Ethics for Research.

I hereby request your consent for your child to be present while video recordings are being made of the teacher teaching the lessons. A conscious effort will be made not to capture learners' faces on video camera and no data will be obtained from the learners directly. Should you accept this request I guarantee confidentiality and anonymity. The name of your child and the name of the school will not be disclosed nor will be present in any formal written work. The data collected and the findings will be made available in an open repository for public and scientific use but the identify of all persons involved will remain anonymous and the findings will be used for research purposes only. Should you not give consent your child will not be removed from the lessons but will be placed out of the recording view of the camera.

Yours sincerely

BVollebregt

Miss B Vollebregt (Researcher)

Date: 07/01/2019

Room 4-1.7, Level 4, Building
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 1234
Fax +27 (0)12 420 5678
Email name.surname@up.ac.za
www.up.ac.za

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Learner Name: ______________________________

Agreement: *I have read and understood the above that indicates the intentions of the researcher and request for my child's participation in the research project.*

	Please tick the appropriate box
I do give *my consent for my child to participate in the research project.*	
I do not give *my consent for my child to participate in the research project.*	

Parent signature______________________________ **Date**____________

***If the agreement is not signed by the parent I will assume that consent is given by the parent for his/her Child to participate in the research project.**

Please read and explain the consent letter to your Child and if he/she agrees to participate in the study to sign below as assent.

Learner signature______________________________ **Date**____________

***If the agreement is not signed by the learner I will assume that assent is given by the learner to participate in the research project.**

Should you have questions or need further clarification about the research, be free to contact me or my supervisor.

Researcher	**Supervisor**
Bronia Vollebregt	Mrs Coetzee
Lasec Education	University of Pretoria
0835725195	Faculty of Education
	Science, Mathematics and Technology Education Department

Researcher's Signature Vollebregt Date: 07/01/2019

Supervisor's Signature Cloete Date: 07/01/2019

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

4 December 2018

Dear Sir/ Madam

Request permission to conduct a research project in you school.

I am an Education specialist stationed at Lasec SA. Currently I am enrolled for a MEd study at the University of Pretoria. In order to fulfil the requirements of the degree, I have to carry out a research project. I am currently conducting a study titled "*Teaching the wave concept: How training in the use of equipment affects teachers' PCK.* I will investigate the impact in-service teacher training on the use of the ripple tank apparatus has on the development of the pedagogical content knowledge (PCK) of teachers who teach the wave-concept in the Grade 10 Physical Science curriculum. The PCK construct is important, because it encompasses the knowledge a teacher has in order to translate the content knowledge about a topic into units understandable for learners. It is important to note that expert teachers are not born with PCK and that PCK is unique to each teacher. Literature has shown that PCK can be gained through practice and be developed and improved during teacher training through in-service education. Literature also indicates that teachers can transfer their PCK in one topic to other topics. As such, it is worthwhile to investigate the effect training has on a teacher's PCK in one topic.

I hereby request permission to conduct research in your school. This research requires me to interact with the Physical Science teacher in order to obtain data. To accomplish this goal, I intend to do the following:

Progress	Approximate time required (minutes)	Action carried out with the teacher
Interaction 1	30	Meet the teacher for pre-semi-structured interview. (after school hours)
Interaction 2	60	Meet to explain the questionnaire and complete it with the teacher. (after school hours)

Room 4-1.7, Level 4, Building
University of Pretoria, Private Bag X20
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Fax +27 (0)12 420 5678
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www.up.ac.za

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

	60	In-service training carried out by a trusted colleague to prevent bias. (after school hours)
Interaction 3	60	Meet to complete the questionnaire. (after school hours)
Interaction 4 a,b, c	Normal school lesson	Observe and video record the teacher teaching waves over three periods. Not intrusive. (during school hours)
Interaction 5	45	Meet +- 3 days after last observation to carry out a final interview.

I hereby also request your permission to do video recording of the lessons during which the Physical Science teacher will teach the topic of Waves. A conscious effort will be made not to capture learners' faces on video camera and no data will be obtained from the learners directly.

Your decision to accept or decline this invitation will not have any adverse effect on the school, yourself, the educators or the learners. As an incentive to take part in the study, the school will be given the ripple tank apparatus to keep once the study has concluded. The teachers will also have the opportunity at no cost to themselves or the school, get trained on using the ripple tank apparatus as well as an opportunity to reflect on their classroom practice. I undertake to maintain confidentiality. Your name, the school name, the teacher's name and the learner names will not be disclosed nor will be present in any formal written work. The data collected and the findings will be made available in an open repository for public and scientific use. The identity of all persons involved will remain anonymous.

We would greatly appreciate it if you would consent to this request. I envisage that the findings of this study will add new information to existing literature about in-service teacher training using Physical Sciences equipment on the topic of waves. My wish is that the findings of this study will be helpful to the private and public sector, the Department of Education and schools when making resource decisions on the development of professional teachers in Physical Sciences.

Agreement: If you are willing to allow me to video record the classroom lessons and to allow the Physical Sciences teacher to participate in the research, please kindly sign below as a declaration of your consent. Thank you for taking the time to read this letter.

Thanking you in advance.
Yours sincerely,

Miss B Vollebregt
Researcher

Date: 04/12/2018

Declaration of consent

Principal signature________________________________ **Date**__________

School Governing Body representative signature______________ **Date**__________

School Executive Management representative signature ___________ **Date**_________

Should you have questions or need further clarification about the research, be free to contact me or my supervisor.

Researcher	**Supervisor**
Bronia Vollebregt	Mrs Coetzee
Lasec Education	University of Pretoria
0835725195	Faculty of Education
	Science, Mathematics and Technology Education Department

Researcher's Signature____________ Date: 04/12/2018

Supervisor's Signature____________ Date: 04/12/2018

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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

4 December 2018

Dear Teacher

Re: Request to Participate in a Research Project.

I am an Education specialist stationed at Lasec SA. Currently I am enrolled for a MEd study at the University of Pretoria. In order to fulfil the requirements of the degree, I have to carry out a research project. I am currently conducting a study titled "*Teaching the wave concept: How training in the use of equipment affects teachers' PCK.* I will investigate the impact in-service teacher training on the use of the ripple tank apparatus has on the development of the pedagogical content knowledge (PCK) of teachers who teach the wave-concept in the Grade 10 Physical Science curriculum. The PCK construct is important because it encompasses the knowledge a teacher has in order to translate the content knowledge about a topic into units understandable for learners. It is important to note that expert teachers are not born with PCK and that PCK is unique to each teacher. Literature has shown that PCK can be gained through practise and be developed and improved during teacher training through in-service education. Literature also indicates that teachers can transfer their PCK in one topic to other topics. As such, it is worthwhile to investigate the effect training has on a teacher's PCK in one topic.

I hereby request permission from you to participate in the above-mentioned research. This research requires me to interact with you in order to obtain data. To accomplish this goal, I intend to do the following:

Progress	Approximate time required (minutes)	Action carried out with the teacher
Interaction 1	30	Meet the teacher for pre-semi-structured interview. (after school hours)
Interaction 2	60	Meet to explain the questionnaire and complete it with the teacher. (after school hours)

Room 4-1.7, Level 4, Building
University of Pretoria, Private Bag X20
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Lefapha la Thuto

	60	In-service training carried out by a trusted colleague to prevent bias. (after school hours)
Interaction 3	60	Meet to complete the questionnaire. (after school hours)
Interaction 4 a,b, c	Normal school lesson	Observe and video record the teacher teaching waves over three periods. Not intrusive. (during school hours)
Interaction 5	45	Meet +- 3 days after last observation to carry out a final interview.

I hereby also request your permission to video record the lessons during which you will teach the topic of Waves. A conscious effort will be made not to capture learners' faces on video camera and no data will be obtained from the learners directly.

Your decision to accept or decline this invitation will not have any adverse effect on the school, yourself or the learners. As an incentive to take part in the study, the school will be given the ripple tank apparatus to keep once the study has concluded. You as the teacher will also have the opportunity, at no cost to yourself or the school, get trained on using the ripple tank apparatus as well as the opportunity to reflect on your classroom practice. I undertake to maintain confidentiality. Your name, the school name and the learner names will not be disclosed nor will be present in any formal written work. The data collected and the findings will be made available in an open repository for public and scientific use but the identity of all persons involved will remain anonymous. The findings of this study will be used for research purposes only.

We would greatly appreciate it if you would consent to taking part in this research project. The purpose of this study is not to assess or judge you in any way. I envisage that the findings of this study will add new information to existing literature about in-service teacher training using Physical Sciences equipment on the topic of waves. My wish is that the findings of this study will be helpful to the private and public sector, the Department of Education and schools when making resource decisions on the development of professional teachers in Physical Sciences.

Agreement: Should you accept this request and if you are willing to allow me to video record the three lesson observations please kindly sign below as a declaration of your consent. Thank you for taking the time to read this letter.

Thanking you in advance.
Yours sincerely

Miss B Vollebregt Date: 04/12/2018
Researcher

Declaration of consent

Teacher signature________________________ **Date**__________________

Should you have questions or need further clarification about the research, be free to contact me or my supervisor.

Researcher	**Supervisor**
Bronia Vollebregt	Mrs Coetzee
Lasec Education	University of Pretoria
0835725195	Faculty of Education
	Science, Mathematics and Technology Education Department

Researcher's Signature____________________ Date: 04/12/2018.

Supervisor's Signature____________________ Date: 04/12/2018

4 December 2018

Dear Trainer

Re: Request to Participate in a Research Project.

I am an Education specialist stationed at Lasec SA. Currently I am enrolled for a MEd study at the University of Pretoria. In order to fulfil the requirements of the degree, I have to carry out a research project. I am currently conducting a study titled "*Teaching the wave concept: How training in the use of equipment affects teachers' PCK.* I will investigate the impact in-service teacher training on the use of the ripple tank apparatus has on the development of the pedagogical content knowledge (PCK) of teachers who teach the wave-concept in the Grade 10 Physical Science curriculum. The PCK construct is important because it encompasses the knowledge a teacher has in order to translate the content knowledge about a topic into units understandable for learners. It is important to note that expert teachers are not born with PCK and that PCK is unique to each teacher. Literature has shown that PCK can be gained through practise and be developed and improved during teacher training through in-service education. Literature also indicates that teachers can transfer their PCK in one topic to other topics. As such it is worthwhile to investigate the effect training has on a teacher's PCK in one topic.

I hereby request permission from you to participate in the above-mentioned research. This research requires for you to carry out the in-service teacher training on the use of the Ripple Tank apparatus to each of the three participating teachers. I hereby also request permission to interview you after each in-service teacher training in order for me to keep an accurate reflective journal. Your decision to accept or decline this invitation will not have any adverse effect on you and I undertake to maintain confidentiality. Your name will not be disclosed nor will be present in any formal written work. The data collected and the findings will be made available in an open repository for public and scientific use but the identify of all persons involved will remain anonymous. The findings of this study will be used for research purposes only.

We would greatly appreciate it if you would consent to taking part in this research project. I envisage that the findings of this study will add new information to existing literature about in-service teacher training using Physical Sciences equipment on the topic of waves. My wish is that the findings of this study will be helpful to the private and public sector, the Department of Education and schools when making resources decisions about teacher professional development for Physical Science teachers.

Agreement: Should you accept this request please kindly sign below as a declaration of your consent. Thank you for taking the time to read this letter.

Yours sincerely

Miss B Vollebregt Date: 04/12/2018

Researcher

Declaration of consent

Trainer signature__________________________ **Date**__________________

Should you have questions or need further clarification about the research, be free to contact me or my supervisor.

Researcher	**Supervisor**
Bronia Vollebregt	Mrs Coetzee
Lasec Education	University of Pretoria
0835725195	Faculty of Education
	Science, Mathematics and Technology Education Department

Researcher's Signature__________________ Date: 04/12/2018

Supervisor's Signature__________________ Date: 04/12/2018

Faculty of Education
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APPENDIX XI: PLANNED CONCEPTUAL TEACHING STRATEGIES

Jessica

During the pre-interview (Electronic Appendix B) a number of questions were asked which informed me of her planned conceptual teaching strategies.

Jessica revealed the following:

- That she uses a number of teaching styles to teach her learners which is also depended on the topic and approach.
- That she believes her teaching strength is her confidence and that she makes effort to always communicate with the learners in order to determine their level of understanding pertaining to the concept being covered.
- That she believes her teaching weakness is that she may not know all the different concepts that she teaches in the depth she would like to know them.
- To improve her content knowledge and conceptual teaching strategy she relies on other resources such as YouTube, research papers and textbooks.
- She believes that to help her teaching approach she would benefit from training opportunities that would unpack sections and that would identify and discuss common learner misconceptions and how to go about fixing such misconceptions.

In order to understand the participant's planned teaching strategies, I asked her during the pre-interview (Electronic Appendix B) to explain her usual strategy for teaching key ideas of *wavelength, frequency* and the subordinate idea of period. The participant revealed that she would use the slinky spring as a representation while explaining the key ideas and subordinate ideas. She indicated that she would link the concepts to real-life, would use a slinky spring and water waves and would get the learners familiar with the terminology. She stated that she would allow the learners to uncover the correct terminology on their own, through guidance. This would be followed by drawing the wave diagram on the board which would include labels. I asked the same question about her conceptual teaching strategy in terms of the third key idea of *superposition*. She indicated that it was a short section and is normally covered at the end of the topic. Again, the slinky spring would be used and would ensure that the learners have an understating about superposition and its subordinate ideas.

Tshuma

During the pre- interview (Electronic Appendix C), the following additional information was revealed about the Participants conceptual teaching strategies:

- That he believed he is successful in teaching the content. He also revealed that he is confident when he is in class and feels competent and strong.
- That he believes his weakness in his teaching is the fact that he works too fast, just due to getting carried away because he enjoys teaching and stated that in future he needs to slowdown in his lessons to meet the learners needs.
- To increase his content knowledge, he sees the value in meeting with colleagues to discuss the different ways of approaching a topic.

To understand his planned teaching strategy, I asked him during the pre-interview (Electronic Appendix C) to explain his strategy for teaching *wavelength, frequency* and *superposition*. He described that he would develop conceptual understanding using the prior knowledge of the learners about the subordinate idea of pulses. He then explained that he would illustrate the transverse wave and would discuss the idea of wavelength. He would follow with the concept of frequency and period. He mentioned that he would draw items on the board and would use teaching aids such as a chart during the lesson. Although he did not indicate which items he would draw. He discussed how he would teach the relevant equations that are used to calculate frequency and period. With regards to the concept of superposition the participant explained that he normally finds this concept easy to teach. He further explained that he would talk about the subordinate idea of constructive interference. He mentioned that he would relate it to water waves which are seen in the sea and how ships at times capsize because of the high waves (i.e. higher amplitude, which I recognise is not necessarily the result of constructive interference). He explained that for destructive interference he would teach the subordinate idea using "raw" data to show that it cancels out (It is not clear what "raw data" indicates - I am not sure if this means that he would use mathematical values to explain destructive interference). He also indicated that he would demonstrate the concept, using a rope, and would give real life examples.

Craig

During the pre-interview (Electronic Appendix D), the following additional information was revealed about Craig's conceptual teaching strategies:

- That he believes his teaching strength is that he interacts with the learners making sure that they are working on their own for most of the time so that they get use to the "stuff".
- That he believes that his weakness in the classroom is that he should do more demonstrations on some of the critical topics.
- That he makes use of the internet to research topics to improve his content knowledge. He also likes to engage with other colleagues to learn about what is new and what he does not know.
- That he is open to further learning opportunities (Electronic Appendix D).

During the pre-interview (Electronic Appendix D), I asked Craig to explain his usual strategy for teaching the *three key ideas*. He stated that he normally discusses a transverse wave and a longitudinal wave and draws a transverse wave to illustrate the trough, crest, the points which they can use to determine the wavelength and the amplitude. He then covers all the definitions to do with wavelength, frequency and period. He then moves onto a discussion about the calculations and would also carry out simulations so that the learners are able to see what waves looks like and how they behave. In terms of superposition, he said that he explains the positive and negative displacement of the particles above and below rest position. This is followed by discussing what happens if "they" are on one side which is where superposition takes place. He then explains how "they" will cancel each other or how "they" will add up. The participant then stated that he would display a simulation after explaining the theory to the learners. The participant indicated that he normally makes them draw their own diagrams after showing them an example of how to draw superposition.

APPENDIX XII: OBSERVER EFFECTS

- Observational bias: Grimes and Schulz (2002) indicates that it is important for investigators to be aware of built-in bias and to furrow through them to determine how they may have affected the data obtained. In this particular aspect of the study, I wanted to investigate how the teachers employed the use of the science equipment and enact the knowledge, taught during the intervention. My assessment of the lesson observations may have been overshadowed by my enthusiasm that the participants would in fact employ the science equipment and enact the pedagogical content knowledge and skills, taught during the intervention. In this study I made use of the enacted TSPCK rubric (Appendix VI) that was adapted from Coetzee (2018) to minimise the effect of observational bias. Furthermore, Grimes and Schulz (2002) advised that information bias (also known as observation bias) is prevented through ensuring that data collection is done in the same way for all of the participants. It is for this reason that the same protocol and design, as discussed in Section 3.4 and Section 3.5 was carried out for all three participants while observing the lessons and when conducting the post-intervention interviews.
- The Hawthorne effect: The Hawthorne effect can be the reason for obtaining favourable results due to a number of effects (Stand, 2000). An effect that is relevant for this study is the possible behavioural change of the participant because the participant is aware of being observed or because the participant knows the wishes of the researcher. The teachers were aware of the purpose of the study because they had to sign consent letters (Appendix X). However, teachers are required to teach in front of a classroom filled with observers (the learners) on a daily basis. In-service teachers are also familiar with being observed by management or Head of Department. This is a requirement that needs to be fulfilled to carry out teacher appraisal lessons such as Integrated Quality Management System (IQMS) lessons. These lessons are used as a performance measurement strategy to rate the teachers' performance and accountability with the idea of improving the quality of education in schools (Rabichund & Steyn, 2014). It should therefore not have been too unfamiliar having myself as an observer in the participants lessons.
- The halo effect: Having taught Physical Sciences myself, I had a pre-determined idea of how I would teach the topic of waves with the use of the ripple tank apparatus. I also had interacted with each participant three times before the observations were carried

out and had pre-informed impressions of each participant. I had to be aware of the perceptions I held of the participants themselves and my biases about teaching the topic when rating the participants' enacted PCK. It was therefore necessary that I rated the lessons purely on the descriptions and ratings provided by the enacted TSPCK rubric (Appendix VI) to minimise the halo effect on this study.

APPENDIX XIII: OTHER EVIDENCE FROM THE VSR INTERVIEW NOT RELEVANT TO THE SECTIONS CHOSEN.

6.2.1.5 Jessica

During the VSR interview, I made the participant aware that she used certain phrases that the trainer used during the intervention. These phrases were: 'what do you see? What do you observe?'. I asked the participant if she had always used such phrases or if it was something that she learnt or pick up from during the training. Her response was as follows:

> *It's something…I think I've always done, but I do think I was more aware of it because of the training…But I do think especially with this section, I was a lot more aware of the fact that it's nice to get them to tell you what they know…then you can see what they don't know.*

Her response indicates that the in-service training made her more aware of the importance of allowing learners to indicate what they know or see when using a representation in order to establish their baseline knowledge.

During the intervention with Jessica, the trainer used the illustration of falling rice through a gap formed by the two longer metal barriers held above the table. This was to compare the way particles behave to the way waves behave when moving through a gap and about the wave nature of particles. When I asked her if she had learnt this particular analogy from the intervention she responded:

> *I did take that from the training…I never usually made them…think about particle versus wave properties…I thought that was very useful in the training. So, I did take it over [Explanatory note: used the idea in class].*

It was observed that the participant illustrated and used the same analogy in class (see section 10, Electronic Appendix K) as taught during the in-service training.

It was also interesting to note that during her VSR interview the participant indicated that wavelength and superposition were the easiest to teach and were the two concepts that the learners "got the best". However, while observing her lesson on *wavelength* (see Figure 6.1) it was evident that the learners had a number of misconceptions about the concept. I believe that the lesson was not very easy to teach nor did it seem as if the learners understood the concept of wavelength well, when compared to the other concepts taught. This may be due to the participants own misunderstanding about the idea of *pulses*. A possible reason for her belief that the concept is easy to teach may be due to her knowledge of the common misconceptions about wavelength which is recorded in her CoRes (see Figure 5.2 and Figure 5.14) therefore being prepared for the lesson.

6.2.2.2 Tshuma

The participant revealed knowledge about Learner prior knowledge and thinking during section 14 when he elicited the learners' prior knowledge to facilitate conceptual development about how temperature affects the way sound travels. It was also elicited during his VSR interview when he reflected back to the event through the following statement:

> *…I had to go back to Grade 9 and why temperature affects the resistance. I do link it because they know that one…I had to explain in detail…what does temperature do to increase the speed of sound? So, I had to link with the prior knowledge of resistance and temperature.* *(He did understand that an increase in temperature increased the speed of sound, seen in section 14 of the narrative account of his lessons in electronic appendix L)

Furthermore, his *knowledge of learner prior knowledge* and learner thinking was evident in section 14 when he linked their real-life experiences during athletics day, hearing and seeing the smoke from the starter gun, to the speed of sound and light. When I asked the participant during the VSR interview to reflect as to why he did this, he gave the following response:

> *For them to be easily engaged, [I thought] let me just go to the concept of the…starter gun…it was for them easier to understand how sound travels slower than…light…I just [brought] in a real-life event because they [had] just came from sports [day] and… it was going to be easier for them to understand how sound travels slower than light.*

Despite the fact that the illustrations and use of learner prior knowledge to develop conceptual development was based upon the concept of sound which was not pertinent to the study, it revealed his continued awareness of learner prior knowledge and its importance in further developing learner understanding.

As mentioned, I did not observe the participant teaching the third key idea of superposition but when the participant was asked about his approach to teach superposition he replied:

> *Yes. It was my… I think during the first two lessons I covered superposition and again it was well understood. So that's why I didn't…have some intervention in that topic. They really understood the topic, to perfection in fact.*

Although the teacher was not observed to use creative components in the form of representations, his teaching strategy included an approach of involving two learners who were seen to take the majority of lesson 2 (sections 7 – 10). When I asked the participant for his reasoning regarding this approach, he had the following response:

> *…The day before…the volunteers just said [that] they want[ed] to do a presentation…they normally know that in science or when you do something [that when] you present you don't forget that concept. So, I was just like "okay if you guys [are] willing to do that, then it's fine"…it's a different approach of learning…also benefitting the same learners that are presenting.*

This methodology, although not involving the ripple tank and not comparable to his own teaching style, still incorporated a method which was a different approach in delivering content to the learners, intervening while these learners were presenting the content, where necessary to consolidate what was said. This further supports the **adequate** rather than limited score for his conceptual teaching strategies chosen during his lessons.

6.2.3.4. Craig

A misconception that the participant also addressed, over and above the important misconceptions of superposition, was that of the amplitude, during Section 12. He ensured that the learners understood that the amplitude was not the distance from a crest down to a trough but from the rest position to the crest or to the trough. He indicated to the learners that despite discussing it, some of them would still make the mistake. During the VSR interview the teacher indicated that he observed the very mistake being done in a test that they had just written, evident through the following comment:

> *…in the test that they wrote, we had some people…who did the same thing. And we were laughing at them yesterday.*

The participant, although not relevant to the key ideas of the study ensured that his learners were aware of misconceptions relevant to other concepts taught during the observations.
When I asked the participant how he would know whether his learners understood the concepts he was trying to teach them, he responded with the following:

> *Normally for you to know how…they understand the concepts, [it] is when they write their tests. Then you get a feeling that what I was teaching them, what I was trying to explain, they understood it. Like what I was saying now, that some of the answers which I got…I realise[d] that no [these] guys, they really, really understood it from the use of that ripple tank. [Explanatory notes: we were discussing the test that the learners had written based upon the topic of waves. The teacher believed that some of the answers were good explanation. He believed it was due to the lessons where the learners were exposed to the ripple tank apparatus].*

His response further reveals his belief in using the ripple tank as a representation. His above response indicated that he believed that the use of the ripple tank as a representation improved learner understanding which was evident through the test his learners wrote after the representation was used.

APPENDIX XIV: SUGGESTED AMENDMENTS OF THE CORE PROMPTS.

Prompt in the CoRe used in this study	**Reason for amending the prompt.**	**Suggested amendment**
What is difficult to understand? *(Prompt 5)* And *What do you consider easy or difficult in teaching this big idea?* *(Prompt 6)*	Prompts 5 and 6 are listed under the component of *Curricular Saliency* however, it was evident that the teacher's revealed a lot about his or her knowledge and understanding through their responses to these two prompts under the component of *Learner Understanding*.	Prompts 5 and 6 should be moved and listed under *Knowledge and Skills related to Learner Understanding.*
What is difficult to understand? And *What do you consider easy or difficult in teaching this big idea?*	It was observed in the CoRe that participants would refer to *What is difficult to understand?* to respond to *What do you consider easy or difficult in teaching this big idea?* The two prompts are seen to overlap. What teachers may find easy or difficult to teach is determined by what the learners find difficult to understand. It was also observed that responses written under the prompt *What is difficult to understand?* were repeated when responding to the prompt *What are the typical learner misconceptions on this big idea?* The prompt *What is difficult to understand?* seems repetitive because the same knowledge would be revealed through the two prompts of *What do you consider easy*	*What do learners consider easy or difficult and as a result, what do you consider easy or difficult in teaching this big idea?* And list it under the component of *Learner Understanding* as per the first suggested amendment.

	or difficult in teaching this big idea? and *What are the typical learner misconceptions on this big idea?*	
What representations would you use in your teaching strategies?	The participants in their responses would list the representations or gave non-specific versions of their chosen representations and did not give an explanation as how they would use the representation to develop conceptual understanding of the key idea.	*What representations would you use in your teaching strategies and why?*
What questions would you consider important to ask in your teaching strategies?	Participants wrote questions down in their responses that were more instructive in nature than those that would develop conceptual understanding of the key idea. Questions prompting learners to grasp the idea is what is required, not instructional questions that are asked once the key idea is understood.	*What questions would you consider important to ask in your teaching strategies to ensure the learners conceptual understanding of the key idea?*

ELECTRONIC APPENDICES

APPENDIX A: RIPPLE TANK TEACHERS GUIDE

APPENDIX B: TRANSCRIBED SCRIPT FOR THE SEMI-STRUCTURED PRE-INTERVIEW, JESSICA

APPENDIX C: TRANSCRIBED SCRIPT FOR THE SEMI-STRUCTURED PRE-INTERVIEW, TSHUMA

APPENDIX D: TRANSCRIBED SCRIPT FOR THE SEMI-STRUCTURED PRE-INTERVIEW, CRAIG

APPENDIX E: DIARY REFLECTION OF THE INTERVENTION FOR JESSICA

APPENDIX F: DIARY REFLECTION OF THE INTERVENTION FOR TSHUMA

APPENDIX G: DIARY REFLECTION OF THE INTERVENTION FOR CRAIG

APPENDIX H: DIARY REFLECTION OF THE OBSERVATIONS AND THE SEMI-STRUCTURED VSR QUESTIONS FOR JESSICA

APPENDIX I: DIARY REFLECTION OF THE OBSERVATIONS AND THE SEMI-STRUCTURED VSR QUESTIONS FOR TSHUMA

APPENDIX J: DIARY REFLECTION OF THE OBSERVATIONS AND THE SEMI-STRUCTURED VSR QUESTIONS FOR CRAIG

APPENDIX K: LESSON NARRATIVES FOR JESSICA

APPENDIX L: LESSON NARRATIVES FOR TSHUMA

APPENDIX M: LESSON NARRATIVES FOR CRAIG

APPENDIX N: TRANSCRIBED SCRIPT FOR THE VIDEO-STIMULATED RECALL INTERVIEW, JESSICA

APPENDIX O: TRANSCRIBED SCRIPT FOR THE VIDEO-STIMULATED RECALL INTERVIEW, TSHUMA

APPENDIX P: TRANSCRIBED SCRIPT FOR THE VIDEO-STIMULATED RECALL INTERVIEW, CRAIG

APPENDIX Q: TRANSCRIBED SCRIPT FOR THE SEMI-STRUCTURED POST-INTERVIEW, JESSICA

APPENDIX R: TRANSCRIBED SCRIPT FOR THE SEMI-STRUCTURED POST-INTERVIEW, TSHUMA

APPENDIX S: TRANSCRIBED SCRIPT FOR THE SEMI-STRUCTURED POST-INTERVIEW, CRAIG

APPENDIX T: AUDIO STIMULATED RECALL INTERVIEW WITH THE TRAINER

APPENDIX U: TRANSCRIBED SCRIPT FOR THE AUDIO STIMULATED RECALL INTERVIEW FOR THE TRAINER