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PRE-SERVICE TEACHERS' DEVELOPMENT OF TOPIC SPECIFIC PCK IN KINEMATICS AND TRANSFERABILITY OF PCK COMPETENCE TO A NEW PHYSICS TOPIC



A research report submitted to the Faculty of Science, School of Education, University of the Witwatersrand, Johannesburg, South Africa, in partial fulfilment of the award of Master of Science (MSc.) in Science Education

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Abstract

There have been indications of inadequate content knowledge of South African physical science teachers and poor pedagogical content knowledge in making the concepts accessible to students. With this, the pre-service teachers are considered a part of the science education foremost links to schools and young science learners. Empirically, it has been reported that this unique teacher knowledge could be developed particularly in pre-service teachers in a planning context and that the new technique of developing pre-service teachers' PCK within a topic helps in their good mastery of teaching concepts and thus making them specialists in topics. The Topic Specific PCK (TSPCK) construct focuses on the transformation of the understanding of content of a particular topic. This study investigated the extent to which focus on kinematics improves pre-service teachers' PCK in the topic and possible transferability of the learnt pedagogical competence to a new physics topic – electric circuits. Guiding this study were two research questions: What is the impact of the intervention on the quality of pre-service teachers' Topic Specific PCK in Kinematics? To what extent is the pre-service teachers' learnt pedagogical transformation competence transferrable to their planning of a new topic in physics topic – Electric circuits? This study used mixed methods to investigate TSPCK in pre-service teachers. It was located in the methodology class of Twenty-three (23) 4th year physical science majors. The study included an intervention where the theoretical framework for TSPCK was used to introduce the construct in Kinematics. The intervention explains each of the five components of Topic Specific PCK using the knowledge concepts of Kinematics. Data were collected using three instruments: an instrument measuring content knowledge in kinematics; an instrument measuring the quality of Topic Specific PCK in kinematics administered as a set of pre/post intervention tests; and an instrument measuring transferability of learnt competence in planning for teaching a new topic electricity. The pre-service teachers' written responses to the TSPCK kinematics tool were analyzed qualitatively and quantitatively. Both methods of analysis revealed that the pre-service teachers improved in their quality of TSPCK in kinematics following the intervention. It was also found out that the pre-service teachers' improvement in the quality of TSPCK in kinematics was as result of rigorous engagement with the TSPCK components at varying degrees. Similarly, on the topic of transfer, electricity which was not discussed during the intervention, TSPCK tool in electric circuits was administered to the pre-service teachers and few records of their actual classroom teaching were analyzed. This

was done to examine possible transferability of learnt pedagogical transformation competence to the new physics topic of electricity. The findings revealed that the pre-service teachers had 'developing level' of TSPCK in the topic of transfer similar to the finding in the topic of kinematics. The study demonstrated that focus on a single topic in a methodology course will enable transfer to another topic provided the teachers have the pre-requisite content knowledge. The findings of this study would contribute to the training of the Physical science student teachers and specifically improve their planning of other physics topics to enhance effective teaching and learning process.

Keywords: content knowledge, pre-service teachers, pedagogical content knowledge, pedagogical transformation competence, topic specific pedagogical content knowledge

Dedication

I dedicate this work to the glory of the Almighty God, the Ancient of days who alone declares the end from the beginning.

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I would like to appreciate my supervisor, Dr. Elizabeth Mavhunga for her efforts, mentorship, availability, contributions and recommendations. She has indeed greatly inspired me. The successful completion of this work would not have been possible without her. I am grateful to her for all round supports – financially, academically and spiritually. May the Almighty God reward her for good!

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I give all the glory to the LORD GOD of all flesh.

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List of Acronyms

PCK – Pedagogical Content Knowledge

TSPCK – Topic Specific Pedagogical Content Knowledge

CHAPTER ONE

1. GENERAL INTRODUCTION TO THE STUDY

In this chapter, I present an overview of the study. This includes introduction with the purpose of the study, justification for carrying out the study, the identified problems, research questions guiding the study and the adopted theoretical framework used in this study. I conclude by giving brief descriptions of the chapters in this research report.

1.1 Introduction

Quality classroom teaching which brings about learning remains one of the fundamental goals of science education. This requires that teachers are well knowledgeable in reasoning and conceptual instructional strategies that enhance learning. This is important for a subject like physics which has often been regarded as conceptually difficult and abstract particularly for high school learners (Erinosho, 2013). In South African high schools, physics and chemistry together make up a subject tagged 'physical sciences' (Department of Education, 2015). Physics, in particular, equips learners with the basic knowledge of science and technology towards preparing them for further studies in sciences and empowering them to make positive contributions to their physical environments (Department of Education, 2012). Kinematics represents an aspect of mechanics in physics, describing the motion of objects and the involved physical quantities (Giancoli, 2005). In this study, kinematics is considered as a topic comprising of concepts. With regards to teaching and learning of these concepts, the pre-service teachers are considered a part of the science education foremost links to schools and young science learners (Lewis, Dema & Harshbarger, 2014). However, there have been concerns about the learners' inadequate conceptual understanding of kinematics concepts as reported in the physics education research studies (Gaigher, Rogan & Braun, 2007). Particularly in the high school learning of physics, some of these difficulties have been associated with teachers' teaching strategies that are not simply defined and without significant influence on the learners' conceptual understanding (Planinic, Milin-Siphus, Katic, Susac & Ivanjek, 2012). Other conceptual problems have been reported to be as a result of the teachers' poor preparation (Spaull, 2013) and hence poor understanding of the required content concepts (Rollnick & Mavhunga, 2013). How then do we

ensure that the pre-service teachers, who are hopefully becoming professional teachers in the nearest future, are adequately equipped to teach physics for conceptual understanding? In response to that Evans, Elen and Depaepe (2015) argued "*to improve the quality of education, investing in (prospective) teachers' PCK seems to be a good strategy*" (p. 2). The pedagogical content knowledge (PCK) according to Shulman (1986, 1987) is most important for teachers to make concepts understandable to learners as it involves transformation of content knowledge. As a strategy for preparing pre-service teachers, emphasis is placed on developing their PCK in science topics (Rollnick & Mavhunga, 2015). This helps them develop sound skills and knowledge needed for pedagogical transformation of content knowledge into the type that learners find interesting and understandable. This is a new version of PCK, a construct known as the 'Topic Specific Pedagogical Content Knowledge' TSPCK (Mavhunga, 2012). Thus, this study explores the development of pre-service teachers' TSPCK in kinematics and transferability of learnt pedagogical transformation competence to a new physics topic (electricity).

1.2 Purpose of the study

The complexity and topic specificity of PCK are both conventionally agreed upon (Gess-Newsome, 2015). It is equally acknowledged that PCK is rooted in the teachers' ability to transform CK in a topic and as such PCK and hence in association TSPCK is not the type of knowledge that is transferable from one topic to another. Based on the empirical evidence of its development particularly in pre-service teachers in chemistry topics, Rollnick and Mavhunga, (2015) recommended it should further be developed in some other core science topics. Building on that, this study is purposefully exploring how an intervention which explicitly discusses five content-knowledge components of TSPCK influences pre-service teachers' development of TSPCK in a specific physics topic (kinematics) and possible transferability of learnt pedagogical transformation competence to a new physics topic (electricity) both in planning context and actual classroom teaching. The quest for transferability which is extensively discussed in the next chapter, chapter 2, is associated with the competence of understanding the categories of knowledge components needed and their interactive use in transforming CK in a specific physics topic.

1.3 Problem statement

Much work has been done in demonstrating the TSPCK construct in chemistry topics e.g. chemical equilibrium (Mavhunga & Rollnick, 2013), electrochemistry (Ndlovu, 2014), organic chemistry (Vokwana, 2013), particulate nature of matter (Pitjeng, 2014). Little is known about the development of the construct in physics topics. Also, there have been records of difficulties learners encounter with regards to conceptual understanding of physics topics (Findlay & Bryce, 2012). Some of the difficulties learners encountered in understanding physics concepts have been associated with teachers' teaching strategies that are not simply defined and without significant influence on the learners' conceptual understanding (Planinic et al. 2012). Particularly in the South African high schools, the difficulties have equally been attributed to the teachers' inadequate content knowledge (Spaull, 2013) poor preparation and hence poor pedagogical content knowledge (Rollnick & Mavhunga, 2014) in making the concepts accessible to students. With the just released Diagnostic Report of the 2014 Grade 12 students who wrote matriculation examination, the performances have not been very encouraging in mechanics (kinematics). The extract of the report is summarized as follows:

> *"....some candidates still wrote force is directly proportional to acceleration and inversely proportional to mass.....Candidates confused gravitational acceleration and the force of gravity with the concept of free fall...Candidates still lack the skills to allocate and use sign conventions....Many candidates confused displacement-time graphs with velocity-time graphs. Many learners could not interpret the motion and depict the values correctly on the graph. They failed to interpret that at time zero, the velocity is 15 ms^{1}.....Candidates appeared to not know the difference between the magnitude of a vector quantity and the vector quantity itself..... Many candidates still lacked understanding of the basic concepts, conceptual interpretation of question and basic calculation skills. The majority of candidates battled with definitions……Learners lacked mathematical skills related to graphs…..Questions involving scientific explanations also posed extensive problems for candidates. Lack of skills to interpret and analyse data to answer questions which require explanations led to poor performance"* (Department of Basic Education, 2015, pp. 143-146).

Consequently, it would not have a good effect if learners' poor conceptual understanding associated with the teachers' ineffective teaching strategies persists without being addressed. The identified TSPCK construct has been observed to be different from the generic PCK as it focuses on the transformation of the understanding of content of a particular topic only (Mavhunga, 2015). Mavhunga has shown in previous studies (Mavhunga, 2014) that this unique teacher knowledge could be developed particularly in pre-service teachers in a planning context. The planning contexts required pre-service teachers to demonstrate their ability to think through and produce lesson planning programs that demonstrate transformation of content knowledge in a topic. The challenge remains to be unknown extent to which focus on kinematics improves pre-service teachers' TSPCK in the topic and transferability of the pedagogical competence to a new physics topic (electricity). As a result, there are two major research questions guiding this study. These are given as follows.

1.4 Research questions

The research questions guiding this study are given as follows:

(i) What is the impact of an intervention, which explicitly discusses transformation of content knowledge using five content specific components, on the quality of pre-service teachers' TSPCK in kinematics?

(ii) To what extent is the pre-service teachers' learnt pedagogical transformation competence transferable to the development of TSPCK in a new physics topic - electricity?

1.5 Rationale

This research study emanates from previous work (Mavhunga, 2012; Ndlovu, 2014; Pitjeng, 2014) that used TSPCK construct in examining how content knowledge in a specific chemistry topic is transformed pedagogically to enhance conceptual understanding of learners. The focus of this present study is on physics topics using the same TSPCK construct. Physics is regarded as the most basic of the sciences dealing with the behaviour and structure of matter (Giancoli, 2005). Physics equips students with the basic knowledge of science and technology towards preparing them for further studies in sciences and empowering them to make positive contributions to their physical environments (Department of Education, 2012). Kinematics,

which is considered as a topic in this study, serves as an important fundamental aspect of mechanics necessary for understanding some other physics topics (Lemmer, 2013). For example for learners to adequately understand 'force' (relating mass and acceleration together), the understanding of speed, velocity and time (concepts of kinematics) must first be in place. The learners' adequate understanding of kinematics concepts (e.g. distance, displacement, time, speed, velocity, acceleration) transfers into better comprehension of dynamics (force, momentum, impulse), the second aspect of mechanics. The South African physical science curriculum reveals the progression of teaching physics topics from kinematics to dynamics and others (Department of Education, 2012). Also, Lemmer (2013) indicated that Newtonian mechanics introduces most of the concepts of physics and a proper comprehension of these concepts is, therefore, essential to understanding physics. However, this topic of kinematics has been found out to be one of the challenging aspects of physics that learners find difficult to understand as analyzed in the South African Diagnostic Report (Department of Basic Education, 2015). The high school physics learners' difficulties in learning kinematics as reported in the literature include: (i) inability to conceptually understand continuous change in motion of objects (Oon, P. & Subramanian, 2012); (ii) difficulty in differentiating between instantaneous speed and average speed (Sengupta & Farris, 2012); (iii) problems with comprehending negative velocities and how to link them to physical situations (Eriksson, 2014). Hence, study first focuses on the pre-service teachers' development of pedagogical transformation competence in the topic of kinematics. The examination of possible transferability of learnt pedagogical transformation competence is there done in electricity, which is equally one of the basic areas of physics that is essential at all levels of physics teaching (Duit & von Rhoneck, 1997). The attention has been on the pre-service science teachers who in most cases find it challenging to convert their science subject matter knowledge into PCK because of their limited classroom teaching experience (Aydeniz & Kirbulut, 2011).

Noticeably, Metzler and Woessmann (2012) reported that teacher content knowledge exerts a statistically and qualitatively significant impact on the learners' performances. More explanatory, Ramma, Bholoa, Watts and Ramasawmy (2014, p. 30) added by pointing out that "*to bring meaning to an abstract physics concept, a teacher has to carefully reflect on his/her content knowledge and use the appropriate curricular and PCK*" (p. 30). This describes the importance of developing such an understanding like TSPCK which is the PCK produced

particularly for a specific topic by pedagogically transforming content knowledge within the topic. That eventually helps in contextualizing concepts into an actual, consistent and logical flow of ideas that enhance learners' conceptual understanding (Ramma et al., 2014) of the topic.

Meanwhile, the thoughts and reasons that influence the actions of a teacher in classrooms are observable in the transformation stage (Shulman, 1987), a stage needed before the actual delivery of the lesson. It is at this stage that teachers are required to think soundly about the transformation of their content knowledge within a topic into an understandable form for their learners. Shulman (1987) argued that "*all these processes of transformation result in a plan or set of strategies, to present a lesson, unit, or course*" (p. 17). This is revealed in the pre-service teachers' planning contexts for the lesson. But on that Nilsson and van Driel (2011) argued that developing PCK in pre-service teachers is done by teaching them the components that make up PCK. This process of teaching the pre-service teachers requires that they first develop pedagogical reasoning skill about topics in their subject of specialization because of their limited teaching opportunities. As a result, exploring pre-service teachers' development of TSPCK in the planning context of a physics topic like kinematics provides useful information regarding their understanding and pedagogical transformation reasoning ability.

Empirically, it has been reported that the new technique of developing pre-service teachers' PCK within a topic helps in their good mastery of teaching concepts and thus making them specialists in topics (Mavhunga, 2014). This helps pre-service teachers in developing unique knowledge for teaching science topics. This is the target of using TSPCK construct which consists of five knowledge components. While pre-service teachers are engaged in explicit discussions of the five TSPCK knowledge components, skills and knowledge for pedagogical transformation of CK is learned. This has been termed the 'pedagogical transformation competence' (Rollnick & Mavhunga, 2015) combining understanding of the knowledge components and their interactive use in explaining a concept in a particular topic. This pedagogical transformation competence developed in a topic has been reported to be transferable to another topic (de Jager, 2015).

However, the sought after transfer is not exploring the pre-service teachers' transferability of TSPCK. This is because TSPCK like the broader PCK, is a kind of knowledge that is not transferable (Mavhunga, 2014). It is the product of rigorous application of the transformation

competence - knowledge of both the components of TSPCK and the skill to apply them interactively while engaging with a topic- (Rollnick & Mavhunga, 2015). So what is transferable, that this study investigates, is the pre-service teachers' pedagogical transformation competence. In support of that, Aydin, Friedrichsen, Boz and Hanuscin (2014) argued that while investigating a particular teachers' PCK for a topic provides useful information, concentrating on the same group of teachers' PCK for different topics in the same discipline helps in understanding better the nature of PCK and hence TSPCK in this study. As such developing pre-service teachers' TSPCK in a topic is helping them to pedagogically reasoning on transforming CK in the topic. This has been argued as a way of enhancing pre-service teachers' CK and ability to think soundly about a topic in such a way that its concepts become understandable to the learners (Mavhunga, 2014). Thus, worth studying is how pre-service teachers develop TSPCK in a specific physics topic (kinematics) and the extent to which they can transfer learnt pedagogical transformation competence to a new physics topic (electricity). This will also improve their ability to think deeply about teaching these fundamental physics concepts, a process of reasoning about their actions, sufficient repertoire of content and conceptual teaching strategies (Rollnick & Mavhunga, 2014). Hence, it is envisaged that the results of this research study will hopefully impact positively pre-service teachers' education programs and enhance students' learning of physics.

1.6 Theoretical Framework

This study is guided by the notion of PCK theorized that Shulman (1986, 1987) for effective classroom teaching and learning. The TSPCK construct (Mavhunga, 2012) with its model has been adopted in this study as the theoretical framework for two important reasons. First, the construct emphasizes transformation of content knowledge in a specific topic using five specific-knowledge components. These knowledge components are: learner prior knowledge with misconceptions (LPK); curricular saliency (CSA); what is difficult to teach or understand (WDT); representations (REP) and conceptual teaching strategies (CTS) (Mavhunga, 2012). Second, the implementation of TSPCK construct in developing pre-service teachers' pedagogical transformation competence has been made explicit in the South African context (Rollnick & Mavhunga, 2015; Kind, 2015). The detailed discussions on this construct and its use are presented in the next chapter, Chapter 2.

1.7 An outline of research chapters

This research report consists of six chapters (1 - 6). Chapter 1 gives the introduction to the study under which the background information, problem statement, research questions and rationale are discussed. Chapter 2 consists of the reviewed literature on the concepts of pedagogical content knowledge, topic specific PCK and its five knowledge components as the theoretical framework, transferability of learned pedagogical transformation competence and methods of capturing PCK in science topics. Chapter 3 describes the research methodology which is mixed methods research approach situated in a case study as used in this study. Research instruments, methods of data collection, organization and content of the intervention focusing on transformation of content knowledge are explicitly discussed in the chapter. Chapter 4 presents discussions on the analysis of data on the pre-service teachers' quality of TSPCK in the topic of kinematics. Chapter 5 presents discussions on the analysis of data on the pre-service teachers' transferability of learnt pedagogical transformation competence to a new physics topic, electric circuits. Chapter 6, the final chapter provides an insightful summary of the whole study based on the discussions from the preceding chapters with answers to the research questions, contributions of the study and recommendations.

CHAPTER TWO

2. LITERATURE REVIEW

In this chapter, I present a critical review of related literature on the knowledge that matters when learning to teach science, significance of PCK in science education and its taxonomies leading its topic specificity. Following that, the model of TSPCK as the theoretical framework in this study is explained in relation to the PCK consensus model. There are discussions on planning versus enacting instruction using TSPCK and then each component of TSPCK with respect to teaching and learning of kinematics and electricity. Further discussions on the evidence of PCK interactions in specific topics are provided with transferability of pedagogical transformation competence. To sum it all, gaps are identified in the literature and conclusions summarize the chapter.

2.1 Introduction

This study begins by acknowledging an important argument Shulman (1986) raised that it is required of teachers to transform content knowledge (CK) in a topic to make the concepts within the topic understandable to learners. This is specifically linked to developing pre-service teachers' capability to transform CK in their subject of specialization (Mavhunga, 2014) as much more valuable than just holding a teaching degree (Kind, 2009). Influentially, pedagogical transformation of CK is highly important for a subject like physics that has often been regarded as conceptually difficult and abstract particularly for high school learners (Erinosho, 2013; Lichtenberger & Wagner, 2014). As indicated in the previous chapter, focus in this study has been on the physics topic of kinematics recently identified as one of the most challenging physics topics for South African high school learners (Department of Basic Education, 2015). The topic has also been realized to serve as an important fundamental aspect of mechanics necessary for understanding some other physics topics (Lemmer, 2013). Some of these difficulties that South African high school learners encountered in physical science (in which physics is embedded) have been associated with the teachers' inadequate content knowledge (Spaull, 2013), poor preparation and hence poor pedagogical content knowledge, PCK (Rollnick & Mavhunga, 2015). As a way of preparing pre-service science teachers for effective teaching

of science topics, emphasis is recently placed on developing their PCK in specific core science topics (Mavhunga, 2014). While quite a number of studies in this direction has been carried out focusing on chemistry topics e.g. chemical equilibrium (Mavhunga & Rollnick, 2013), electrochemistry (Ndlovu, 2014) to mention a few, little is known about physics topic. Hence, this study explores pre-service teachers' development of PCK in a specific physics topic of kinematics and transferability of learnt pedagogical transformation competence to a new physics topic (electricity).

2.2 Knowledge that matters when learning to teach science

In the classrooms, teaching and learning are two important inseparable components that could be said to be tightly bounded together. Good teachers make all efforts ethically to ensure learners engage in productive learning in the course of teaching. As a result, teaching has been referred to as a process that involves teachers' cognition (Yung, Zhu, Wong, Cheng & Lo, 2013). This calls for the need to examine how pre-service teachers develop their pedagogical transformation reasoning in preparation for effective science teaching. The focus has been on the pre-service science teachers who in most cases find it challenging to convert their science subject matter knowledge into PCK because of their limited classroom teaching experience (Aydeniz & Kirbulut, 2011). In this context, the pre-service teachers are regarded as the category of student-teachers who are still learning to teach. Park and Chen (2012) while describing teaching, referred to it as a highly complex act that requires a teacher to apply knowledge from multiple domains so as to enhance students' learning. That teaching is complex could mean that it has to be carefully designed to achieving purpose particularly in training pre-service teachers. Supporting that, Olaleye (2012) argued such successful learning may not be without specially designed effective teaching. Worth point out is the fact that teachers have been regarded as one of the most significant factors in students' understanding and success calling for enriching their knowledge and skills (Aydin & Boz, 2013). Emphasis was placed on recognizing the complexity of pre-service teachers' learning to teach sciences where experiences and previous knowledge shape the growth of new knowledge (Nilsson & van Driel, 2011). This is because learning to teach science goes beyond just mastering or acquiring the knowledge of the contents of a subject especially for those who are future professional teachers. In relation to that, Abell (2008) is of the opinion that "*learning to teach science is not about acquiring a bag of tricks based on a set*

of general pedagogical strategies, it is about developing a complex and contextualized set of knowledge to apply to specific problems to practice" (p. 1414). While Ball, Thames and Phelps (2008) observed that practicing mathematics teachers need more than just either CK or general pedagogy, Luft, Hill, Nixon, Campbell and Dubois (2015) argued science education community have not discussed agreeably on what constitute knowledge for teaching science. This reveals that the kind of knowledge required of a science teacher to teach science concepts is not the same as that required for teaching another subjects like English language. Furthermore, Ball *et al*. (2008) emphasized that teachers rather require 'specialized content knowledge' (Ball et. al, 2008) when it comes to teaching mathematics topics for conceptual understanding. Thus, there is also the need for an agreement on and examination of such knowledge that matters for teaching sciences and hence physics topics in this study. Brown, Friedrichsen and Abell (2012) suggested that in order to comprehend ways by which pre-service teachers develop knowledge during training, there must be identification of the vital types of knowledge to effective science teaching. Most of the research studies in this direction focus on the Shulman's (1986) theorized 'pedagogical content knowledge' (PCK) which takes into account teachers' ability to pedagogically transform their CK into a learning experience for learners (van Driel & Berry, 2010; Luft, Hill, Nixon, Campbell & Dubois, 2015). As a result, attention is most recently towards the significance of PCK in relation to teaching science topics effectively. Thus, this study investigates the pre-service teachers' Topic Specific PCK (TSPCK) in the physics topic of kinematics and transferability of learnt pedagogical transformation competence to a new physics topic (electricity).

2.3 Significance of PCK construct in Science Education

The concept of PCK as theorized by Shulman (1986, 1987) makes teachers different from subject specialists like Physicists, Biologists, Chemists, and others. According to him, PCK is the "*distinctive body of knowledge for teaching that represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interest and abilities of learners, and presented for instruction*" (Shulman, 1987, p. 8). While this description indicates the importance of teachers' content knowledge, it extends the arm of PCK beyond ordinary knowing or just general ways of teaching contents. There appears to be universal conformity that PCK is a functional and potent

construct, particularly for teacher education (Oh & Kim, 2013). It has served as a theoretical framework for examining teacher knowledge by a number of researchers (e.g. Cochran, King & DeRuiter, 1991; Padilla & van Driel, 2011). Also, it has been pointed at as an essential knowledge base necessary in preparing pre-service science teachers (Anderson & Mitchener, 1994) for effective teaching. It has also been observed to have a strict connection with improving students' comprehension of concepts learnt in the classroom (Mansor, Halim & Osman, 2010). Likewise, PCK and its components give science education researchers the opportunities of designing and exploring structures that help teachers to improve their quality of teaching (Findlay & Bryce, 2012). However, Nezvalova (2011) agues a range of accounts that describe and define PCK have placed little importance on its development. This calls for examining Taxonomies of PCK with different levels of development and features.

2.3.1 Taxonomies of PCK leading to its topic specificity

This discussion on PCK taxonomies is provided to establish the need for developing TSPCK particularly in pre-service teachers and to show how that is different from the generally known broader PCK. Generically, PCK has been taxonomically grouped into the main categories including the general PCK; domain-specific PCK and topic-specific PCK (Veal and Makinster, 1999). The general PCK describes the understanding a teacher demonstrate regarding pedagogical techniques of teaching in a discipline like science or art (Nezvalova, 2011). Conceptualizations based on this general PCK were made in an attempt to describe the nature of PCK. While some show teacher CK very clearly (e.g. Cochran, DeRuiter, and King, 1993) in some other conceptualizations CK appears hidden (e.g. Magnusson, Krajcik and Borko, 1999). These models nevertheless describes PCK construct in the broad sense and hence they could not be used so directly in this study since the target here is the topic specificity of PCK in a physics topic. Similar to that is the domain-specific PCK which targets different domains or subject matter within a specific discipline like science (Veal & Makinster, 1999). For instance, Magnusson *et al.* (1999) PCK model is noted to have been well referred to in science subject areas like biology (e.g. Juttner & Neuhaus, 2012), chemistry (e.g. Tepner & Witner, 2011). It reveals descriptions of PCK components in such a way that they are science specific. An example includes the components science curriculum, knowledge of science, orientation to science (Jing-Jing, 2014). Nevertheless, such a PCK model could not be employed in its original

form as a theoretical framework for this study since the focus here is on the topic specific nature of PCK with emphasis on the transformation of CK.

With increasing work on PCK for teachers and records of research studies, there is wide-spread understanding that PCK is topic-specific (Abell, 2008; Aydin *et al*., 2014). In supporting that, Mthethwa-Kunene, Onwu and de Villiers (2015) argued "*PCK is construed as the blending of topic-specific content knowledge, pedagogical knowledge and knowledge of students' preconceptions and learning difficulties*" (p. 1143). Moreover, the topic-specific PCK, which happens to be associated with the topics such as kinematics, electric circuits and so on, is the last category in the PCK taxonomies (Veal and Makinster, 1999). With respect to that, Veal and MaKinster (1999) argued "*the most specific and novel level of the general taxonomy (of PCK) is topic specific PCK*" (p. 9). Commenting on the importance of that, Nezvalova (2011) is of the opinion that based on a theoretical assumption, once a teacher is able to have knowledge in the topic-specific PCK category; there is possibility that such teacher could demonstrate sound understanding and competence in the previous categories. Thus, this study adopts a construct that examines PCK at a specific topic level for developing pre-service teachers' PCK in a physics topic to enhance their pedagogical transformation competence in the topic.

2.4 Model of TSPCK as a theoretical framework in this study

The Mavhunga's (2012) TSPCK model serves as the theoretical framework in this study. This TSPCK construct is based on the Shulman's arguments that: "*comprehended ideas must be transformed in some manner if they are to be taught*" (Shulman, 1987, p. 16). Central in this argument is the teachers' ability to transform content knowledge (CK) in a specific topic all towards making the concepts within the topic understandable for students. This means possession of sufficient CK is very important to be able to apply correctly pedagogical transformation skill (Oh & Kim, 2013). In connection to that, Aydin *et al*. (2014) argued the main questions with PCK "*remain regarding how teachers transform their subject matter knowledge (SMK) of different topics into PCK for teaching different topics in the same discipline*" (p. 658). This is also supported by Geddis, (1993) as well as Gess-Newsome (1999a) opinion that a teacher is required to be aware of the importance of transforming subject matter knowledge so as to enhance learning. This argument has been the basis of a number of research

studies in PCK leading to the commonly accepted verdict of its topic specific nature (Rollnick and Mavhunga, 2014). The TSPCK model is shown in the Figure 2.1 below.

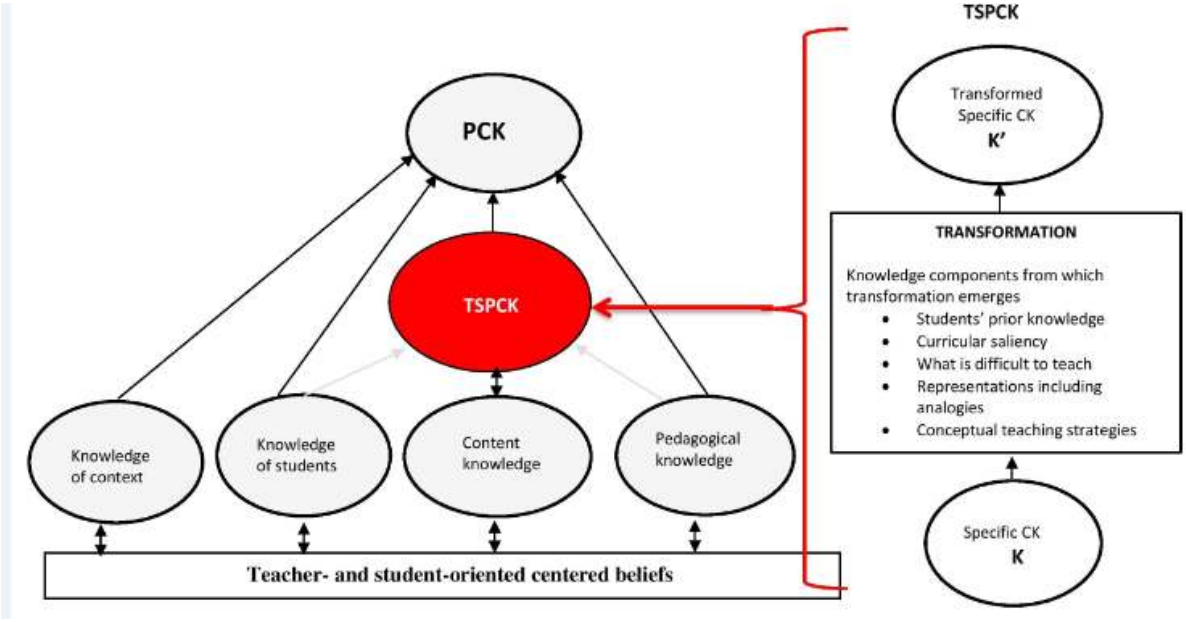


Figure 2.1: Mavhunga's (2012) TSPCK Model

As shown in the Figure 2.1 above, the entire left-hand side illustrates PCK model that considers four generic knowledge domains from which a teacher draws to make his/her PCK. These knowledge domains, as derived from PCK model conceptualized by Davidowitz and Rollnick (2011) include: knowledge of context; knowledge of students; content knowledge; and pedagogical knowledge. The knowledge domains are also observed to have been identified with the Grossman's (1990) model pointing out they are subjected to teacher beliefs of the concepts being taught in the classroom. As indicated in the left-hand side of the diagram, there is a direct link from only three of the knowledge domains to the TSPCK. These knowledge domains are knowledge of students (KS), content knowledge (CK) and pedagogical knowledge (PK). The KS and PK have been observed to be similar to the TSPCK knowledge students' prior knowledge and conceptual teaching strategies. In addition, the significance of teachers' content knowledge (CK) cannot be overemphasized in this study looking at the pedagogical transformation process with the assumption that CK is necessary for PCK development (Kind, 2009). Meanwhile, the whole of the right-hand side of the Figure 2.1 above describes how the pedagogical transformation occurs. In a topic, when a teacher thinks and reasons about a

specific content knowledge CK tagged K (shown in the bottom circle) using the five knowledge components (shown in the square on top of the bottom circle) then a special understanding for teaching the concepts emerges. These knowledge components are: students' prior knowledge (otherwise called 'learner prior knowledge with misconceptions' **LPK**); curricular saliency (**CSA**); what is difficult to teach or understand (**WDT**); representations including analogies (**REP**); and conceptual teaching strategies (**CTS**). Geddis (1993) had earlier identified these knowledge components and referred to them as the 'multitude of particular things' (p. 676) with which transformation of content knowledge is made easy thereby enhancing teachability of the specific topic. These knowledge components of TSPCK that bring about transformation have been referred to as the '*content-specific components*' (Mavhunga & Rollnick, 2013) because of their connection with the teachers' content knowledge.

Similarly, the content-specific knowledge components were discovered in transforming CK in a specific mathematics topic as discussed in the previous section and they have been referred to as the 'Specialized Content Knowledge' (Ball, Thames & Phelps, 2008) specific to a particular mathematics topic. The specialized content knowledge include understanding prior conceptions and misconceptions of students; recognizing major concepts in a topic, selecting certain strategies for explanation or analogies to enhance students' understanding of the topic (Ball et al., 2008). Equally, the study by Luft *et al*. (2015) which argued for knowledge for science add to empirical data demonstrating TSPCK as valued construct and, a construct concerned with teachability of topics. Consequently, in teaching a science (physics in this study) topic, the knowledge or understanding produced, as a teacher reasons soundly through these knowledge components, is the 'Transformed specific CK' tagged K' as shown in the Figure 2.1 above. This is specific to the topic in which the transformation of CK takes place and it is referred to as the 'Topic Specific Pedagogical Content Knowledge' (TSPCK) (Mavhunga, 2012). This understanding allows considering topic by topic in a subject (physics) with little concentration on the entire knowledge domains that affects PCK at a generic level (Rollnick & Mavhunga, 2015). This as a result distinctively differentiates TSPCK from the previously examined generic PCK at a discipline and subject levels as it targets a specific topic in a subject. Hence, in this study, in accordance with the argument by Park, Jang, Chen, and Jung (2011), the quality of pre-service teachers' TSPCK in a particular physics topic is considered to be under the influence of the understanding of the five content-specific knowledge components and their interactions.

While TSPCK construct has been extensively used in chemistry topics with pre-service teachers (Mavhunga & Rollnick, 2013), efforts are made in this study to further validate the construct. This is because this study targets pre-service teachers' quality of TSPCK in physics topics unlike in chemistry topics. In that regards, the discussions above could be said to have established interpretative argument to validate (Kane, 2013) the construct of TSPCK which serves as the theoretical framework in this study. There have been explained, underlying principles guiding the construct as well as the associated assumptions regarding the construct. Nevertheless, Messick (1989) argued for the need to establish a validity argument of a construct in addition to the interpretative argument. Such a validity argument explains how plausible and coherent the established interpretative argument regarding a construct is (Downing, 2003; Potter & Levine-Donnerstein, 1999). For this purpose, statistical methods using Rasch Analysis Model have been employed to validate TSPCK kinematics tool (Boone, Staver & Yale, 2014) used in measuring pre-service teachers' quality of TSPCK in the topic. Detailed information on this is provided in the next chapter, chapter 3. Nevertheless, the acceptance of this TSPCK construct is not without the international agreement of PCK educational researchers. This consensus is discussed as follows.

2.4.1 PCK Consensus Model

As a way of reaching some level of agreement regarding various conceptualizations of PCK, a worldwide group of PCK researchers put up an agreed model referred to as the 'PCK Summit Consensus Model' (Gess-Newsome, 2015, p. 31) shown in the Figure 2.2 below. This was done to ensure that general understanding about PCK is modified to considering PCK as being topic specific. As a result, embedded in the consensus model is the construct referred to as the 'Topic Specific Professional Knowledge' (Gess-Newsome, 2015). This construct has a similarity with the Topic Specific PCK which serves as the theoretical framework in this study. The significance of the PCK summit consensus model to this study is that it recognizes PCK as being topic specific and emphasizes methods of understanding content knowledge to enhance learning.

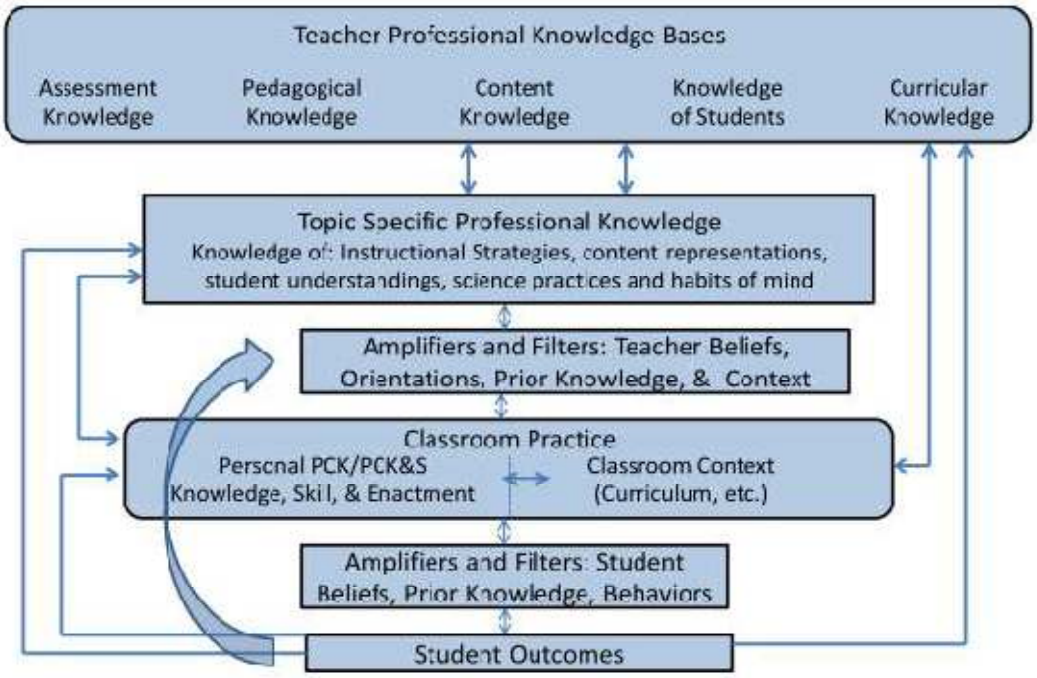


Figure 2.2: Model of teacher professional knowledge – Consensus PCK Model

The consensus PCK Model as shown in the Figure 2.2 above shows the knowledge base for teaching theorized by Shulman (1986, 1987) as the origin. It resembles a complex version of all the PCK models (Kind, 2015) acknowledged but not discussed in detail in this study, as the focus is on Topic Specific PCK. The model indicates the connection between teacher knowledge for teaching as a profession, their actual classroom teachings and the student outcomes. This illustrates an excellent way of picturing what the teacher knows and how it comes into classroom with significant influence on the students' understandings. Embedded in the 'teacher professional knowledge bases' (TPKB), the first stage in the model, are the various teacher knowledge domains: the assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students and curricular knowledge (Gess-Newsome, 2015). Noticeably, the pedagogical content knowledge (PCK) is not part of this first stage. This stage is linked to the Classroom practice and student outcomes.

The second stage of the consensus PCK model is tagged 'Topic Specific Professional Knowledge' (TSPK) (Gess-Newsome, 2015) comprising of the 'knowledge of instructional strategies, content representations, student understandings, science practices, and habits of mind'

(Gess-Newsome, 2015). The Topic Specific PCK model constructed by Mavhunga (2012) on which this study is based, fits into this second stage. Emphasis is better placed on the specificity of topic and "the more Topic Specific professional knowledge reduces the dominance of generalized canonical PCK" (Kind, 2015, p. 193). This equally distinguishes the Topic Specific PCK from the general PCK. Also, the arrows in the consensus model indicate that the TSPK is informed by and interconnected to the TPKB. This implies that the place of teacher content knowledge (a component of TPKB) cannot be over-emphasized in the course of developing pre-service teachers' Topic Specific PCK (embedded in TSPK). This second stage is linked to the classroom practice as the student outcomes.

Thus, the discussions above support such a demonstrated model (like TSPCK construct used in this study) for how to implement TSPCK in pre-service teachers – resulting in improved quality of TSPCK in core physics topics long before they become qualified teachers – contradicting the understanding that PCK and by association, TSPCK is developed over time in practice (Loughran, Berry & Mulhall, 2004). Based on arguments for the significance of TSPCK construct, this study is of two important theoretical propositions. The first theoretical proposition is that an intervention, which entails explicit discussions of five content-specific knowledge components in a specific topic, contributes to the development of quality of TSPCK in that topic. The second theoretical proposition is that following such explicit discussions, there is learned pedagogical transformation competence which first is used to develop TSPCK in the topic of the intervention itself, and thus the exploration to determine transferability of this competence to a new topic.

2.5 Planning versus enacting instruction using Topic Specific PCK

This study is aware that PCK is observed mostly in the classrooms while teachers carry out their teaching activities. However, it is important to re-emphasize that teaching is about pedagogical transformation of CK which entails reasoning through concepts in specific topic in a particular way. In the Shulman's (1987) explanation of teachers' pedagogical reasoning, transforming content knowledge first happens in the planning context, a stage proceeding actual classroom teaching. He argued "*All these processes of transformation result in a plan…….Pedagogical reasoning is as much a part of teaching as is the actual performance itself*" (Shulman, 1987, p.

17). This shows the significance of developing pedagogical transformation ability of pre-service teachers who are still in the process of taking up teaching as a profession. In connection to that, Taylor-Thomas (2010) shared the same view by stating that "*transformation is the key to understanding the intersection of content and pedagogy and the teachers' capacity to convert content knowledge into pedagogically powerful knowledge*" (p. 75). So, what is eventually observed in the actual classroom teaching is a product of the transformation that takes place at the planning stage. While teachers' PCK in the planning context is called espoused PCK (Park & Oliver, 2008) the pre-service teachers' TSPCK in a specific topic as observed in the planning context is similarly tagged 'espoused TSPCK'. This espoused PCK as majorly observed in this study eventually serves as guidance to teachers in making decisions that have to do with teaching concepts in a specific topic, choice and use of representations and instructional strategies (Park & Oliver, 2008). Thus, this study investigates pre-service teachers' quality of TSPCK in kinematics in the planning context and transferability of learnt pedagogical transformation competence in planning a new physics topic (electricity) as well.

With the benefit attached to improving pre-service teachers' pedagogical transformation competence in the planning context, Aydeniz and Kirbulut (2011) however argued, that teachers have such espoused PCK does not guarantee the use in the actual classroom teaching. Baxter and Lederman (1999) too added that PCK is not limited to what teachers know but it is as well embedded in "*what a teacher does*" (p. 158). When that kind of knowledge teachers possess in the planning context get enacted and observed in their actual classroom teaching then it is referred to as the enacted PCK (Park & Oliver, 2008) and thus pre-service teachers' enacted TSPCK in this study. As described by Nilsson and Loughran (2012), PCK is a widely accepted unique form of teacher knowledge that expands on constant basis as teachers plan, carry out and reflect on science teaching and learning. This means examining pre-service teachers' at both planning and actual delivery of lesson are most important. As a result, as this study explores pre-service teachers' TSPCK in planning kinematics and electricity, efforts were also made to investigate their understanding of interactive use of TSPCK components in the actual classroom teaching.

2.6 Knowledge of TSPCK Components in teaching physics topics (kinematics and electricity)

2.6.1 Learner Prior Knowledge (LPK)

The Learner prior knowledge (LPK) as a component of TSPCK involves teachers' knowledge of students' preconceptions including misconceptions. Shulman (1986) referred to it as the teacher knowledge of students comprising "*an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and background bring with them to the learning of those most frequently taught topics and lessons*" (p. 9). Similarly, some other studies have considered it as the teacher knowledge of students' understanding (Grossman, 1990; Park & Oliver, 2008). That means LPK consists of students' knowledge from their preceding lessons or teachings as well as knowledge acquired impulsively and experientially through everyday occurrences (Rusznyak & Walton, 2011). Aydin and Boz (2013) further argued that a teacher with PCK demonstrates its component of learner knowledge when there is awareness of learners' pre-requisite knowledge, difficulties as well as misconceptions. Supporting the importance of LPK, Can and Yezdan (2011) stated a situation whereby fresh knowledge is constructed with no link to the prior knowledge, results in no meaningful students' learning and hence no comprehension. With regards to physics teaching, Urban-Woldron (2014) advised in order to have an insight into the learners' understanding, it is important for teachers to be aware of what learners do not know and their kinds of alternative conceptions. For instance, the noticeable learners' misconceptions about electricity include: the idea of no bulb lights on if the switch is off in a circuit, associated with the interpretations in everyday language (Kucukozer & Kocakulah, 2007); no influence of either increasing or decreasing total resistance on the brightness of a bulb in connected in series or parallel (Ipek, Hava & Calik, 2008). Widely reported in the literature are other learners' misconceptions that in electrical circuits current is consumed (Arnold & Millar, 1987; Lee & Law, 2001), battery is the source of constant current rather than a constant voltage source (Licht & Thijs, 1990; McDermott and Shafer, 1992; Duit & von Rhoneck, 1997) and interchangeably use of electricity e.g. voltage for current and vice versa (Engelhard & Beichner, 2004). These are not without links to the teachers as Kucukozer and Demirci (2005) pointed out the fact that these misconceptions are

observed with learners particularly during classroom instruction has to do with the extent to which teachers themselves hold the same misconceptions.

Consequently, a number of science education researchers have made efforts to stimulate pre-service teachers' interest in learning about how students reason, their preconceptions and misconceptions. Examples include such studies that focused on developing pre-service teachers' PCK (e.g. Heller, Daehler, Wong, Shinohara & Miratrix, 2012; Mavhunga & Rollnick, 2013; Hanuscin, 2013). Zhou, Wang & Zhang (2015) argued since pre-service teachers do not really have many classroom teaching experiences, they could only accumulate an appreciable understanding of students' preconceptions and knowledge in the course of their teacher education programs. While Park and Oliver (2008) were studying PCK as a tool to understand teachers as professionals they found out that the teachers placed great emphasis on students' misconceptions in their planning and enacting of a particular topic and as a result their PCK expanded. They argued "*as teachers developed better understanding of students' misconceptions, their PCK became more sophisticated*" (Park & Oliver, 2008, p. 275). This implies that developing PCK is associated with teachers' understanding and considerations of students' misconceptions in teaching. Also, while Mthethwa-Kunene, Onwu and de Villiers (2015) were exploring teachers' PCK in the topic of Genetics, they found out that although the participants employed diverse teaching strategies, they commenced their lessons by using the questioning technique. This was observed to have helped the teachers in linking previous concepts to the new ones thereby enhancing students' learning (Mthethwa-Kunene *et al*., 2015). On the other hand, (Halim & Meerah, 2002) in their studies found out that pre-service teachers, in teaching science topics, are most times unaware of students' difficulties and misconceptions. In support of that, (Ozden, 2008) argued the most essential educational gap observed in the student teachers was an understanding of their students' knowledge of science. In filling the gap (Rusznyak & Walton, 2011) suggested that attentions of pre-service teachers should be "*drawn to what common misunderstandings or mistakes learners might make and what examples could be used to expose and explicitly explore such misunderstandings*" (p. 277). This has been attested to as an important part of effective teacher knowledge (Geddis 1993). This shows how important it is guiding pre-service teachers in building ability to explore learner prior knowledge in their teaching.

2.6.2 Curricular saliency (CSA)

Curricular saliency is also a component of TSPCK necessary for teachers to understand in teaching a particular topic. The discussions on the component of curricular saliency are based on three aspects (i) structuring the topic into its Big Ideas (ii) reflecting on the pre-concepts that are needed and lastly (iii) the sequencing of the big ideas in teaching the topic. With reference to the broad PCK, Geddis, Onslow, Beynon and Oesch (1993) integrated 'curricular saliency' as part of the knowledge components. In the TSPCK construct, curricular saliency encompasses teacher knowledge of core and peripheral concepts that enhances transformation of specific content (Rollnick & Mavhunga, 2014). Likewise, Geddis and Wood (1997) consider this component as the teachers' knowledge of the arrangement of topics in the curriculum, the concepts that should come before and during teaching of the topic and after. Also, this component entails teachers' understanding of identifying big and subordinate ideas and ranking them in sequential order of presentation appropriately. Big ideas are referred to as the science ideas that the teacher consider central for the development of students' comprehension in that concept or topic (Loughran, Berry & Mulhall 2012). Also, the teacher's awareness of the foundational topic that students ought to learn before the current lesson (topic) is an essential component that influences learning and bring about students' conceptual understanding.

In teaching kinematics, Lichtenberger and Wagner (2014) as well as Giancoli (2005) identified the central necessary for learners to know which include the concepts of: displacement as an area under the curve obtained in a velocity versus time graph; velocity and acceleration as vector quantities because of their magnitudes and directional properties; speed as a scalar quantity because it has magnitude only. While showing the importance of linking pre-concepts to the concepts to teach Rane (2015) pointed out that, learners must well understand the concepts of displacement versus time graph, velocity versus time graph for them to reasonably interpret instances like that of projectile motion. Likewise, Tarsar (2010) also added that learners' understanding of increase in the magnitude of velocity enhances their understanding of the impact on the acceleration which thus helps in making out of the related graph of such concepts. As much as concepts in kinematics are concerned, it is required of learners to adequately understand scalars and vectors with respect to direction and magnitude (Wutchana, & Emarat, 2011). In the case of electricity, the reported important concepts include: current, consisting of

the flow of electric charges, voltage, ohm's law (Trudel & Metioui, 2012); electric circuits as the path for flow of electric charges involve circuits' elements (Licht & Thijs, 1990); electromotive force and terminal potential difference (Kucukozer & Kocakulah, 2007) and resistors with their resistances (Shipstone & Cheng, 2001) to mention a few. Included in the list of basic concepts for learners to understand is the knowledge that materials naturally contain charges and understanding terms the three terms current, voltage and resistance (Duit & von Rhoneck, 1997). The need for teachers to made learners understand the behavior of electrons and charges at microscopic level when teaching the concepts of electricity was also pointed out (Korganci, Mirona, Dafineia, & Antohe, 2015).

With regards to that all these, Loughran et al. (2012) argued "*expert science teachers use this knowledge and information to shape the manner in which they teach particular concepts….without this feature of PCK it could well be argued that teaching is not genuinely responsive to constructivist views*" (p. 13). This assists teachers while planning their lessons with regards to the time that should take teaching a particular aspect of a topic as well as the extent to which the concept should be taught. Consequently, developing pre-service teachers' understanding of curricular saliency helps them in understanding necessary concepts in a topic learners are expected to know and the order in which they should be taught. Mthethwa-Kunene *et al*. (2015) in their investigations of teachers' PCK in Genetics found out that the participant understanding of curriculum influenced their PCK, served as their knowledge source and guided their planning and sequencing of the contents. Similarly, Penuel, Gallagher and Moorthy (2011) indicated that teachers' knowledge of curricular plays a significant role in improving outcomes of science teaching and learning. Thus, pre-service teachers' knowledge of curricular saliency has the tendency of enhancing their TSPCK in the topic.

2.6.3 What is difficult to teach (WDT)

This comprises of teachers' knowledge of gate-keeping concepts in a specific topic and ability to identify concepts that might be difficult either to teach or for learners to understand. While describing this component, Zhou *et al*. (2016) argued "*the ability to predict students' ideas or performances is commonly seen as an indicator to measure teachers' knowledge of students' difficulties and misconceptions*" (p. 376). Understanding such concepts in addition calls for teachers' knowledge of possible reasons for the difficulty with regards to learners'

misconceptions and prior knowledge. With regards to that, learners' difficulties in kinematics as reported in the literature include: (i) inability to conceptually understand continuous change in motion of objects (Oon & Subramanian, 2012); (ii) difficulty in differentiating between instantaneous and average quantities like speed and velocity as they have different meanings when used in different contexts (Sengupta & Farris, 2012); (iii) problems with comprehending negative velocities and how to link them to physical situations, interpreting position-time graph, speed/velocity-time graph (Eriksson, 2014) (iv) inability to differentiate between distance versus displacement, speed versus velocity with the thoughts that each pair has the same meaning and can be used interchangeably Antwi, Hanson, Savelsbergh and Eijkelhof (2011). A related case is that of aspects of circular motion reported to be difficult (Meyer, 2012) such that: learners subconsciously use velocity as a synonym for speed (McLaughlin, 2006); learners assume acceleration of $0m/s^2$ only means the object is stationary (Antwi et al., 2011); learners think a body undergoing circular motion having constant speed must have acceleration of $0m/s^2$ not considering changes in velocity (Antwi et al., 2011) and so on. In addition, Jager (1987) found out that learners' have difficulty understanding concepts of velocity and acceleration because of their vector nature. Reif and Allen (1992) also reported learners' difficulty is embedded in their in ability to differentiate between the two concepts. The difficulty in conceptualizing velocity and acceleration was also traced to learners' confusion with the 'rate' and 'rate of change' as used in describing both concepts.

Furthermore, in the physics topic of electricity, Kucukozer and Kocakulah (2007) pointed out learners do have difficulties understanding the effect of 'switching on and off' on other components in an electric circuit. The authors associated this difficulty to everyday use of the words. According to the authors learners believe that no light bulb lights on if switch is off because "in everyday language, expression such as '*close the switch*' to light off a lit bulb and '*open up the switch*' to lit the bulb are used" (p. 107). Also, there is also a record of learners finding it challenging to understand that battery as one of the electrical components does not produce current (Urban-Woldron, 2014), difficulties in considering a circuit as a system such that for instance increasing resistance affects the equivalent resistance in the whole circuit (Dupin & Johsuam, 1987). Further pointed out are the learners' difficulties in identifying diagrammatic representations of series and parallel connections (Caillot, 1985) and inadequate understanding and application of the concepts of a complete circuit (Engelhardt & Beichner,

2004). Thus, teacher knowledge of difficulties students encounter in learning particular concepts has been widely singled out as an essential component of PCK which is worth investigating thoroughly (Depaepe, Verschaffel & Kelchtermans, 2013) and thus necessary for pre-service teachers. Shulman (1986) argued expert teachers reasoned through their teaching by reflecting on their personal difficulties as teachers. Mthethwa-Kunene et al. (2015) in their study found out that all the observed teachers pointed out difficulties related to the: terminology of genetics; comprehending processes of cell division; and abstract nature of some aspects of the concepts with the comments that those are not readily visible as students only learn their definitions. Also, Nilsson and Loughran (2011) reported considerable improvement with professional teachers on the aspect of what is difficult for learners to understand while examining the teachers' PCK. However, while Usak, Ozden and Eilks (2011) were investigating beginning science teachers' PCK they found out that, five out of eight teachers did not show evidence of being conscious of the conceptual difficulties their learners might face in studying chemical reactions. This shows how important it is developing pre-service teachers' understanding of WDT.

2.6.4 Representations (REP)

Representations with use of analogies as one of the components of TSPCK require that teachers demonstrate understanding of the use of different levels of representations in explaining concepts of a topic. These forms of representations have been reported to include micro, sub-micro, macro and symbolic representations (Cheng & Gilbert, 2009). Commonly in teaching physics topics forms of representations are found in practical demonstrations with the use of laboratory equipment, use of models, charts, diagrams, scientific and mathematics equations (Carrejo & Marshall, 2007) and so on. While Shulman (1986) was addressing PCK as it relates to the teaching of a topic he described it as "*the most useful forms of representation…the most powerful analogies, illustrations, ….demonstrations…..ways of representing and formulating the subject that make it comprehensible to others*" (p. 9). This shows how connected pre-service teachers' PCK in a specific topic is to their understanding of the use of representations. The use of representations motivates learners' interest in learning by engaging their minds in constructive and critical thinking (Prain & Tytler, 2012) resulting in sound comprehensive long-term learning outcomes (Olaleye, 2012). While indicating how important representations are in teaching

physics, Rane (2015) argue "*if the graphical representations of the displacement versus time, velocity versus time, and acceleration versus time, are not understood correctly, students cannot use them for deductive reasoning of related cases scenarios like tossing the ball, projectile motion***"** (p.1). This implies that learners' understanding of how graph representations enhances their ability to interpret in some other instances that call for the understanding. Tarsar (2010) added that utilization of analogies helps in anchoring learners' understanding how velocity is related to acceleration. Similarly, Carrejo and Marshall (2007) proposed the use of representations such as diagrams, tables, graphs and arrows in bringing about learners' conceptual understanding of kinematics concepts. Moreover, in teaching the topic of electricity, Shipstone and Cheng (2001) indicated the use of diagrams combined with the knowledge of Ohm's law would help learners in solving various problems related to the concepts. Metioui and Trudel (2012) pointed out the various forms of analogies help in enhancing learners' understanding of the concepts of current and voltage. A number of researchers (Cutis and Reigeluth, 1983; Korganci et al., 2015) also found out that use of pictures, models, charts and analogies is effective in making learners understand abstract aspects of electricity like flow of charges at both macroscopic and microscopic levels. Engelhardt and Beichner (2004) also pointed out that schematic diagrams are used in electricity as representations for circuits' elements and their behaviours. The authors added that learners' ability to recognize what these diagrammatic representations mean stands as an essential part of their understanding of electric circuits (Engelhardt & Beichner, 2004, p. 98). This is showing how important teachers' knowledge and use of representations is in teaching. While Mthethwa-Kunene et al. (2015) were examining experienced teachers' PCK in Genetics, they reported teachers used pictorial chats and labelled diagrams illustrating factual information about the concepts and also to assist students to visualize the more abstract concepts and comprehend relationships between concepts of chromosomes, gene and allele. This shows how important it is developing pre-service teachers' understanding of the use of REP in both planning and actual teaching.

2.6.5 Conceptual teaching strategies (CTS)

The conceptual teaching strategy draws on other four TSPCK knowledge components (Mavhunga, 2012). In this case, a teacher with the knowledge of CTS demonstrates an understanding of learner prior knowledge, addressing misconceptions combining two or more

different forms of representations. At the same time, the teacher has in place the knowledge of important concepts in a topic with appropriate sequencing to enhance learners' understanding. This is of strategies for conceptual understanding rather than general pedagogy, logistics and memorization. In other words, just teaching techniques or general pedagogical approaches alone cannot guarantee learning (Loughran *et al*., 2012) but "*informed and thoughtful use in appropriate ways at appropriate times can influence students thinking and may well promote better understanding of science ideas*" (Loughran *et al*., 2012, p. 15). Such an informed and thoughtful teaching strategies combine all the components of TSPCK already discussed. While Mthethwa-Kunene et al. (2015) were exploring experienced teachers' PCK in teaching the topic of Genetics, they found out that the topic-specific instructional strategies employed by the teachers included the use of analogies, illustrative diagrams, questioning techniques and sequencing of content to teach genetics. This shows the teachers' understanding of the use of representations and knowledge of an aspect of curricular saliency. Hence, it is of benefits developing pre-service teachers' knowledge of CTS.

2.7 Interactions of PCK (TSPCK) components as a measure of its quality

There is a consensus in the literature that a teacher needs to incorporate components of PCK in a logical manner in planning and enacting teaching (Mehmet & Zubeyde, 2014). Friedrichsen, Driel & Abell (2011) argued various PCK models have been able to identified different kinds of PCK components without explicit indication of interaction of the components with each other. However, it is important that studies specify clearly the simultaneous use of PCK components by teachers to enhance students' understanding of the concepts being taught (Park & Chen, 2012). Similarly, Abell (2008) is of the opinion that PCK is not the sum of the individual components rather their interactions, likewise I do not consider TSPCK to be the sum of more components but the interactions as alluded in agreement with Aydin, Demirdogen, Akin, Uzuntiryaki-Kondakci and Tarkin (2015). Furthermore, Krauss and colleagues (2008) argued that teachers' level of PCK is determined by the extent to which the components integrate coherently in the classroom teaching. Park and Oliver (2008) also added that "*the enactment of PCK within a given lesson requires a teacher to integrate different components of PCK*" (p. 278). So determining the quality of a teacher's PCK entails observing the manifestations and nature of interaction of PCK components. As argued by Rollnick, Bennett, Rhemtula, Dharsey and

Ndlovu (2008), effective teaching is associated with the teachers' quality of PCK. They further emphasized the need for the teacher to integrate knowledge of all various domains individually so as to create successful learning opportunities for students. Mthethwa-Kunene et al. (2015) linked teachers' ability to integrate PCK components in this way to their adequate understanding of individual components. I therefore point the same for pre-service teachers' interactive use of TSPCK components as evidence of their quality of TSPCK.

Using TSPCK construct, Mavhunga and Rollnick (2013) explored pre-service teachers' development of TSPCK in the chemistry topic of chemical equilibrium. The participating pre-service teachers were taken through an intervention in which explicit discussions on TSPCK knowledge components were held. The pre-service teachers after the intervention were reported to have improved in their ability to reason about the teaching of the topic. This improvement in reasoning was observed to have been as a result of their knowledge of interactive use of TSPCK components demonstrated (Mavhunga & Rollnick, 2013). They reported that the pre-service teachers' found TSPCK component LPK least difficult and component CTS to use interactively with other components. Similarly, Mavhunga (2015) studied the nature of interactions among TSPCK components of pre-service teachers in two chemistry topics of chemical equilibrium and particulate nature of matter. From the pre-service teachers' written work, nature of components was described in the study by identifying TSPCK episodes using maps to represent them. It was found out that (i) in the two topics, the interaction majorly occurred among three components which include: curricular saliency; representations; and learner prior knowledge or what is difficult to understand (ii) there were two cases of interaction of the component of conceptual teaching strategies with other components (Mavhunga, 2015). The interaction in the first instance was reported to have taken place in such a way that the components that interacted and their links were clearly identifiable (Mavhunga, 2015). This confirms the argument by Park and Chen (2012) that PCK is more than the sum of the individual components but also the extent in which they interact. All these evidence from previous studies implying that for a successful teaching to take place, a lot of thinking and transformation of contents must have gone into planning context before actual delivery of the lesson. Hence, helping the pre-service teachers through transforming content knowledge in Kinematics is of great advantage in teaching some other physics topics.

Using some other PCK constructs, quite a number of studies have investigated in what way components interaction occurs to give the entire PCK a structure. Aydin et al. (2014) carried out a study that examined the topic specific nature of pedagogical content knowledge in teaching electrochemical cells and nuclear reactions. They found out that the observed teachers' use of representations made their content more concrete and visual to the students (Aydin et al., 2014). They referred to this as the evidence of teachers' PCK within the topics which enhanced learners' conceptual understanding. They stated that the teachers were observed using "*a lot of Topic Specific analogies in their teaching*" (Aydin et al., 2014, p. 669). In terms of the observed teachers' knowledge of the curriculum, they found out that the teachers had a highly integrated knowledge of how topics were integrated across the horizontal and vertical curriculum (Aydin et al., 2014). Aydin and Boz (2013) examined the integration of PCK components of two experienced teachers teaching chemistry topics of redox reactions and electrochemical cells. They found out that: (i) the teachers showed awareness of the pre-requisite knowledge that learners need, the topics taught in the previous grades and the previous chemistry topics; (ii) knowledge of curriculum and knowledge of assessment were the components that were less frequently connected to other PCK components; (iii) Knowledge of instructional strategies and Knowledge of learner i.e. learner prior knowledge had more connections among other components (iv) the teachers could identify students' misconceptions and difficulties but there was no evidence of implementing strategies to confront such. Based on the findings, they brought up an argument that *"….experience does not make all PCK components expand; therefore, teachers need support through professional development……..Additionally, it is clear that the development of one component does not mean that others develop as well*" (p. 623). With respect to that, Abell (2008) is of the opinion that PCK is more than one, two or an addition of its components. Similarly, Park, Jang, Chen and Jung (2011) examined how two components of PCK (Knowledge of student understanding, KSU and Knowledge of instructional strategies and representations, KISR) and reform-based science teaching interconnected. The study was conducted in the topic of photosynthesis and heredity. It was found out that interrelatedness of the two PCK components (KSU and KISR) had positive impact on the reformed science teaching (Park et al., 2011). Also, Park and Chen (2012) further investigated PCK of four biology teachers in the topics of photosynthesis and heredity. They found out that "*another salient pattern in the synthesis of the PCK components was that knowledge of science curriculum (KSC)*

had the most limited connection with other components" (p. 937). The explanations provided by Park and Chen (2012) for the teachers' difficulty with KSC included: narrow perspective of curriculum as a collection of topics; and using the curriculum to select topics but hardly referring to its scope and sequence in preparing lesson plans. They suggested "*in order to support teachers' PCK development……. teachers should be given opportunities to analyze students' misconceptions and difficulties in learning a particular topic and then to connect the analysis results to practice*" (Park & Chen, 2012, p. 937). This could imply that taking pre-service teachers through understanding of TSPCK components has a way of developing their quality of TSPCK.

2.8 Transfer of pedagogical transformation competence

Research studies refer to PCK as tacit knowledge that a teacher gains in practice (Kind, 2009) and hence not the type of knowledge that a teacher can pass on to another teacher. This is also the same with the PCK in specific topic (i.e. TSPCK). The topic specificity of PCK makes it necessary to be learned for every topic as the TSPCK developed in a particular topic is only specific to that topic (Rollnick & Mavhunga, 2014). In that regards, the construct TSPCK gives the understanding required for the transformation of concepts in a topic and thus essential to be learnt for every topic (Mavhunga, 2014) a teacher plans to teach. Thus, the understanding of TSPCK knowledge components in a particular topic and the skill to use them interactively enhances the production of PCK which is specific to that topic. This kind of PCK is termed Topic Specific Pedagogical Content Knowledge, TSPCK which is PCK exclusively in the specific topic of concern (Mavhunga & Rollnick, 2013). As a result, expecting transferability of such knowledge seems to be contradicting the topic specific nature of PCK. Then, this calls for adequate understanding of the issue of transformation of content knowledge which is central in developing pre-service teachers' TSPCK. There has been a number of studies (e.g. Mavhunga & Rollnick, 2013; Mavhunga, 2015; Rollnick & Mavhunga, 2015) conducted with pre-service teachers using the TSPCK construct with regards to this. The studies have been able to establish that with the pre-service teachers, "*improvement in TSPCK through explicit discussion of a topic through the five components of TSPCK occurs when there is successful engagement with the concepts of a topic*" (Rollnick & Mavhunga, 2015, p. 142). This implies that for an improvement to have taken place, the pre-service teachers' understanding of collective TSPCK

components must interactively engage with the content and concepts in a topic. While engaging in explicit discussions of these knowledge components, knowledge and skills, which rest in using the components interactively, for pedagogical transformation of CK are learned. This has been termed the 'pedagogical transformation competence' (Rollnick & Mavhunga, 2015). It combines understanding of the knowledge components and their interactive use in explaining a concept in a particular topic. The sought after transfer is however not the transferability of TSPCK developed in the topic of kinematics as TSPCK is the product of the rigorous application of the transformation competence, but the understanding of both the knowledge of the TSPCK components and the skill to apply them interactively in engaging concepts in a topic (Rollnick & Mavhunga, 2015). So, what is transferable to a new topic is the learned pedagogical transformation competence (Rollnick & Mavhunga, 2015). In supporting this, Rollnick and Mavhunga (2015) argued that "*what is transferable to another topic is the ability to use the five TSPCK components, where successful engagement with the concepts of the new topic is still needed to improve TSPCK in the new topic*" (Rollnick & Mavhunga, 2015, p. 142). This means that the transferability of the learnt pedagogical transformation knowledge and skills comes to play in the pre-service teachers' ability to successfully engage the five TSPCK components (Rollnick & Mavhunga, 2014) while planning and teaching a new topic. From the psychological perspective, the pre-service teachers who are learning to teach could be considered students. In that context, Pea (1987) indicated that the concept of transfer is effective in assessing students' learning ability stating "*If students can only solve specific problems which they have been taught to solve in the classroom, and fail to solve related problems in a series, one would not attribute mastery of the material to them*" (p. 639). This implies that parts of the ways of considering how pre-service teachers utilize the knowledge acquired is by measuring to what extent they are able to transfer the knowledge on their own to a fresh situation context. In support of that, Vygotsky (1978) argued "*if someone learns to do any single thing well, he will also be able to do other entirely unrelated things well as a result of some secret connection*" (p. 82). Thus, helping the pre-service teachers through the transformation of content knowledge in kinematics using the Topic Specific PCK framework is developing their transferability competence firstly in the topic of discussion and - in planning another physics topic in doing so, they develop their TSPCK in the new topic (Mavhunga, 2014).

2.9 Gaps identified in the literature

One of the important issues most recently agreed upon is the topic-specific nature of PCK as indicated in the consensus model which defined canonical PCK (Gess-Newsome, 2015: Kind, 2015). However, few studies have established this topic-specificity by contrasting the PCK that a teacher develops for two different topics (Aydin et al., 2014). Indeed, there have been a number of studies that used the TSPCK construct in examining teachers' PCK in chemistry topics as already discussed above but little is known about studies that used the same construct in developing pre-service teachers' in physics topics particularly in the South African context. Similarly, Mavhunga (2015) argued while there have been studies that investigate how teachers' PCK components interact in a model like that of Park and Chen (2012), none has been done with such a model like that of TSPCK with emphasis on topic specific knowledge in its epistemological design. In support of that Park and Chen (2012) argued the "*nature and dynamics of the interaction among the components through which they are integrated into PCK have not been fully resolved*" (p. 923). Thus, this study is hoping to provide useful information on how explicit discussions of five knowledge components of TSPCK in a specific physics topic influences the of pre-service teachers' development TSPCK in the topic with evidence of interactive use of knowledge components. This study also focuses on expanding the literature on PCK through findings that show how pre-service teachers' learned pedagogical transformation competence in a specific physics topic (kinematics) is transferable to a new physics topic (electricity). These efforts target preparing pre-service teachers in preparation for effective teaching as part of the strategies addressing for addressing high school learners' difficulties with physics topics in the South African classrooms.

2.10 Conclusion

In this chapter, discussions on the related literature were provided with regards to the significance of developing pre-service teachers' TSPCK in physics topics in preparing them for effective classroom teaching. The problems this study targets to solve as well as the identified gaps in the literature were explained. This then calls for an appropriate research methods suitable for fulfilling the purpose of the study. Thus, the next chapter, Chapter 3 present discussions on the research methodology employed in this study.

CHAPTER THREE

3. RESEARCH METHODOLOGY

In this chapter, I present a full account of the methodological processes involved in this study. This begins by recalling the research problem and the formulated research questions guiding this study. Following that is the research design and its rational, the research strategy, participants and the intervention. The discussions are also provided on the data collection processes and techniques for analysis with the establishing of validity and trustworthiness of the measures. The explanations of the observed ethical issues in the study followed. The conclusive remark summarizes the whole discussions and projection into the next chapter.

3.1 Introduction and overview

Since quite a number of research studies have been carried out using the construct of TSPCK in chemistry topics (e.g. Mavhunga, 2012; Mavhunga & Rollnick, 2013; Pitjeng, 2014) and there are identified issues with effective teaching and learning of physics topics then I developed an interest in exploring pre-service teachers' TSPCK in physics topics. My study is carried out under a bigger research project at the University of the Witwatersrand targeting the implementation of Topic Specific PCK as a teaching strategy across Science and Technology Education Programmes. Based on the identified problems, this study purposefully explores how an intervention which explicitly discusses five content-knowledge components influences pre-service teachers' pedagogical transformation competence in a physics topic (kinematics) and possible transferability of such competence to a new physics topic (electricity) not discussed during the intervention. The quest for transferability is associated with the competence of understanding the categories of knowledge components needed and their interactive use in transforming CK in a specific physics topic. Thus, this chapter discusses the research design and methods employed in this study to achieve the stated purpose of the study. This involves all the arrangement put in place regarding the selection of participants, research sites, instruments for collecting data, kind of data collected, data collection procedures, methods of data analysis and ethical issues. The goal of this research design is to provide results that are judged to be credible (McMillan & Schumacher, 2010) in answering the research questions guiding this study. The formulated research questions which this study aimed at answering are: (i) what is the impact of

the intervention on the quality of pre-service teachers' TSPCK in kinematics? And (ii) to what extent is the pre-service teachers' learnt pedagogical transformation competence transferable to the development of TSPCK in a new physics topic - electricity?

3.2 Mixed Methods Paradigm

This study employed mixed methods as the research methodology. The term mixed methods as used in this study refers to "*an emergent methodology of research that advances the systematic integration, or mixing, of quantitative and qualitative data within a single investigation or sustained program of inquiry*" (Wisdom & Creswell, 2013, p. 1). This combines both quantitative and qualitative research methods. Using a quantitative method involves transforming data into a numerical form and analyzing by means of quantitative analysis techniques e.g. statistical methods (Azorin & Cameon, 2010). Meanwhile, qualitative method involves collecting data in textual or narrative form and analyze by employing qualitative data analysis techniques e.g. identifying recurring theme (Creswell, 2013). So, the philosophical assumption connected with the use of mixed methods in this study is situated within pragmatism as it combines detailed descriptions (qualitative) and numerical (quantitative) explanations of collected data in answering the research questions. Pragmatists do connect the choice of research approach directly to the nature of the study, research problems and the kind of research questions guiding the study (Creswell, 2012).

Choosing mixed methods in this study was based on three reasons. The reasons include: an underlying principle investigating an issue requires different research methods; the fact that this study explores a social issue; and the need of mixing both qualitative and quantitative methods in the process of analyzing the same data. First, it was based on the underlying principle that investigating an issue holistically from different perspectives requires different research methods. In support of that, Frels and Onwuegbuzie (2013) argued that the fundamental premise of mixed methods is that integration of the two methods involved may give a better understanding of the research problems and complex phenomena than individual approach does alone. So of all the factors that made a mixed methods approach preferable in this study is the offered opportunities to access multiple perspectives of the development of a complex TSPCK construct (Loughran, et al. 2012), specifically in a population (pre-service teachers) traditionally known to have poor PCK in general (Mavhunga & Rollnick, 2013). Furthermore, its ability to

extract aspects of the construct that cannot be reached by quantitative and qualitative means is singly desirable. Varied perspectives were accessible from the two approaches and so the use of the method provided a more complete investigation (McMillian & Schumacher, 2010).

Second, the mixed methods is further recognized to be of active roles in studies that explore social related issues and the significance of intervention programs in addressing such (Luft, Firestone, Wong, Ortega, Adams & Bang, 2011). In this study, the pre-service teachers were involved in the process of learning to teach by developing their PCK within a topic. Maries and Singh (2013) referred to such student teachers' learning as a social activity. As reviewed in the literature chapter, PCK is a specific knowledge of a teacher that must be learned. Thus, the pre-service teachers learn to develop as they engage in the process of learning to teach. Smith and Banilower (2015) attested to the argument that "PCK is a complex, multidimensional construct specific to a topic/idea" (p. 99) and hence, TSPCK in this study. So, developing pre-service teachers' TSPCK becomes a social issue as they learn to teach. As a result, the potent of using a mixed methods approach in this study is found in examining the complex nature of the pre-service teachers' PCK in the two physics topics (kinematics and electricity). Examining this basically encompasses the pre-service teachers' engagement of cognitive ability while reasoning through the components of TSPCK. This is based on their ability to apply the learnt pedagogical transformation skills in planning kinematics for conceptual understanding. Additional thing to that is the pre-service teachers' transferability of the learnt pedagogical transformation competence in planning and teaching a new physics topic (electricity) not discussed in the intervention. Such an examination requires a research design that gives an in-depth understanding with valid reasons and evidence. This makes a mixed methods design most appropriate in this study.

Third, in this study the qualitative method was more suitable to gather evidence of developing TSPCK as the pre-service teachers engage in the process of planning for teaching a physics topic in both the topic of learning and that of transfer. Moreover, the quantitative method which involves statistical analysis was found useful in determining the extent to which improvement in the quality of TSPCK in the topic of intervention has occurred. Also, the method was found useful in determining the extent at which transfer of the learnt pedagogical transformation competence has occurred. However, of interest is the mixing of the methods where: the TSPCK

tools used were of qualitative information analyzed quantitatively by scoring in reliable way, converted to measures placed on a scale with equal intervals from which reliability and validity are calculated; findings from each methods were used for triangulation or confirmation, with respect to that, scoring responses were compared among two raters and agreement reached for reliability. The two methods would be establishing the validity and trustworthiness of the data and research findings. In this way, the argument by Ocathain, Murphy and Nicholl (2008) is justified that it is required of a research to illustrate in what way the mixing happens, where it happens and those who are affected by the mixing, whenever a mixed methods approach is applied in research studies. A mixed methods design can also generate a truthful and enlarged level of confidence in the results obtained from the research (Schram, 2014); give clarification of the individual opinion of those who participated in the mixing (mixed methods study) (Schram, 2014). Thus, the use of mixed methods for this study gave the enabling benefits of studying pre-service teachers' development of TSPCK in kinematics and transferability of the learnt pedagogical transformation competence to a new physics topic.

3.3 Research Strategy – Case Study

This study employed a case study strategy as it targeted TSPCK development of a group of pre-service teachers. According to McMillan and Schumacher (2010) a case study is one of the numerous ways of carrying out research studies to understand human beings in a social context by interpreting their actions. In this study, the social context which a case study has been employed to investigate was the pre-service teachers' process of learning to teach thereby developing TSPCK as explained in the previous section. A case study, as a research strategy is as well considered a kind of bounded system (Yin, 2011) by time, place and some other factors. This could be representing one of the important features of a case study. In satisfying that, this study was located in a physics methodology class consisting of twenty (24) final year pre-service teachers at the University of the Witwatersrand, South Africa. Also, the set of pre-service teachers involved were studying at the same time, for the same duration (four years for most of them); at the same institution of learning and for the same Bachelor of Education (B.Ed) degree qualification in the same physical science, as a discipline. Moreover, the pre-service teachers have had instances, from previous years of being posted to high schools within South Africa for teaching experience. Within these instances they have all had the privilege of teaching both

physics and chemistry at the high school level. With this background, it was reasonably assumed that the pre-service teachers would be familiar with some challenges associated with classroom teaching and learning of physics. In addition, as final year students, they were expected to have learnt most physics topics according to the university curriculum for the physical science teacher qualification (B Ed degree). Hence, at the beginning of their 4th year study they were assumed to have acquired most (80%) required basic content knowledge of at least school based topics of physics. Equally, as students of education, at this stage they were expected to have been adequately familiar with the general pedagogical knowledge (PK) of teaching their subject of specialization through methodology classes. With regards to that, Mavhunga (2012) while referring to 4th year students argued that "*the methodology class is inherently concerned with the teaching methodologies of science content and therefore most suitable for the explicit discussions on transformation of subject matter knowledge*" (p. 53) on which this study is based. These represented the boundaries that did not change in the course of carrying out this research study. Furthermore, using a case study as the research strategy allows for in-depth explorations of the issues under investigation (Creswell, 2012). In conjunction with that, Rule and John (2011) highlighted its benefits to include: examining a phenomenon in a limited and focussed setting and developing theoretical assumptions through the phenomenon or validating an existing theory. Thus, employing a case study as a strategy in this study helped in conducting an extensive and in-depth investigation of: how pre-service teachers develop PCK in the topic of intervention; and possible transferability of the understandings of the use of knowledge components to a new physics topic.

However, having highlighted the benefits of using a case study as a research strategy, its limitations cannot be ignored without being acknowledged. A noticeable weakness of this strategy is its limitation in terms of opportunities to generalize findings. Punch (2009) argued that because a case study strategy concentrates on a specific situation, its findings cannot be generalized to some other situations. In order to cater for this limitation in this study the largest population sample of the class was used and thick explanations of all events (Teddlie and Tashakor, 2009) at the beginning, during and after the intervention were provided. In line with that, Creswell (2012) pointed out that the results of a case study strategy can apply to some other circumstances of similar features as the one under investigation. In that case, the findings obtained using this case study can be applied to examining pre-service teachers' pedagogical

transformation abilities in some other physics topics and contextually similar teacher development programmes. Hence, using a case study produces an extent of generalization (Rule and John, 2011).

3.4 Participants

As earlier discussed in the previous section, this study was located in a physics methodology class at the University of the Witwatersrand, South Africa. The methodology class consisted of twenty-four (24) fourth year (4th) pre-service teachers, studying for a Bachelor of Education (B.Ed) degree with physical sciences as the major teaching subject. The methodology courses in the science and technology education division at the University of Witwatersrand have as their goal, the development of TSPCK in core topics of the physical science school curriculum. To this end, specially designed programmes are implemented. This is one of the reasons for the location of my study in the methodology course as it focuses on TSPCK discussions. Likewise, the class of pre-service teachers used represented the population for this study. Although the class with a total of 24 participants was a population of interest and also a captive audience, participation in the project remained voluntary in alignment with ethical principles. McMillan & Schumacher (2010) pointed out that a research sample can be selected from a larger group of persons, identified as the population. As a result, nineteen (N=19) participant pre-service teachers represented the total sample size for this study. McMillan & Schumacher (2010) further argued that a population encompasses a group of individuals that conforms to certain criteria and from which a researcher plan to generate the research results. In justifying that, generally in South African high schools, a physical science teacher teaches both physics and chemistry together as a subject. Thus, a set of physical science pre-service teachers like this was targeted in this study. Accordingly, it was also ensured that the nineteen pre-service teachers attended all the methodology sessions on kinematics (the topic of intervention) for this study. The sessions in the methodology course were collectively regarded as an intervention as, otherwise known as the treatment later discussed below. It explicitly targeted pre-service teachers' development of TSPCK in a specific physics topic (kinematics).

3.5 Treatment – Intervention to develop TSPCK

The treatment involved an intervention which exposed the pre-service teachers to the idea of transforming content knowledge (CK) within a specific physics topic, kinematics. As earlier argued in the rationale, kinematics was chosen as the topic of intervention because it is fundamental in understanding other physics topics especially in mechanics. The key feature of the intervention was explicit in discussing the TSPCK and how the constituent components, once understood could be used interactively to transform CK when thinking and planning to teach a topic. As a result, the intervention was made up of carefully planned series of explicit discussions on the understanding of TSPCK components that bring about the transformation of CK. The physics methodology course happened over a period of six weeks. The six weeks period was organized into a total of 12 sessions of 50 minutes each. In each week there were three sessions structured as a single period early in the week and a double period at the end of the week. Largely the single period was used to introduce a single component of TSPCK and the double period used to illustrate how the component could be used in kinematics. Naturally, while the focus was on the demonstration of one component of TSPCK at a time, the spontaneous emergence of other components in the explanations was pointed out. In such a moment, an accompanying comment was made whether the emerging component(s) is yet to be discussed in full (in upcoming sessions) or a reminder of its discussion in the previous sessions. However, pre-service teachers were encouraged to make note of how the components interact. Typically sessions that introduced a component would have a mix of teacher and learner centred discussions. For example the session introducing misconceptions, the pre-service teachers were divided into two groups.

Each group was asked to identify various learners' misconceptions in kinematics. The group discussions typically lasted for about 20minutes after which the whole class shared ideas and the lecturer consolidated. Moments of consolidation by the lecturer were crucial as they focused on how consideration of the discussed TSPCK component has influenced explanations of a concept. Also, they were used to highlight emerging interaction of multiple components of TSPCK in the planned explanations. The CK concepts used across the explicit discussion of the respective components of TSPCK were: scalars, vectors, distance, displacement, speed, velocity and acceleration. The skill of interpreting graphical representations was demonstrated largely when

introducing the component of 'representations'. It was however, noted that the listed concepts were sometimes repeated when introducing and discussing the next TSPCK component, see Table 3.1. Such moments, in my view, showed different aspects of the concept for the benefit of the pre-service teachers. Table 3.1 below presents the sequence in which the components were introduced and the CK component discussed under each.

Table 3.1: Description of Topic Specific Intervention Activities

Week	**Session**	**TSPCK component used**	**Intervention/Activity**	**Concepts of CK used**
1	1	Administration of TSPCK Pre-test	Formal introductions and discussion of ethics issues	
	2	Learner Prior Knowledge	Discussions were on widely researched common misconceptions on the topic found in the literature. Participants were also encouraged to identify misconceptions that they know. Discussions were followed by a presentation of recommended teaching strategies to correct misconceptions. Where a strategy naturally draws on other components such as representations, such moments would be explicitly highlighted	- Scalars and vectors, - Distance and Displacement - Speed, Velocity and Acceleration -Graphs of uniformly accelerated motion

2	3 & 4	Curricular saliency	Discussions were geared towards an understanding that each topic has major concepts that are core to the topic to be understood. When thinking about teaching, it is important to identify and express these major concepts in terms of their meaning through statements called the '*Big Ideas*'. Also the identification of sub-concepts called subordinate concepts is important. The thinking of 'big ideas' is derived from Loughran, Berry and Mulhall (2006) where key concepts in a topic are expressed as statements reflecting their meaning. This was followed by a discussion on sequencing the identified big ideas for scaffolding learning; awareness of the foregrounding concepts needed prior to teaching the Big Idea and knowing what is most important to understand in the big idea. It was explained that the knowledge of a topic in terms of its big ideas, subordinate ideas, prior concepts and sequencing is called curricular saliency.	Big ideas include: - Distance is a scalar quantity while displacement is a vector quantity, speed is a scalar quantity while velocity is a vector quantity - There is a relationship between motion graphs for position, velocity and acceleration - There are equations for motion in one direction
3	5 & 6	What is difficult to teach	Exploration of concepts considered difficult to learn, and identifying the actual issues that make understanding difficult. This was more than settling on the abstractness of concepts but pin-pointing the actual difficulty. It was also explained that this concept is different from misconceptions – but refers to potential difficulties by students in	Concepts of distance and displacement especially in calculations; average and instantaneous speed/velocity; deceleration and acceleration; Positive and negative acceleration

			understanding full meaning of a major concept or subordinate concept. For example practical meaning of concepts calculated from – first order derivatives (e.g. speed vs second order derivatives acceleration).	
4	7 & 8	Representations	Introduction of different levels of representations including macroscopic, symbolic in terms of: equations, scientific formula, diagrammatic illustrations; and microscopic in some cases. Emphasis was on placed on the use of all these representations side by side in explaining a concept.	Kinematics concepts represented using graphs, side by side with calculations of the quantities and gradients. Equations and S.I units of quantities
5	9 & 10	Conceptual Teaching strategies	Emphasis was placed on conceptual teaching strategies rather than general pedagogy and logistics. A conceptual teaching strategy would consider the generated knowledge from the other four components.	Misconceptions identified above used as stimuli and conceptual considerations made for curricular saliency, what is difficult and representations pulled to work together in formulating explanations that tackle the misconceptions.
6	11	Pulling it together	Introduction of Content Representations (CoRe) as a tool to capture thoughts as one thinks about content knowledge of a topic through the knowledge components of TSPCK. The prompts of the original Core were modified to highlight correspondence to the five set of components as discussed in the intervention.	The Big Ideas selected were based on the concepts of kinematics listed above in the component of curricular saliency

	12	Administration of TSPCK Post-test	Formal closure and sharing of the next steps of action by the researcher in the research of analysis – study. This included an indication of upcoming invitations for interviews.	

As shown in the Table 3.1 above, in the intervention theoretical framework for TSPCK was used to introduce the construct in kinematics. The intervention explained each of the five components of TSPCK using the knowledge concepts of kinematics. Through this program, the pre-service teachers are expected to interrogate the content of the topic from the perspective of each of the TSPCK components. Through the support of the lecturer in the process, opportunities for trial and error develop the competency to formulate teacher responses such as explanations that demonstrated the use of components interactively. The intervention took place in the first semester of the academic calendar. The intervention was strategically placed in time for the succeeding formal period of teaching experience practicum in secondary schools. Purposefully, the intervention targeted engaging pre-service teachers' pedagogical ability to transform concepts for teaching, using kinematics as an instance. This pedagogical transformation as it takes place through intervention entails pre-service teachers' ability to reason about kinematics concepts using the five components of TSPCK (Mavhunga, 2014). The intervention was coordinated by an experienced and expert university lecturer (not me) in the area of physics teachers' development of TSPCK. The conceptualization of big ideas is traceable to Loughran, Berry and Mulhall (2006) using statements to express the main concepts within a topic. The big ideas discussed in the intervention included: distance is a scalar quantity while displacement is a vector quantity, speed is a scalar quantity while velocity is a vector quantity; there is a relationship between motion graphs for position, velocity and acceleration; there are equations for motion in one direction. Then, the pre-service teachers were taking through the method of sequencing the identified big ideas for effective teaching, emphasizing that which is important in the big ideas. The formulation of big ideas in a topic is a difficult process (Loughran, 2007) often done by a group of practicing teachers. Thus, the discussion of the component of curricular saliency generated opportunities for pre-service teachers to trial out their efforts. Third week dealt with the concepts considered difficult to learn in kinematics. There were discussions on the

actual issues that make understanding of kinematics difficult. These included interpreting graphs of uniformly accelerated motion, positive and negative acceleration, calculating distances and displacements using graphs (Department of Basic Education, 2015). The fourth week lectures were based on the use of representations to enhance learners' understanding of Kinematics. The use of symbols, formula, equations, graphs, demonstrations was emphasized. Week five of the intervention was based on the conceptual teaching strategies as the fifth component of TSPCK. The use of the previous four components interactively was emphasized. This distinguishes conceptual strategies from general pedagogy and logistics. Naturally this component is relatively harder as it demands drawing considerations made from the other components of TSPCK into a coherent suggested conceptual teaching strategy. The last week of the intervention was used to introduce content representations (CoRe) as an instrument for capturing reasoning as a teacher thinks through TSPCK components to transform concepts. Research instruments were administered for data collection at the beginning and end of the intervention.

3.6 Data Collection

In this study, two major steps were taken in collecting data. These include: obtaining ethics approval and consent of the participant; and the actual data collection. Each of these steps is described in the sub-sections below.

3.6.1 Obtaining approval for data collection and participant consent for participation

The first step I took before data collection process began was to seek permission to conduct this research study. For that reason, I submitted an Ethics application to the University of the Witwatersrand Human Research Ethics Committee Secretary and obtained an approval with protocol number 2015ECE036M (see appendix I). Thereafter, I took the step of contacting the physics methodology lecturer for permission to carry out this study in his methodology class. I discussed with the lecturer the purpose of my study, presented ethics application approval and requested for his permission. I presented written research information and consent letter (see appendix II) to the lecturer, with the assurance of confidentiality and anonymity of any information gathered. On that very day, the lecturer gave his permission for the research to be conducted in his methodology class by signing the consent letter. With the permission of the lecturer, I approached the pre-service teachers with the information letters and consent forms

(see appendix III). I discussed purpose of the research with them and requested for their individual participation as it would improve the quality of physics teaching and learning in South African schools. In my explanation I indicated that this study entails collecting their views through TSPCK tool in kinematics before and after methodology sessions. I also pointed out that the process would involve collecting their submitted tasks on the topic of transfer after the intervention. I added that I would need to interview them on their responses to the TSPCK tools and that their voice would be audio recorded for ease of capturing their responses. I assured them all information gathered from them would be kept confidentially and that only they themselves, myself and my supervisor would have access to the information. I told them they were allowed to refuse permission to participate and that there would be no penalty in any form to them for refusing to participate in this research study. I added that the value of the responses gathered and recordings were to improve the way Universities prepare and train future science teachers. I made it clear that if they decided halfway through to stop participating, this would completely be their choice and will not affect them negatively in any way. I assured them that in the analysis I would not be using their names but would make up one so no one can identify them. I emphasized to them that all recordings and collected information would be stored safely in a lockable place and destroyed between 3-5 years after I have completed my research project. All the participating pre-service teachers present that day were 18 years old and above. They indicated their willingness to participate voluntarily by signing the consent forms. All these steps were taken to enhance cooperation from the course lecturer and pre-service teachers and ethics of the research was observed.

3.6.2 Actual collection of data

In this study, treatment served as the platform for data collection. The treatment consisted of an intervention where pre-service teachers were introduced to the idea of transformation of content knowledge in kinematics. The data was collected in four strategic points. These are: (i) prior to the intervention; (ii) during the intervention; (iii) immediately after the intervention; (iv) about three weeks after the intervention.

(i) Data collection prior to the intervention

Data related to the quality of TSPCK in the topic was collected prior to the treatment. The reason was to create a baseline from which future shifts or lack of TSPCK could be calculated (Ball, Thames & Phelps, 2008). For measurement of the quality of pre-service teachers' TSPCK in kinematics, a test was conducted with an already developed TSPCK kinematics tool (see appendix IV), targeting pre-service teachers' knowledge of the contents in the topic. The tool had already been developed and piloted alongside with TSPCK tool in chemical equilibrium earlier with ethics protocol number 2011ECE003C (meant for the bigger project) but it has not been validated. The tool was designed and piloted as a research tool for the bigger project under which my study was carried out, having a structure similar to the validated TSPCK tools in the topic of electricity (Zimmerman, 2015), organic chemistry (Vokwana, 2013), chemical equilibrium (Mavhunga & Rollnick, 2013) and electrochemistry (Ndlovu, 2014). It contains items grouped under five categories of TSPCK components. It targeted the pre-service teachers' ability to pedagogically transform concepts in the topic of kinematics using the five TSPCK knowledge components. To ensure construct validity of the TSPCK tool, it was examined by a team of assessors who are professional physics teacher educators and equally knowledgeable in using TSPCK construct. Then the administration of the tools followed.

The TSPCK tool was administered to the pre-service teachers as a pre-test take-home assignment on the first day of the intervention. Nineteen (N=19) pre-service teachers were present on that day and they all collected the tool. I was also present in the examination hall to assist the course lecturer with the handing out of the tool to the pre-service teachers. They were instructed by the course lecturer to work independently without consulting or sharing ideas with peers as their responses would be assessed and marked individually. They all completed the tool and returned the following week for submission. The course lecturer provided no feedback on TSPCK pre-test. After collecting the completed TSPCK tools from the pre-service teachers, I made duplicate copies while the course lecturer kept the original copies for marking. I agreed with the course lecturer on the assigned codes to the participating pre-service teachers instead of using their names. The assigned codes were used in reporting in this study. This was done in line with the research ethical principle.

(ii) Data collection during the intervention

As part of the data considered in this study, the pre-service teachers' submitted class activity group discussions during the intervention were collected. The particular one used in this study consists of questions framed as class tasks (see appendix V) by the course lecturer. The pre-service teachers were given the task to discuss in their groups early in the intervention and later in the intervention. To this, there were written responses submitted which represented collective group discussions. There was no feedback to the pre-service teachers from the course lecturer on the submitted tasks until after the second submission and there was no prior knowledge or awareness that the task was going to be repeated. So, the pre-service teachers had the total number of two submitted class activity group discussions reported in this study. This was examined in this study for two reasons: to support evidence of developing or understanding TSPCK; and to provide thick descriptions and establish arrangement of intervention activities as shown in the Table 3.1 above. The analysis of the data was done qualitative as later described in the next chapter.

(iii) Data collection immediately after the intervention

After all discussions on the transformation of kinematics concepts using the five knowledge components of TSPCK have been completed, then the TSPCK kinematics tool was administered as a take home post-test. A week before the post-test was conducted; the course lecturer informed the pre-service teachers there was going to be another test. The course lecturer disclosed neither the content of the test nor its similarity to the pre-test. Except for the cover sheets with different dates, the contents of the TSPCK kinematics tool administered as a take-home test were the same as in the pre-test. The number of pre-service teachers who collected the TSPCK kinematics tool was nineteen (N=19). In a similar way to the pre-test, the pre-service teachers were instructed by the course lecturer not to discuss their responses with peers. All the nineteen pre-service teachers who got the TSPCK tool returned the completed copy for submission the following week at the designated time.

(iv) Data collection about three weeks after the intervention

Precisely three weeks after intervention activities were completed; different kinds of data were collected. These include data collected through the use of: a validated TSPCK tool in electric circuits (see appendix VI); interview schedules (see appendix VII); and records of actual classroom teaching. First, as an additional part of the course requirements, the pre-service teachers were expected to write a take-home examination equivalent on a new physics topic which was neither discussed nor disclosed to them. Based on the course organization, the topic of 'electricity' happened to be the one on which the pre-service teachers were expected to write a take-home examination equivalent. For that purpose, a copy of validated TSPCK tool in electric circuits (Zimmerman, 2015) was handed out to each of the pre-service teachers as a take home examination equivalent task. The tool consists of items on the concepts of electricity grouped under five knowledge components of TSPCK as fully described in the section below. The tool was administered to the pre-service teachers as a take home examination equivalent assignment, three weeks after the intervention. The pre-service teachers had no prior knowledge that electric circuits would be the topic of assessment. However, the fact that it was administered as a task equivalent to an examination, it meant that they will demonstrate their best effort. They were instructed not to discuss answers or exchange ideas with their colleagues. An online computer university platform known as SAKAI was created for the submission of the task with specific date after which submissions were no longer allowed. The pre-service teachers were given a week to complete and submit the task on SAKAI a week after. Nineteen (N=19) pre-service teachers collected the take home assignment and submitted at the appropriate time. I met with the course lecturer to download the submitted tool, assign codes and make duplicate copies of the completed tools for scoring. Second, after examining the pre-service teachers' performances on the tool, I identified a mix of successful and unsuccessful participants. Then, I selected a number of pre-service teachers (6) with whom a semi-structured interview was conducted. The interview investigated the both the factors that promoted and inhibited successful engagement with TSPCK components in the topic of the intervention. The interview schedule was extracted from the one used by Aydin and Boz (2013) while investigating teachers' nature of PCK components interaction. This took about 30 minutes with each pre-service teacher that participated; it was conducted behind a closed door where only I and individual participating pre-service teacher were present. Third, the pre-service teachers were asked by the course lecturer to submit

audio/video of their classroom teaching during teaching experience (T.E) after the intervention. This was part of their assessments for the methodology course. With appropriate permissions, I made efforts to collect records of the audio classroom teaching of three pre-service teachers who taught a physics topic of electricity during T.E. This was done to provide additional data on the pre-service teachers' engagement with TSPCK components in the classroom actual teaching of the topic.

The Table 3.2 below summarizes the discussions above on the actual data collection.

Table 3.2: Overview of the data collected

Stage	Instrument used/ Other means of collecting data	Type of data collected	Point of Mixing/integration
Prior to the intervention	TSPCK kinematics tool	Quantitative and Qualitative data	TSPCK kinematics tool integrates qualitative and quantitative measurements
During the intervention	Submitted class activity group discussions	Qualitative data	No mixing
Immediately after the intervention	TSPCK kinematics tool	Quantitative and Qualitative data	TSPCK kinematic tool integrates both qualitative and quantitative measurements
About three weeks after the intervention	TSPCK electricity tool Interview Audio/video recorders	Qualitative data Qualitative data only Qualitative data	No mixing No mixing No mixing

3.7 Research Instruments

The research questions guiding this study require that appropriate research instruments are used for data collection. Likewise, the significance of PCK for enhancing teachers' instructional quality is embedded in its topic specific nature (Mavhunga & Rollnick, 2011), speaking to why a tool for measuring TSPCK is needed. Since this study employed a mixed methodology approach, instruments that would be able to gather quantitative and qualitative data were considered appropriate for data collection. This study was based on the topic of kinematics (as

the topic of intervention) and electricity (as the topic of transfer). The instruments for data collection are as follows: a validated TSPCK tool in electric circuits; TSPCK kinematics tool; and Interviews.

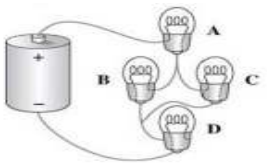
3.7.1 TSPCK tool in electric circuits

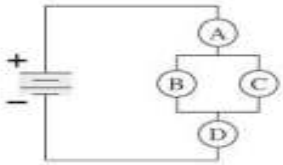
The validated TSPCK tool in electric circuits (see appendix VI) (Zimmerman, 2015) was used in this study to investigate pre-service teachers' transferability of learnt pedagogical transformation competence to a new physics topic (electricity). This gave the picture of pre-service teachers' quality of TSPCK in the topic. Similar to other existing validated TSPCK tools in other topics, the TSPCK tool in electric circuits is structured to have five content knowledge specific components of TSPCK. These knowledge components include: learner prior knowledge; curricular saliency; what is difficult to teach or understand; representations; and conceptual teaching strategies. This tool was developed to bring to the fore front the transformation of content knowledge of secondary physical science teachers in a planning context. Thus, the tool consists of items grouped under five categories (A – E), each representing a component of TSPCK. Category A (TSPCK component '*Learner Prior Knowledge*') consisted of two questions each of which has four typical multiple choice items that learners have answered incorrectly. Similar to other existing validated TSPCK tools in other topics, the TSPCK tool in electric circuits consists of items grouped under five categories (A – E), each representing a component of TSPCK. Category A (TSPCK component '*Learner Prior Knowledge*') consisted of two questions each of which has four typical multiple choice items that learners have answered incorrectly. To each set of students' multiple choice items, four possible teacher responses were provided, none of which was incorrect. This was based on the series and parallel connections of four electric bulbs to a battery. The pre-service teachers were required to choose one of the teachers' responses they would most likely use in their teaching and explain the reason for their choice. A sample of the item is given in the Table 3.3 below. Category B (TSPCK component '*Curricular saliency*') was related to planning and sequencing concepts in the topic of electricity. The participant pre-service teachers were required to give responses that would assist in developing a consensus on the big ideas. Category C (TSPCK component '*What is difficult to teach'*) demanded that the pre-service teachers reflect on which ideas about electricity, are difficulty to teach and get across to students. This gave the picture of the pre-

service teachers' ability to identify possible difficult concepts in the topic of electricity. Category D (TSPCK component '*Representations*') provides different types of representations and analogies on electricity concepts. The pre-service teachers were required to think about which ones they find useful and then fill in the table relating to the effectiveness of these analogies in the classroom setting. The category E (TSPCK component '*Conceptual teaching strategies*') presented a student's exercise and asked the pre-service teachers to think about how they would assist the student develop her/his conceptual understanding of electric circuits.

A1. How would you respond to a student who **selects A** as the answer to the question below?

Rank the bulbs in the following circuit according to their brightness, from brightest to dimmest. Assume that the bulbs are all identical.





A. A > B = C > D

B. A = B = C = D

C. A = D > B = C

D. B = C > A > D

Response A: Bulbs in series will always be brighter than those in parallel, so your answer is wrong.
Response B: Current in a series circuit is the same and it divides in a parallel circuit, so A and D will be brighter than B and C.
Response C: Current does not change with position from the battery source but only with the arrangement in a circuit, so A and D should be brighter than B and C as they receive twice the current as in B and C.
Response D: None of the above
Choose your response, and expand on the reason for your selection in the space provided

My choice is _____

Figure 3.1: Sample Item from the TSPCK tool in electric circuits

Under each category, the pre-service teachers were required to give qualitative explanations of their opinions and the options chosen. The quality of pre-service teachers' written responses in each case helped in examining their understanding of TSPCK components in transforming the contents of electricity. Through this, the pre-service teachers' transferability of learned pedagogical transformation competence was investigated.

3.7.2 TSPCK kinematics tool

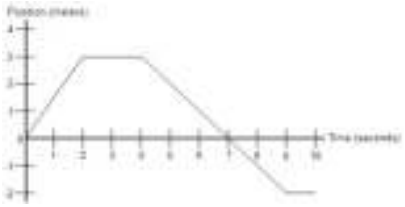
Similar to the validated TSPCK tool in electric circuits (Zimmerman, 2015) described in the section above, an appropriate TSPCK kinematics tool – already developed and piloted by a team of TSPCK researchers and experienced pre-service teachers' educators who make the bigger project group under which this study carried out - was adopted in this study. The protocol number for the bigger research group is 2011ECE003C. The tool had earlier been developed and piloted before this present study commenced. Because this study is part of the TSPCK bigger project, one of the targets of this study is to validate the tool. The TSPCK kinematics tool (see appendix IV) contained test items which are in accordance with kinematics contents that students learn in Grade 10 to 12 in South African schools. The development of this tool was done in consultation with a reference team of science teacher educators (with specialization in physics) who have many years of teaching experience and conducting academic research in PCK and TSPCK. With regards to that, the identified kinematics central concepts include: scalar and vector; distance and displacement; speed, velocity and acceleration; position/displacement-time graph; speed/velocity-time graph; and uniformly accelerated motion graphs (Department of Basic Education, 2015). In this sense, the test items are in line with the curriculum needs and standards for South African high school. Also, the contents of the tool were observed to have been grouped into five categories each representing a component of TSPCK. The components include: learner prior knowledge; curricular saliency; what is difficult to teach; representations; and conceptual teaching strategies. TSPCK kinematics tool was similar to other validated TSPCK tools in the topic of organic chemistry (Vokwana, 2013), chemical equilibrium (Mavhunga & Rollnick, 2013), and electrochemistry (Ndlovu, 2014). The nature of the items in the tool required the pre-service teachers' adequate understanding of TSPCK components in transforming contents within kinematics. The items were divided into five categories.

Category A (TSPCK component '*Learner Prior Knowledge*') consisted of two questions each of which has four typical multiple choice items that students have answered incorrectly. To each set of students' multiple choice items, four possible teacher responses were provided, none of which was incorrect. The pre-service teachers were required to choose one of the teachers' responses they would most likely use in their teaching and explain the reason for their choice. A sample of the item is given in the Figure 3.2 below. Category B (TSPCK component '*Curricular*

saliency') was related to the planning and sequencing of concepts in the topic of kinematics. The participant pre-service teachers were required to select and rank three foundational concepts regarded as basic and thereafter draw a concept map show the interrelatedness of the subordinate concepts. Category C (TSPCK component '*What is difficult to teach'*) demanded that the participant pre-service teachers reflect on which ideas about kinematics, are difficulty to teach and get across to students. Category D (TSPCK component '*Representations*') provided different types of representations and analogies on kinematics concepts. The participant pre-service teachers were required to think about which ones they find useful and then fill in the table relating to the effectiveness of these analogies in the classroom setting. Lastly, category E (TSPCK component '*Conceptual teaching strategies*') presented a student's exercise and asked the pre-service teachers to think about how they would assist the student develop her/his conceptual understanding of kinematics. Under each category, the pre-service teachers were required to give qualitative explanations of their opinions and the options chosen. The quality of pre-service teachers' in each case helped in examining their understanding of TSPCK components in transforming the contents of kinematics. Establishing the reliability and validity of this tool was associated with the statistical analysis later explained in the next chapter. The Figure 3.2 below presents a sample the TSPCK kinematics tool on the component of learner prior knowledge.

A1. How would you comment in writing to the student who **selects C** as the answer to the

question below? Determine the total distance travelled by the car for the whole journey.



A. Distance = Area under the graph
= $\frac{1}{2}(2)(3) + (4-2)(3) + \frac{1}{2}(3)(3) + \frac{1}{2}(2)(-2) + 1(-2)$
= 9.5 m

B. Distance = Sum of all distances
= $3 + 0 + 3 + 2 + 0$
= 8 m

C. Distance = Sum of all distances
= $3 + 3 + (-3) + (-2) + (-2)$
= -1 m

Response A: There are three types of graphs in kinematics (i) position-time (ii) speed-time, and (iii) acceleration-time. When you are given a speed-time graph you calculate the distance travelled by getting the area under the curve. In this case, this is a position-time graph, position is distance, so just add the distances moved

Response B: When you have a position-time graph, the total distance travelled is the sum of the individual distances, so you add not taking signs into consideration

Response C: Distance is not a vector and it cannot have a negative sign

Response D: When you have a position-time graph, the total distance is the sum of the individual distances. However, when distance does not change but time does, it means the car has stopped. When the distance starts to decrease, it means it is moving in the opposite direction. This distance is still added as distance moved. From the graph at 7 seconds, the car has reached its initial starting position and is still moving in the opposite direction, so add the distance as well not including the sign

Response E: None of the above

Choose your response, and expand on the reason for your selection in the space provided

Figure 3.2: Sample Item from the TSPCK kinematics tool

3.7.9 Interview

In this study, an interview was used to further investigate the pre-service teachers' challenges with pedagogical transformation reasoning in kinematics. In research studies, an interview is regarded as "*a good way of accessing people's perceptions, meanings, definitions of situations; and construction of reality*" (Punch, 2009, p.144). McMillian and Schumacher (2010) also added that interview is the most prominent data collection tool in qualitative research as it involves accessing people's perceptions, meanings, and definitions of situations and construction of reality. Meanwhile, there are basically two kinds of interviews: structured interviews and semi-structured interviews (Creswell, 2012). Structured interviews are used when a research study is of a very large sample from which results are to be generalized (Creswell, 2012). McMillian and Schumacher (2010) is of the argument that structured interview in most cases prevents respondents from sharing important information with the researcher since there are specific answers that they have to chose from. As a result, this would not be appropriate for my study since I am interested in the participants freely expressing their mind regarding strategies for planning a new physics topic. Hence, consideration was given to the use of semi-structured interview in this study, also because I have a small sample size and needed information without any restriction to what the respondents might want to say. As reported in the literature, semi-structured interviews when used as research instrument increases the data with details as it allows respondents to be flexible while responding to the questions (Creswell, 2013). Through the use of an interview in this study, useful pieces of information were gathered verbally from the pre-service teachers. The interview schedule used in this study contains questions that sought to know how the pre-service teachers found the process of developing TSPCK in the topic of the intervention (kinematics). The interview schedule (see appendix VII) used was adopted from previous research studies on pre-service teachers' development of TSPCK by Mavhunga and Rollnick (2013); and Mavhunga (2014). This was done to enhance validity of the research findings. Conducting an interview with the pre-service teachers also helped in gathering more evidence of the impacts of TSPCK intervention as seen in the written work of the participants. With these outlined benefits of interviews notwithstanding, McMillan and Schumacher (2010) indicated interviews are not without a weakness such as the tendency the researchers' bias interfering in the process of gathering information. To avoid possible bias, I audio-recorded each segment of the interview conducted. In support of this, Creswell (2012)

pointed out that audio-recording of information is efficient when collecting data from a small group of people than in the real classroom teaching.

3.8 Analysis of data

The analysis of data followed the process of data collection in this study. As earlier discussed, qualitative and quantitative data were collected all working towards answering the research questions. Based on the nature of the TSPCK construct, careful steps were taken in ensuring suitable approaches were employed in the data collection process. As a result, appropriate methods were sought in analyzing the data. The discussions on the analysis of TSPCK data collected are presented in the sub-sections below.

3.8.1 Analysis for engagement of TSPCK components in kinematics and electricity

The analysis of data in mixed methods research occurs within both the quantitative and qualitative research approach (Frels & Onwuegbuzie, 2013). Firstly, the aspect of quantitative analysis was done in this study to examine the pre-service teachers' shifts in development based on the pre and post-TSPCK tests written responses in kinematics. The written responses were pictures of their engagement with the TSPCK components in transforming CK in the topic. Also, the quantitative analysis of TSPCK electricity data was done to determine the extent to which the pre-service teachers were able to transfer learnt pedagogical transformation competence to the topic of electricity. In doing this, the pre-service teachers' written responses to the TSPCK tools were marked using a validated TSPCK rubric (Mavhunga & Rollnick, 2013). The rubric is similar to that developed by Park and Chen (2012) in terms of components. It represents a kind of assessment instrument containing criteria for scoring magnitudes of pre-service teachers' quality of engagement with the five components of TSPCK. Mavhunga and Rollnick (2011) argued that using TSPCK rubric in this way can, with good reliability, estimate participants' qualities of PCK in the topic to evaluate the entire TSPCK construct. It is worth pointing out at this point, that the TSPCK rubric used by Mavhunga and Rollnick (2013) was used for the topic of chemical equilibrium. Using the same rubric in this study, the contents were described in terms of kinematics concepts for scoring TSPCK kinematics responses; and electricity concepts for scoring responses to the validated TSPCK tool in electric circuits. A sample of the adapted rubric is shown in the attached (see appendix VIII). Myself as the

researcher and the course lecturer individually marked the pre-service teachers' responses to the two TSPCK tools using the same validated rubric. The two of us thereafter met to discuss our individual scoring to ascertain consistencies in the marks thereby enhancing reliability. Where there were differences, we looked again at the pre-service teachers' responses in accordance with the rubric, discussed and reached an agreement on the final scores. We also calculated Cohen's Kappa interrater agreement value and got 0.88 which was satisfactory to ensure credibility. Thereafter, the agreed raw scored were analyzed using two statistical methods: the Rasch Model Analysis; and the Wilcoxon paired signed rank test for non-parametric data. While the full explanations on these statistical methods are provided in the two analysis chapters, chapter 4 and 5, the brief descriptions are given as follows.

The Rasch Model Analysis (RMA) does convert the scores to linear measurements on an equal interval scale with undimensionality as its underlying assumption (Boon, Townsend & Staver, 2011; Bond & Fox, 2015). The measurements allow for estimating empirically the hierarchy with regards to the: pre-service teachers' ability (person ability) as they responded to the items in the administered TSPCK tools; and order of item difficulty (Boone *et al*. 2014). The underlying assumption on which RMA works is that the observed participants' performances reflect a single underlying construct which becomes explicit by the connection of the items with the participants' ability in the sample measured (Boone *et al*. 2014). With regards to that, Bond and Fox (2001, p. 26) argued the data matrix which connects persons and items together in such a coherent and integrated manner has the tendency of representing the underlying the concerned construct suitably. This implies that the Rasch generated person and item statistical indices that are found within the range of +2 and -2 are regarded a suitable match, coherent and conventionally acceptable (Boone *et al*. 2014). Such signals that all the constituent items work jointly to measure a single construct and thereby establishing the validity of the measures. The Wilcoxon paired signed rank test for non-parametric data (Whitley & Ball, 2002) was preferable in this study to a paired-sample t-test because of its appropriateness for such non-parametric data of small size sample (N=19) of participating pre-service teachers in this study. This was done to calculate the significant difference between pre-TSPCK and post-TSPCK tests in kinematics.

Secondly, the aspect of qualitative analysis was done in this study to establish how pre-service teachers' use of TSPCK knowledge components influence their quality of TSPCK. With the

quantitative analysis of TSPCK data described above, certain aspects regarding the purpose of the study would have been established. However, the nature of this study (in relation to the formulated research questions) demands that only quantitative analysis would not be enough to bring about complete and quality findings. The quality of the findings relates to the in-depth investigation of how the pre-service teachers interactively used knowledge components of TSPCK as they formulated responses to teacher tasks. In the first case, this was qualitatively examined in the pre-service teachers' written responses to the TSPCK tools. In the second case, the qualitative content analysis as a mixed methods approach (Mayring, 2014; Sandorona, 2014) was used to analyze the pre-service teachers' submitted class activity group discussions. This helped by providing insight into the struggle and success as the pre-service teachers were developing their TSPCK in the kinematics during the intervention. Such insight, according to (Mavhunga, 2014) is important in understanding the nature of the emerging TSPCK. In the third case, the pre-service teachers' records of actual classroom teaching were qualitatively analyzed for possible transfer of pedagogical transformation competence to the topic of electricity. The selection of the pre-service teachers whose audio records were analyzed was based on the condition that physics topic of electricity was taught during the teaching experience. In each case, the pre-service teachers' quality of PCK in the topic was analyzed by describing the nature and number of knowledge components interactively engaged. Abell (2008) argues that for a researcher to comprehend the quality of PCK, efforts must be made to study the interaction of the components having looked at the components one after the other. Park and Chen (2012), while examining the broader interaction between PCK components indicated such would promote effectiveness of the PCK construct. Then, such an argument holds for TSPCK construct which serves as the theoretical framework in this study. As such, the description made use of TSPCK Episodes in a similar way to how Park and Chen (2012) demonstrated of PCK components interaction. In relation to that, a TSPCK episode represents a moment in the pre-service teachers' response where two or more TSPCK components were interactively used in explaining a concept. To visually represent this episode, a TSPCK map was used in this study similar to that used by Aydin and Boz (2013); and Park and Chen (2012).

Thirdly, for the mixed methods aspect in this study, there were three noticeable instances whereby the data collected using one technique (e.g. qualitative method) were converted and infused into the other technique (e.g. quantitative method). The instances were observed with

the data collected using TSPCK tool prior to the intervention (in the topic of kinematics), immediately after the intervention (in the same topic of kinematics) and three weeks after the intervention (in the topic of electricity). The pre-service teachers' written responses to the TSPCK tool in each instance were captured using the tool. The collected data all these cases has a descriptive nature with semi-closed questions that required pre-service teachers to choose an option and then provide explanations on the option chosen. The method of analyzing required harmonizing the pre-service teachers' written explanations with the stated set of criteria in the validated rubric used for scoring. This rubric (see appendix VIII), as earlier explained consists of five categories each having a specific numerical figure for instance '1' for limited TSPCK; '2' for basic TSPCK, '3' for developing TSPCK and '4' for exemplary TSPCK. So there were numerical figures, in line with the criteria in the rubric, assigned to the pre-service teachers' written explanations (responses). These numerical figures were treated as raw data and then transformed into interval data using Rasch measurements to generate item and person difficulty (Boone *et al*. 2014). Similarly, while describing the pre-service teachers' quality of TSPCK, explanations of the interactively used of knowledge components were given concurrently with the number of those knowledge components seen. To sum it all, while findings from the qualitative analysis showing interactive use of more knowledge components in the post-TSPCK test than pre-TSPCK test complemented the statistical significant difference calculated using Rasch measurement, the observed qualitative evidence of transferability in both written responses and actual classroom teaching supported Rasch statistical measurements. These are well explained in the analysis chapters, chapter 4 and 5.

3.9 Validity and Trustworthiness of the Research Instruments

In a mixed methods research study like this, examining the quality of data and findings is very important and cannot be over-emphasized. Since such a research study combines both qualitative and quantitative methods, the quality of data dwells on the quality of standards of each (Ihantola & Kihn, 2011) strand involved. In support of that, Teddie and Tashakkori (2009) indicated if the data of the individual strands is valid and credible, then the mixed study will have a high overall data quality. The sub-sections below discuss the establishment of data quality generated from the quantitative and qualitative methods employed.

3.9.1 Quantitative Method

In quantitative research, validity refers to whether the research actually measures that which it was planned to measure or the truthfulness of the results obtained from the research (McMillan and Schumacher, 2010). This description is pointing at two important issues: the accuracy of the data collected through the instruments used; and evidence that the instruments used measured what they have been designed to measure. To account for the first issue in this study, two raters were involved in scoring pre-service teachers' responses to all the administered tools, myself (as the researcher) and an experienced physics methodology lecturer. The two of us are well familiar with using TSPCK rubric in scoring responses to the tools. To account for the second issue, construct validation as argued by Messick (1995) was considered. This involves establishing evidence of statistical inference validity (Bond & Fox, 2015) and validating a new developed instrument (Ismail, Zali, Noh, Ismail & Tamil, 2015) such as the TSPCK kinematics tools used in this study. In addition, another important basic element of construct validation is reliability (Tavakol & Dennick, 2011). Reliability describes the consistency of a research tool in getting the same results when used to measure over and over again to the same person under similar conditions. Acceptable item and person reliability indices were generated in this study as further presented in the analysis chapters, chapter 4 and 5. Tavakol and Dennick (2011) indicated that a research tool cannot be valid unless it is reliable; nevertheless the reliability of an instrument does not depend on its validity. Based on that, Rasch Model Analysis (RMA) was used in this study to provide statistical information on person and item measures which tells on the validity of the instruments. As argued by Boone, Staver and Yale (2014), evidence of valid measures is provided when RMA is used as seen in: all items working together to measure a single construct; and the generated difficulty order of the items. Thus, RMA generated fit statistical indices for persons and items such that the fit statistical indices in both cases were found to be in an acceptable range of -2; +2. Thus, both person measures and item measures in this study worked together to measure TSPCK as a single construct thereby constituting a valid measure (Boone et al., 2014). Within this statistical framework, the validity of the findings was established in this study. This is explicitly explained in the data analysis chapter four.

3.9.2 Qualitative Method

In qualitative research, the underlying principles are based on the fact that validity is an issue of trustworthiness (Zohrabi, 2013). This concept of trustworthiness entails credibility, dependability, transferability and confirmability of the findings as the quality measurements in qualitative research (Ihantola & Kihn, 2011). As a result, Zohrabi (2013) suggested triangulation of data which gives a researcher the privilege of obtaining information through different means. Bond and Fox (2015) added that triangulation of methods in developing converging lines of inquiry helps in making case study findings and conclusions more convincing and accurate. This would enhance the trustworthiness of the data, the interpretations and conclusions drawn. Hence in this study, the triangulation method of analyzing data from different sources - such as written responses to the TSPCK tools, submitted class activity group discussions, and actual classroom teaching of selected pre-service teachers – was used so as to enhance the trustworthiness of this qualitative method. Likewise, while qualitatively examining the interactions of TSPCK knowledge components in the pre-service teachers' written responses and actual classroom teaching, the identification of TSPCK Episodes observed were compared between two raters involved in this study (myself as the researcher and the course lecturer). There were two acceptable Inter-rater reliabilities estimated using Cohen's Kappa statistics (Boon *et al*. 2011): 0.88 for all the TSPCK Episodes observed in the pre-service teachers' written responses; and 0.76 for the TSPCK Episodes observed in the analyzed pre-service teachers' actual classroom teaching. All these steps were taken in this study as 'member checks' (Teddlie and Tashakkori, 2009) so as to maintain the validity and trustworthiness of the findings.

3.10 Ethical Consideration

All the processes of data collection as highlighted in this study began and ended with ethical considerations. Creswell (2012) pointed out that empirical research in education inevitably carries ethical issues, because it involves collecting data from people, and about people. Hence, this started with obtaining ethics approval (see appendix I) from the Wits University Ethics Committee. Thereafter, consent forms were given to the pre-service teachers who indicated their willingness to voluntarily participate in this study. The form explained purpose of the research study, its benefits, the confidentiality and anonymity of the data collected. It was indicated in the consent form that the participant pre-service teachers were free to withdraw at any stage without

any negative effect on them and this was strictly adhered to in this study. To sum it all, while reporting in this study, the assigned codes to the participating pre-service teachers were used and no personal identities were revealed in any way.

3.11 Conclusion

This chapter provided full accounts of the methodological processes involved in this study with regards to the participants, the tools used and establishing validity and trustworthiness of the measures. The next chapter gives the accounts of the measurement of pre-service teachers' development of TSPCK in the topic of kinematics.

CHAPTER FOUR

4. MEASUREMENT OF PRE-SERVICE TEACHERS' TSPCK IN THE TOPIC OF KINEMATICS

In this chapter, I present discussions on the measurement of pre-service teachers' TSPCK in the topic of kinematics starting with a brief introductory paragraph. The qualitative analysis of the pre-service teachers' written responses to the TSPCK kinematics tool and submitted class activities is carried out. This is followed by the quantitative analysis of the data. The conclusion gives the summary of the analysis and findings and the projection to the next chapter.

4.1 Introduction

This Chapter presents discussions on the analysis of data collected about learning to teach kinematics in an intervention that targets the development of TSPCK in the topic. The two methods used in analyzing the data were qualitative and quantitative methods. Using these methods was based on the fact that construct explored in this study, TSPCK, is tacit (Rollnick & Mavhunga, 2015) and best studied from both qualitative and quantitative methods. As the result of the extent of data and discussion needed to answer the two research questions, the analysis is spread over this Chapter and the next Chapter, Chapter 5. In this Chapter the analysis of data answering the first research question – *What is the impact of an intervention, which explicitly discusses transformation of content knowledge using five content specific components, on the quality of pre-service teachers' TSPCK in kinematics?* - is presented. I first look at qualitative evidence for shifts in the quality of TSPCK in the topic and then examine the extent of the shifts quantitatively. The next chapter discusses the analysis of data collected in answering the second research question which is the transferability of pedagogical competence to a new physics topic – electricity.

As explained in the previous chapter, data on the topic of the intervention (kinematics) were collected from a number of different sources. Collecting research information from various sources enables triangulation of data as suggested by Zohrabi (2013). Bond & Fox (2015) argued that triangulation of data collection methods in developing converging lines of inquiry helps in making a case study findings and conclusions more convincing and accurate. This

approach was followed, as it will be shown in several cases in this Chapter and the next, to enhance the trustworthiness of the data collected in this study as well as the interpretations and conclusions drawn. The data were collected from the participating pre-service teachers and the sources included: (i) written qualitative responses to the set of completed pre-and post-TSPCK tools in kinematics; (ii) two sets of submitted work from groups during the intervention tasks; and (iii) responses to the interview schedules. The data presented here below shows findings from the TSPCK kinematics tool supported by those from the submitted work and the interviews. Giving the extent of data collected the style of putting the finding as the sub-heading and then supporting this by describing the analysis of the data has been adopted in this study. This was done as an organized and strategic way of reducing extent of data and having clearer presentations. The analysis of data collected and findings from each are discussed in the sections below.

4.2 Improvement in the quality of TSPCK in Kinematics

Two major findings were observed from the analysis of the collected data about learning to teach kinematics from the TSPCK perspective. First is that the pre-service teachers improved in the quality of TSPCK in kinematics following the intervention. Secondly, the pre-service teachers' improvement in the quality of TSPCK was not an automatic process of simply recalling or regurgitation of learnt knowledge in the intervention rather a process of rigorous engagement with each of the knowledge component at varying degrees. The first finding is discussed in this section. For the purpose of positioning the context in which the analysis of data was done, this discussion briefly recaps what has been explained in chapter three regarding the tool and methods of analysis. It is in this context that the trends observed in the data are explained. The present study was intervention based. The intervention aimed at teaching pre-service teachers how to plan and teach kinematics by developing their TSPCK in the topic. In order to measure the nature and the extent of the shifts in the quality of the developing TSPCK in kinematics, the TSPCK kinematics tool was administered prior to the intervention and after the intervention as a pre-test and post-test respectively. In both cases, the tool was administered as take-home tests due to the nature of the test items and the time needed to think through them. The course lecturer instructed the pre-service teachers, that although the test was not for marks, they were to complete the tool individually without sharing ideas, as their responses would be examined and

regarded as their individual baseline point of learning. They were given a period of one week to hand-in the completed tool. After the pre-service teachers handed-in the completed tool for the pre-test, the course lecturer then informed them that another test (the post-test) would be conducted. The date was announced but the nature of the test and its similarity to the pre-test was neither discussed nor included in the announcement. Both pre-test and post-test conducted were of the same contents except for the different cover sheets and the different dates they were written. The post-TSPCK tool in kinematics was administered on the last day of the intervention and the completed version handed-in the following week, the same period as for the pre-test. The tool targeted pre-service teachers' ability to engage with the five knowledge components of TSPCK, both individually and also interactively in transforming concepts within the topic as to bring about students' understanding of the topic. Submitted class activities from sessions where each component was discussed as well as those submitted later in the intervention were subjects to content analysis.

As mentioned in Chapter 3, the structure of the TSPCK tool in kinematics (see appendix IV) consisted of five categories corresponding to the five components of TSPCK, as in the structure of similar tools such as that in electric circuits (Zimmerman, 2015) in physics and chemical equilibrium (Mavhunga & Rollnick, 2013) in chemistry. After receiving the completed TSPCK kinematics tools, the pre-service teachers' responses were marked using a 'validated TSPCK four points (1-4) scale rubric' (Mavhunga, 2012) (see appendix VIII). As explained in the previous chapter, the criteria specified according to the rubric were used in marking pre-service teachers' responses on each TSPCK component. Myself (as the researcher) and the course lecturer individually marked and scored the pre-service teachers' responses to the tools. Thereafter, we meet to discuss our individual scoring to ascertain consistencies in the marks. Where there were differences, we looked again at the pre-service teachers' responses in accordance with the rubric, discussed and reached an agreement on the final scores. The sections below present discussions on the qualitative and then quantitative analysis of the TSPCK data collected so as to determine the pre-service teachers' quality of TSPCK in kinematics.

4.2.1 Qualitative Evidence supporting improvement of TSPCK in Kinematics

The raw scores obtained from the TSPCK pre and post-test using the rubric for each participating pre-service teacher is given in the Table 4.1 below. The first column displays the codes assigned

to each pre-service that participated in this study. The remaining five columns represent the five knowledge components of TSPCK under which items in the TSPCK tool were grouped. The Table displays the pre-service teachers' scores per category of knowledge components in the pre-test and post-test. For each knowledge component, the average group score is calculated at the last two bottom rows. The group average of TSPCK score in the two last rows was also calculated for pre and post-test by considering average score for each knowledge component.

Table 4.1: Raw scores for pre-service teachers' test in kinematics

Pre-service teachers	Learner Prior Knowledge (LPK)		Curricular saliency (CSA)		What is difficult to teach (WDT)		Representations (REP)		Conceptual teaching strategies (CTS)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TMAM	2	4	1	3	2	4	**3**	**3**	2	4
TANA	**3**	**3**	1	2	2	4	**3**	**3**	**3**	**3**
TEMA	**4**	**3**	2	3	3	4	2	4	2	3
TISI	2	3	2	3	2	4	2	4	2	3
TOSM	2	4	**2**	**2**	2	4	**2**	**2**	**2**	**2**
TNAH	1	3	1	2	2	4	2	3	2	3
TAKA	**3**	**3**	1	2	2	3	2	3	2	3
TCMM	2	3	**2**	**2**	2	4	2	4	1	4
TUMA	2	3	2	3	2	4	1	4	2	3
TMAT	**2**	**2**	**2**	**2**	2	3	2	3	1	4
TSZO	2	3	**2**	**2**	2	4	1	3	2	3
TAZU	2	4	**2**	**2**	2	3	1	3	**2**	**2**
TUMO	2	3	2	3	1	4	2	4	1	4
TIFA	2	3	2	3	2	3	2	3	2	3
TIGO	1	2	1	2	2	4	1	3	1	2
TLMO	1	3	1	2	1	4	1	3	**1**	**1**
TLEM	2	3	1	2	1	3	1	3	1	3
TSIU	1	3	1	1	1	3	1	3	1	3
TSMO	1	3	1	2	1	4	1	3	1	3
Average group score per category	2	3	2	2	2	4	2	3	2	3
Group average pre-test TSPCK score	2									
Group average post-test TSPCK score	3									

Note: The order in which the pre-service teachers are presented in the table above is arbitrary

While the Table 4.1 above presents pre-service teachers' performances in each component, it should be noted that the criteria in the TSPCK rubric actually calls for interaction of each of the components with others, see an example of the extract from the TSPCK rubric and note the shaded text in Figure 4.1 below. For example, on the component of 'learner prior knowledge'

(LPK), for a pre-service teacher's response to be scored 2 (i.e. the Basic category of TSPCK), another TSPCK component must have been interactively used with the component 'learner prior knowledge' (LPK) in formulating the response in such a way that the response to be scored '2' has two knowledge components. Likewise, the '3' (i.e. developing TSPCK) requires interactive use of two other TSPCK components in addition to LPK such that the response to be scored '3' has three knowledge components. Similarly, on other TSPCK components in the Table 4.1 above, each score from '2' to '4' demands that pre-service teachers' response demonstrate interactive use of additional knowledge components (see appendix VIII). The evidence of these interactions across each component is provided in the analysis of the pre-service teachers' responses discussed below.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • Repeats standard definition with reference to any other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Repeats standard definition drawing on one other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two other component of TSPCK interactively	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on three or more other component of TSPCK interactively

Figure 4.1: An extract of the TSPCK rubric for the component of learner prior knowledge

Therefore the average group score was calculated as a measure of their possible effect onto each other. With regards to that, Abell (2008) argues PCK is not the sum of the individual components rather their interactions, likewise I do not consider TSPCK be the sum of the mere components but their interactions as also alluded in Aydin et al. (2015). Thus, considering the overall group score for pre-test (that is, 2) which can be seen to be lower that the post-test (that is, 3), the pre-service teachers seemed to have experienced improvement in their understanding of the knowledge components and their interactive nature. According to the rubric used, '2' corresponds to 'Basic' and '3' corresponds to 'Developing'. The pre-service teachers can be observed to have moved from a lower category '2' (Basic) to a one level higher category 3' (Developing). This newly acquired category (3, i.e. Developing) implies that, following the intervention the pre-service teachers were able to provide evidence of responses to teacher tasks drawing on three components of TSPCK interactively rather than drawing on only one or two in

the beginning (i.e. prior to the intervention). Meanwhile, in as much as a mathematical calculation may not be sufficient in representing a complex trait such as TSPCK fully, it was used in this study as a proxy measure reflecting the overall interactions and the influence of the components on each. Such components interactions are an indicator of the likely quality of the TSPCK in the topic.

To support the calculated group score of 3, which corresponds to the Developing category of TSPCK, in the discussion below I show qualitative examples of pre-service teachers' responses that draw on three categories extracted from the post-TSPCK test. In addition to providing an example of what a statement drawing on three components looks like, these qualitative examples further provide insight into the struggle and success as the pre-service teachers were developing their TSPCK in the topic during the intervention. Such insight, according to (Mavhunga, 2014) is important in understanding the nature of the emerging TSPCK. Thus, in additional to the pre-service teachers' responses in the TSPCK pre and post-test, the submitted written group discussions were also analyzed for further evidence of developing TSPCK. These are discussed in the subsections below.

- ***A sample response based on the component of 'Learner Prior Knowledge' (LPK)***

Figure 4.2 below presents a test item extracted from the TSPCK tool on Learner Prior Knowledge, where the pre-service teachers were required to provide a feedback response to a learner who has a misconception about the meaning of a negative value associated with distance. An extract of the actual test items on this component is provided below in order to provide the context to the responses.

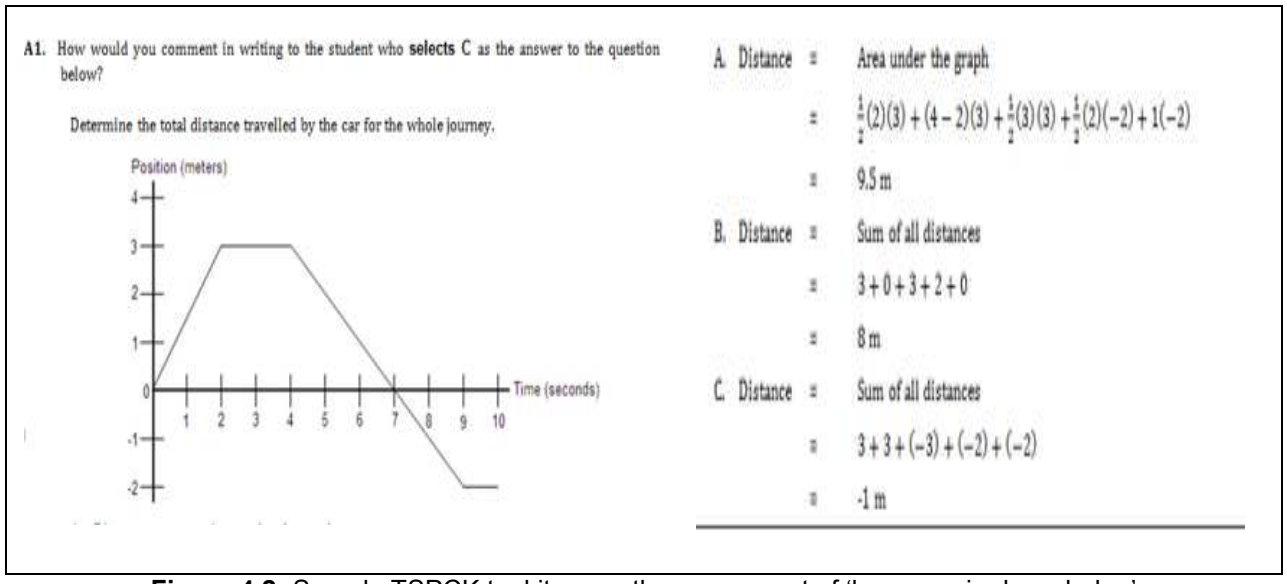


Figure 4.2: Sample TSPCK tool item on the component of 'learner prior knowledge'

An example of the pre-service teachers' written responses which shows developing TSPCK and interactive use of three knowledge components is that of the pre-service teacher TIFA. An extract of the pre-service teachers' pre and post-test written work is displayed in the Figure 4.3 below. As shown in the Figure, in the pre-test, TIFA briefly talked about distance and time with no explicit discussions of the concepts. Meanwhile in the post-test, a level of improvement seemed to have taken place as shown by TIFA's response. He started by acknowledging the learner existing knowledge with misconception as showed in the statement "*learner understands that you have to add the distance together but does not understand that the signs are not to be considered when the car is travelling at the opposite direction*". This describes TIFA's understanding of the TSPCK component 'learner prior knowledge' (**LPK**). Linked to that is the expression of what TIFA considered important for the student to know. This is understanding of the fact that such an object has distance irrespective of the direction as distance is a scalar quantity which is without any directional property (Rane, 2015) as revealed in the statement "*It thus important for the learners to know that the car is still covering a certain distance regardless of its direction*" is evident.

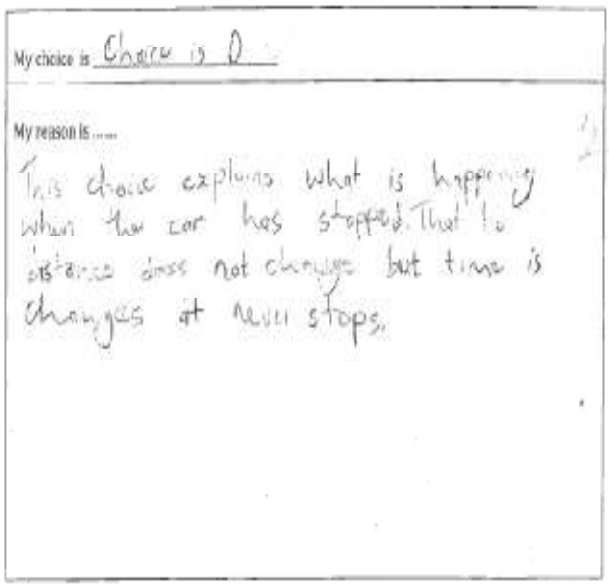
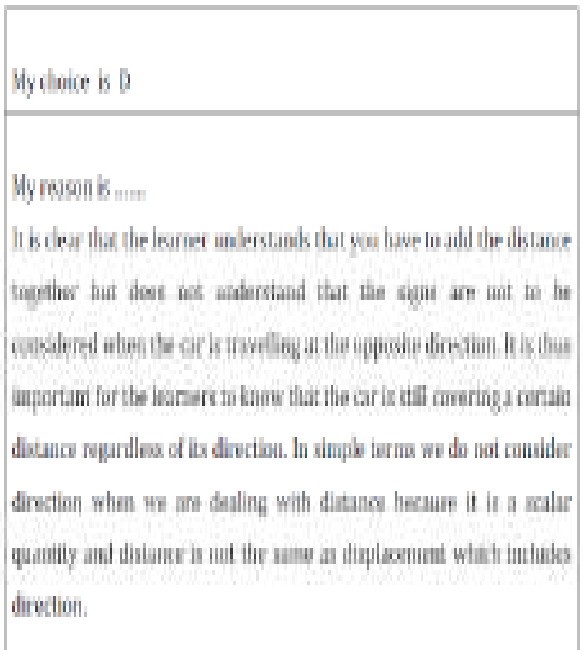
Pre-test	**Post-test**
	
Typed out: My reason is… This choice explains what is happening when the car has stopped. That the distance does not change but time is changes at never stops.	**Typed out extract:** It is clear that the learner understands that you have to add the distance together but does not understand that the signs are not to be considered when the car is travelling at the opposite direction.It is thus important for the learners to know that the car is still covering a certain distance regardless of its direction. In simple terms we do not consider direction when we are dealing with distance because it is a scalar quantity and distance is not the same as displacement which includes direction.

Figure 4.3: Pre-service teacher TIFA's written responses to the TSPCK tool

While such a statement in italic above may be regarded as a demonstration of a content knowledge, from a teaching perspective, it is however more than just content knowledge as it demonstrates understanding that distinguishes the most important point to be learnt (Rane, 2015).

Teachers' understanding of what is important to teach or necessary for students to know at a point in time describes their knowledge of the TSPCK component 'curricular saliency' (**CSA**) (Mavhunga, 2014) which TIFA can be seen to have demonstrated. Associated with that is a statement that re-emphasized the correction of the misconception shown indicated as "*In simple terms we do not consider direction when we are dealing with distance*" still describing TIFA's awareness of learner prior knowledge. TIFA also made a reference in the statement to distance being a scalar quantity. The understanding of scalars and vectors is important in kinematics (Wutchana, & Emarat, 2011), it is part of knowledge of pre-concepts that students need to first understand to be able to clearly differentiate quantities like 'distance' and 'speed' from 'displacement' and 'velocity' respectively (Wutchana & Emarat, 2011). This awareness further points at the TIFA's understanding of TSPCK component CSA. The last statement highlighted "*and distance is not the same as displacement which includes direction*" simply refers to the TIFA's understanding of concepts considered confusing (Antwi et al., 2011), not necessarily a misconception, but an aspect difficult for the learner to understand as both these concepts are related to distance. This demonstrates TIFA's knowledge of the TSPCK component 'what is difficult to understand' (**WDT**). The learner's response in the Figure 4.3 above shows he/she lacks adequate understanding of the concepts of distance and displacement with regards to direction (using positive or negative sign with a numerical value).

It is evident that the response from pre-service teacher TIFA displays use of three TSPCK components. While examining the extract from TIFA's post-test one can see the interrelatedness of the sentences. They have interconnecting terms flowing from one sentence into another, yet each sentence brings a different element for consideration. This gives a sense that the components are working together interactively and not necessarily in isolation or in separate stand alone parts. In order to present this interaction pictorially the idea of TSPCK Maps taken from Park and Chen (2012) is used. Park and Chen (2012) used the idea in an analysis called in-depth analysis where a teaching segment is first identified as a PCK Episode, analyzed for the components that are interacting then drawn pictorially as a PCK Map. As in this study my construct is TSPCK rather than PCK, the identified teaching segments that display component interactions are called TSPCK Episodes and the pictorial representations called TSPCK Maps. A TSPCK Episode corresponds to a segment of teaching that displays interaction of a minimum of two components. In this study, the TSPCK Episodes were generated from the pre-service

teachers' written responses in contrast to the study by Park and Chen (2012) where PCK Episodes emerged from actual classroom teachings. As a result, findings in this study were interpreted with respect to a planning context for the topic of kinematics. In a simple way, when constructing TSPCK Maps, the abbreviation of the TSPCK components was done as follows: **LPK** for Learner Prior Knowledge; **CSA** for Curricular saliency; **WDT** for what is difficult to teach or understand; **REP** for Representations; and **CTS** for Conceptual teaching strategies. In each of the TSPCK Maps, solid circular lines were used to signify noticeable TSPCK components observed in a particular teacher task. The teacher task also represents the platform from which TSPCK components and Episodes emerge. The identification of TSPCK Episodes and their component composition were compared between two raters (Myself as the researcher and the course coordinator) and the Inter-rater reliability was estimated to be 0.88 using Cohen's Kappa statistics (Boon et al., 2011). The TSPCK Map showing the interactive use of knowledge components as observed from TIFA's formulated response is displayed in the Figure 4.4 below.

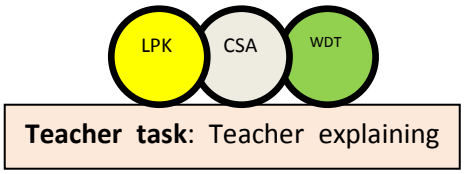


Figure 4.4: TSPCK map for pre-service teacher TIFA's post-test response

The Figure 4.4 above shows how the pre-service teacher TIFA interactively demonstrated knowledge of three TSPCK components (**LPK**, **CSA** and **WDT**) in addressing the learner misconception. The order of appearance of the components in the teaching segment identified as a TSPCK Episode is retained in the TSPCK Map as shown in Figure 4.4. The circular solids are represented as interwoven, shows the interrelatedness of each statement or sentences in contained in a TSPCK Episode.

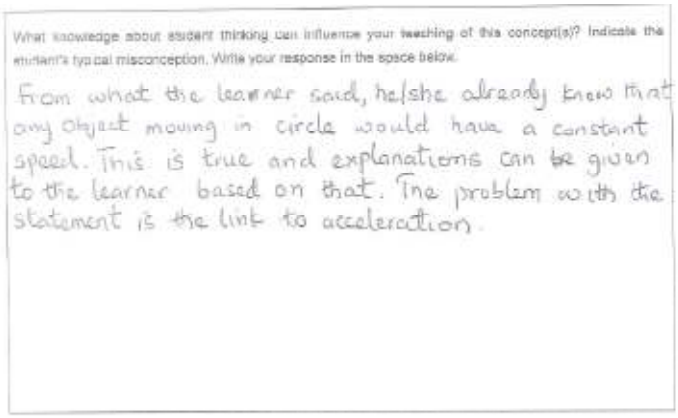
The extract above serves as an example of typical evidence of written responses on the component of learner prior knowledge (LPK) drawing on two other components at an individual level. While the data collected from the written activities from the group discussions during the intervention serve as an example of the pre-service teachers' improved TSPCK following the intervention, it further uncovers the development of TSPCK during the intervention. The pre-

service teachers were expected to discuss in their groups a statement given by a learner as follows: "*If I were driving a car in a circle at a constant speed of 40m/s, then the speed is neither decreasing nor increasing, therefore there must not be an acceleration*" (see appendix V). For this purpose, the pre-service teachers' submitted group discussions were analyzed and presented in the section below.

An example from group discussions (early in the intervention vs later in the intervention)

The comparison below is of extracts taken from submitted class activities, one from the early stages and the other from the later stages during the intervention. The pre-service teachers were working in groups and expected to submit work that reflects the accumulative group's input. The tasks were both related to learners' thinking that the pre-service teachers would know to influence their planning of teaching the topic of kinematics. This is in agreement with the Geddis (1993) argument that teacher knowledge of learners' conceptions is essential in planning the content knowledge for teaching as indicated in the literature review section. Aydin and Boz (2013) also added that a teacher with PCK demonstrates awareness of learners' pre-requisite knowledge, difficulties as well as misconceptions. Thus, Figure 4.5 below presents the Group 1's first responses much early and later in the intervention about their thoughts.

Group 1 – Early in the intervention

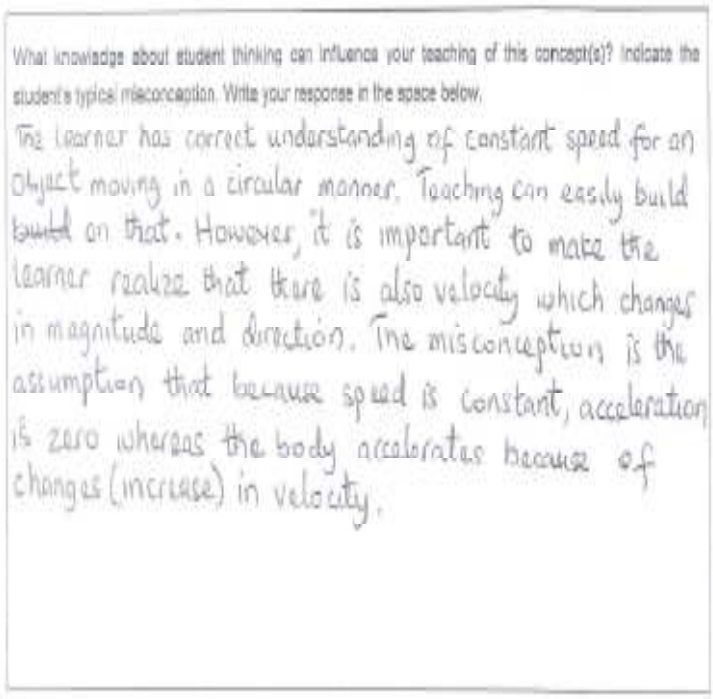

What knowledge about student thinking can influence your teaching of this concept(s)? Indicate the student's typical misconception. Write your response in the space below.

From what the learner said, he/she already knew that any object moving in circle would have a constant speed. This is true and explanations can be given to the learner based on that. The problem with the statement is the link to acceleration.

Typed out extract:

From what the learners said, he/she already knew that any object moving in circle would have a constant speed. This is true and explanations can given to the learner based on that. The problem with the statement is the link to acceleration.

Group 1 – Latter in the intervention


What knowledge about student thinking can influence your teaching of this concept(s)? Indicate the student's typical misconception. Write your response in the space below.

The learner has correct understanding of constant speed for an object moving in a circular manner. Teaching can easily build on that. However, it is important to make the learner realize that there is also velocity which changes in magnitude and direction. The misconception is the assumption that because speed is constant, acceleration is zero whereas the body accelerates because of changes (increase) in velocity.

Typed out extract:

The learner has correct understanding of constant speed for an object moving in a circular manner. Teaching can easily build on that. However, it is important to make the learner realize that there is also velocity which changes in magnitude and direction. The misconception is the assumption that because speed is constant, acceleration is zero whereas the body accelerates because of changes (increase) in velocity.

TSPCK Map

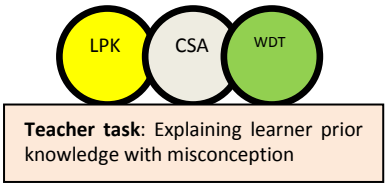


Figure 4.5: Extract of Group 1 initial and final task on the component of LPK

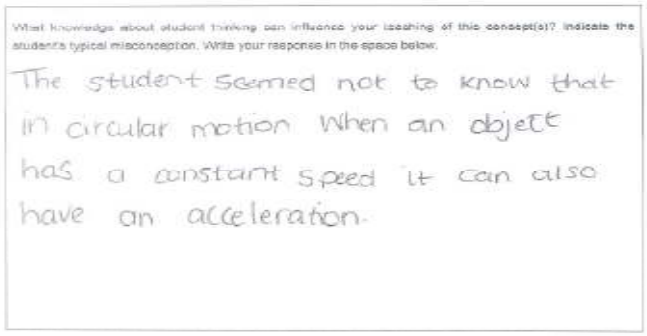
As shown in the Figure 4.5 above, while responding in the task early in the intervention, the Group 1 pre-service teachers pointed out that the learner in question understood constant speed

as it affects an object in circular motion. However, the student's misconception was not well stated as the pre-service teachers just stated "*the problem with the statement is the link to acceleration*". The link to acceleration was not explained. Meanwhile, later in the intervention, the pre-service teachers in the group demonstrated a level of improvement in their discussions of knowledge about student thinking and misconceptions. Responding to the same question later in the intervention, the pre-service teachers were observed to have improved considering the depth of the explanations and the components of TSPCK in actions. As shown in the Figure 4.5 above, the statements highlighted in yellow - *The learner has correct understanding of constant speed for an object moving in a circular manner..... The misconception is the assumption that because speed is constant, acceleration is zero* - describes understanding of learner prior knowledge (Rusznyak & Walton, 2011) with a specific misconception (LPK). Also observed is the understanding of what is important to teach (McLaughlin, 2006; Lichtenberger & Wagner, 2014) as indicated in the pre-service teachers' highlighted statement "*it is important to make the student realize that there is also velocity which changes in magnitude and direction*". This describes the pre-service teachers' understanding of an important concept for learner to learn (Geddis & Wood, 1997) and hence an aspect of the TSPCK component 'curricular saliency' (CSA). Lastly, the highlighted statement "*the body accelerates because of changes in velocity*" could be regarded as an aspect difficult (Antwi et al., 2011) for the learner in question to understand which lead to the misconception. Referring to such statement, describes the pre-service teachers' understanding of the TSPCK component 'what is difficult to teach' (WDT). In all, the pre-service teachers in Group 1 could be assumed to have interactively used the TSPCK knowledge components LPK, CSA and WDT as shown Figure 4.5 TSPCK Map above.

Similarly, early in the intervention and later in the intervention, the Group 2 pre-service teachers' written responses nearly followed the same trend. This is shown in the Figure 4.6 below. As shown in Figure, earlier in the intervention Group 2 pre-service teachers acknowledged the learner prior knowledge including misconception as highlighted. There seems to be no further discussions. However, in the final task, later in the intervention they started by pointing out learner prior knowledge including misconception as indicated in the statement "*The noticeable student's belief is that in circular motion an object moves with a constant speed and zero acceleration*". This has been reported in the literature as discussed in chapter 2 (Antwi et al., 2011). This describes the pre-service teachers' understanding of the TSPCK component 'learner

prior knowledge' (**LPK**). Linked with this statement is why the learner has such a misconception which accounts for what is difficult for the learner to understand, a TSPCK component **WDT** as revealed in the highlighted statement "*This misconception is as a result of associating only speed with acceleration not considering velocity*". That is, the difficulty could have been with the learner not seeing acceleration as a function of velocity (Jager, 1987; Reif & Allen, 1992). Thus, the pre-service teachers' highlighted last statement "*velocity which involves magnitude and direction unlike speed which is only magnitude*" could be regarded what is important concept (Lichtenberger & Wagner, 2014) for the learner to learn. This shows the pre-service teachers' understanding of the knowledge component 'curricular saliency' (**CSA**). Considering the entire final written response, the Group 2 pre-service teachers could be noticed to have interactively used three knowledge components of TSPCK which include LPK, WDT and CSA. The TSPCK Map as displayed in the Figure 4.6 below shows the interrelatedness of these knowledge components describing pre-service teachers' developing quality of TSPCK in kinematics with reference LPK.

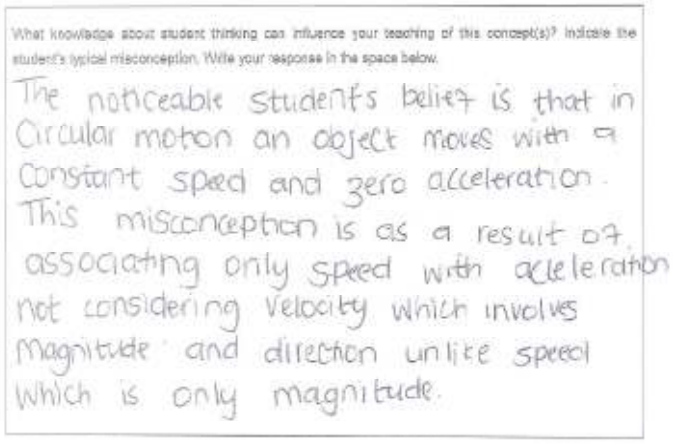
Group 2 – Early in the intervention



Typed out extract:

The student seemed not to know that in circular motion, when an object has a constant speed it can also have an acceleration.

Group 2 – Latter in the intervention



Typed out:

The noticeable student's belief is that in circular motion an object moves with a constant speed and zero acceleration. This misconception is as a result of associating only speed with acceleration not considering velocity which involves magnitude and direction unlike speed which is only magnitude.

TSPCK Map

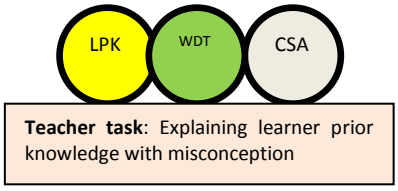


Figure 4.6: Extract of Group 2 initial and final task on the component of LPK

As TSPCK is made of more than just the singular component of learner prior knowledge, evidence of interaction of three components in formulated stated for the component of what is difficult to teach is also looked at for additional evidence of TSPCK improvement.

- ***A sample response based on the component of 'What is difficult to teach' (WDT)***

The question asked in this category as extracted from the TSPCK tool (see appendix IV) is presented in the Figure 4.7 below. The pre-service teachers were asked to list five most difficulties concepts in kinematics with reasons. Three concepts were given as examples; the

emphasis of the test item was in the reasons ascribed to the potential difficulty. The second part of the question required that pre-service teachers write five terminologies in kinematics that pose most difficulty for students with reasons.

Category C - What is difficult to teach?

C1. What **three** kinematics concepts, in your experience, are the most difficult to present effectively to students and what do you think the reason for this is? Some **examples** are provided, which you may use as a basis for your response or **give your own ideas. (Only give reasons for 3 concepts, either using the ones given or your own)**

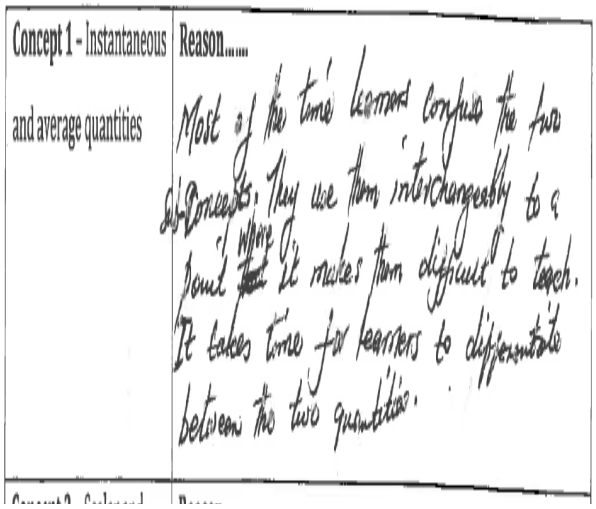
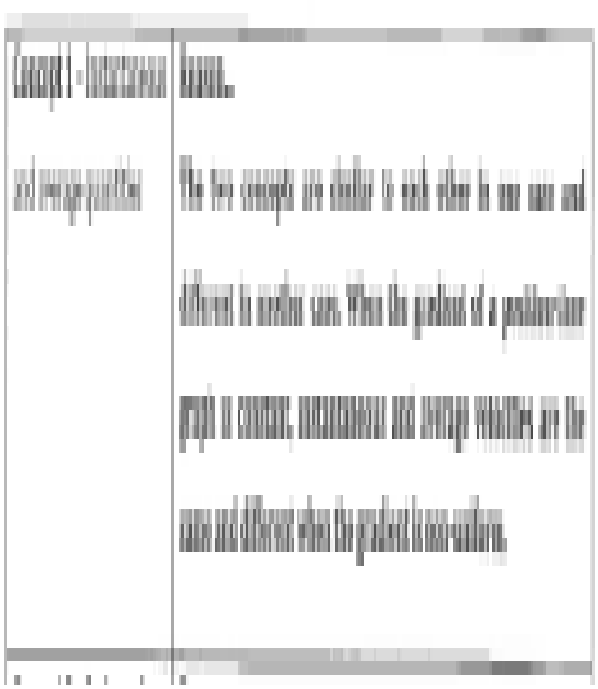
Fill in your response in the table below

Concept 1 *– Instantaneous and average quantities*	***Reason……***
Concept 2 *– Scalar and vector quantities*	***Reason……***
Concept 3 *– Acceleration due to gravity is always constant and pulling downwards*	***Reason……***
Concept 4 –	***Reason……***
Concept 5 –	***Reason……***

Figure 4.7: Sample TSPCK tool item on the component of **WDT**

Based on the sample item in the Figure 4.7 above, a sample of written response showing evidence on drawing on three TSPCK components pre-service teacher TEMA, examined for evidence of developing TSPCK as shown in the Figure 4.8 below. As shown in the Figure, in the pre-test, TEMA acknowledged instantaneous and average quantities as difficult concepts. This was supported with a broad and generic reason that the interchangeably use of these words account for the difficulty. However, there seemed to be an improved perspective as TEMA responded in the post-test. The leaner difficulty can be seen to have been linked to the different meanings of the words 'instantaneous and average' when used in different contexts (Sengupta & Farris, 2012) as stated in the highlighted statement "*The two concepts are similar to each other in one case and different in another case*". This describes the pre-service teachers' knowledge of the TSPCK component 'what is difficult to understand' (**WDT**). While expanding on the next highlighted statement, TEMA stated "*when the gradient of a position-time graph is constant, instantaneous and average velocities are the same and different when the gradient is non-uniform*". TEMA could be carefully observed to have demonstrated understanding of two

TSPCK knowledge components from this statement. The first understanding is that making reference to the gradient (also known as the slope) of a position-time graph is awareness of an important concept (a TSPCK component **CSA**) that leads to speed or velocity in kinematics (Lichtenberger & Wagner, 2014). This is because the significance of finding the slope in such a graph is to estimate either speed or velocity of the object involved (Lichtenberger & Wagner, 2014). The second understanding which seems to be hidden is the awareness of possible misconception (a TSPCK component **LPK**) that might result when there is no adequate knowledge of the gradient of a of a non-uniform position-time graph (Eriksson, 2014). This understanding distinctively describes the concept of instantaneous velocity and average velocity with regards to uniform and non-uniform position-time graph (Lichtenberger & Wagner, 2014).

<table>
<tr><th>Pre-test</th><th>Post-test</th></tr>
<tr>
<td> 
</td>
<td>  </td>
</tr>
<tr>
<td>Typed out extract:

Concept 1 - Instantaneous and average quantities...

Reason: ... Most of the time learners confuse the two sub-concepts. They use them interchangeably to a point where it makes them difficult to teach. It takes time for learners to differentiate between the two quantities.</td>
<td>Typed out extract:

Concept 1 - Instantaneous and average quantities....
Reason: ..... The two concepts are similar to each other in one case and different in another case. When the gradient of a position-time graph is constant, instantaneous and average velocities are the same and different when the gradient is non-uniform.

TSPCK Map

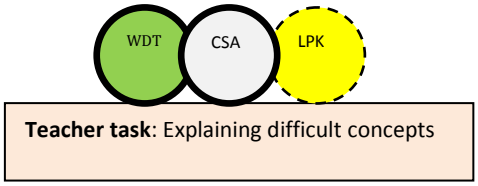
 
</td>
</tr>
</table>

Figure 4.8: Extract of Pre-service teacher TEMA's pre and post-test response on the component **WDT**

Thus as shown in the Figure 4.8 TSPCK Map above, the pre-service teacher could be observed to have interactively used three knowledge components **WDT**, **CSA** and **LPK**. The broken circular line used for the knowledge component **LPK** is because TEMA's knowledge of **LPK** seems to be hidden in the **CSA**. This serves as the pre-service teacher's developing quality of TSPCK in kinematics with regard to the component of what is difficult to teach (**WDT**).

Similar to what was done on the TSPCK component of LPK, further evidence of developing TSPCK was sought by analyzing pre-service teachers' written group discussions on the component of WDT during the intervention. The discussions are presented in section below.

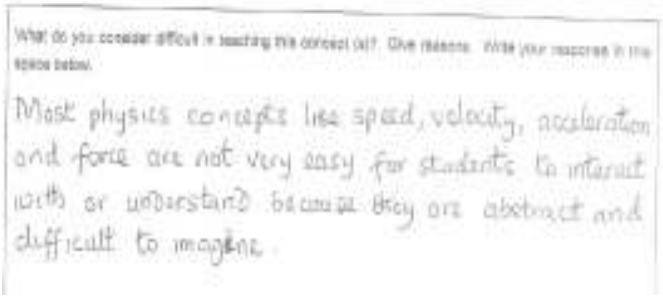
An example from group discussions (early in the intervention vs later in the intervention)

It could be assumed that based on a teacher's level of experience, the issue of identifying what is difficult in a particular topic should be easy. So when the participating pre-service teachers had tasks related to this component at the early stage of the intervention, it was not shocking that their responses were not so explicit with the concepts (Gess-Newsome, 1999a). However, while as the pre-service teachers were taking through the intervention; there was evidence of improvement in their responses. The analysis of the submitted task revealed considerable improvement in understanding similar to what Nilsson and Loughran (2011) observed with professional teachers. Shulman (1986) argued expert teachers reasoned through their teaching by reflecting on their lessons and concepts they are to teach, possibly including their own difficulties as teachers. This is of the implication that pre-service teachers' improvement in explaining kinematics concepts considered difficult helps them to reason on their individual knowledge. In this category, the pre-service teachers were expected to state what could make the identified idea difficult to teach. This is shown in the Figure 4.9 below.

As indicated in the Figure 4.9 below, early in the intervention the Group 1 pre-service teachers mentioned the central kinematics concepts of speed and acceleration and associated the difficulty basically with their abstract nature of the concepts. The pre-service teachers could be observed to have demonstrated understanding of important concepts in their explanation; however, short of sifting out what particularly makes the concepts difficult other than rendering generally abstract. Meanwhile, there appeared to be an improvement as the pre-service teachers responded

in the final task, later in the intervention. The first highlighted statement "*that velocity is different speed because it has magnitude and direction might be difficult*" describes the pre-service teachers' knowledge of learner misconception as against learner assumption that velocity and speed are the same. There is also a kind of awareness that the learner finds it difficult differentiating velocity from speed (Sengupta & Farris, 2012). The pre-service teachers' understanding of learner misconception (TSPCK component **LPK**) and what is difficult to understand (TSPCK component **WDT**) could be observed from the statement. In conjunction is the statement "*as it requires good demonstrations with practical illustrations*" implies the pre-service teachers' understanding of the use of macroscopic representations (TSPCK component **REP**) in the form of physics laboratory equipment (Carrejo and Marshall, 2007), although not specified. The last statement highlighted as shown in the Figure, that is, "*student needs to fully understand scalars and vectors in order to understand the difference between speed and velocity*" describes pre-service teachers' understanding of big ideas (Loughran *et al*. 2012) (scalars, vectors and speed and velocity) and how the knowledge of one affects the other. Such concepts have been regarded central for development of learners' comprehension in the topic (Loughran et al. 2012). This is an aspect of the TSPCK component 'curricular saliency' (**CSA**).

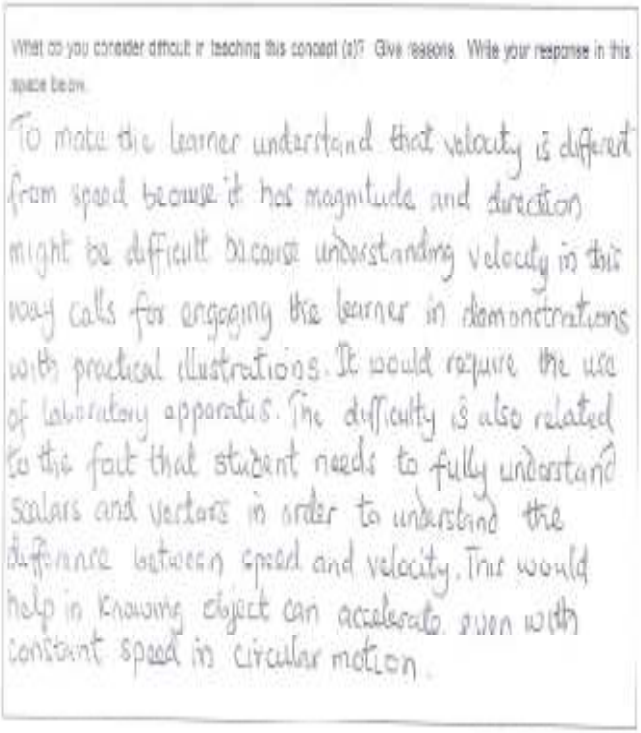
Group 1 – Early in the intervention



Typed out extract:

Most physics concepts like speed, velocity, acceleration and force are not very easy for students to interact with or understand because they are abstract and difficult to imagine.

Group 1 – Latter in the intervention



Typed out:

To make the learner understand that velocity is different speed because it has magnitude and direction might be difficult because understanding velocity in this way calls for engaging the learner in demonstrations with practical illustrations. It would require the use of laboratory apparatus. The difficulty is also related to the fact that student needs to fully understand scalars and vectors in order to understand the difference between speed and velocity. This would help in knowing object can accelerate even with constant speed in circular motion.

TSPCK Map

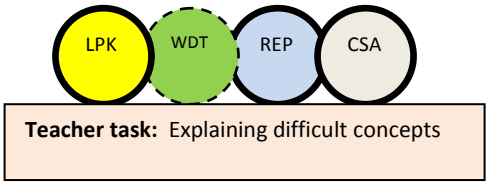


Figure 4.9: Extract of Group 1 initial and final task on the component of WDT

As already discussed above, in all the Group 1 pre-service teachers' response demonstrates interactive use of the knowledge components LPK, WDT, REP and CSA as shown by the TSPCK Map in the Figure 4.9 above.

Likewise, for the Group 2 pre-service teachers, an extract of the initial and final written task is provided in the Figure 4.10 below. As shown in the Figure, the Group 2 pre-service teachers with the first highlighted statement "*Students are familiar with velocity and speed but as having the same meaning*". *This is common in everyday use of the two terms*" demonstrated understanding of learner prior knowledge (**LPK**) a component of TSPCK. Linked to that statement is the pre-service teachers' knowledge of concepts that could have been regarded difficult (Reif & Allen, 1992) (signifying TSPCK component **WDT**) for the learner as in the statement "*velocity is different from speed*". This was connected to the pre-service teachers' understanding of representation (TSPCK component **REP**) as indicated in the statement "*requires some practical demonstration to correct this misconception*".

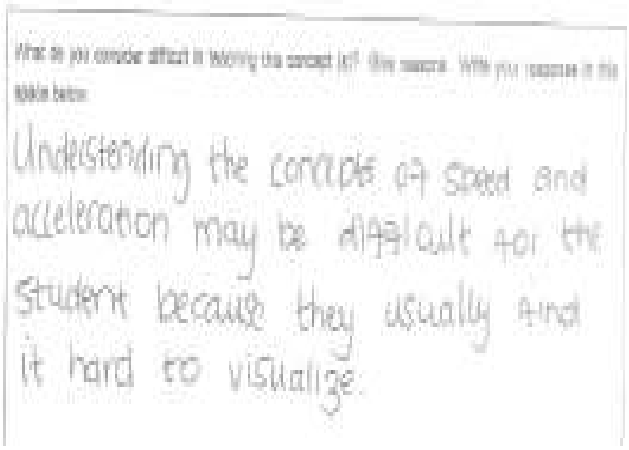
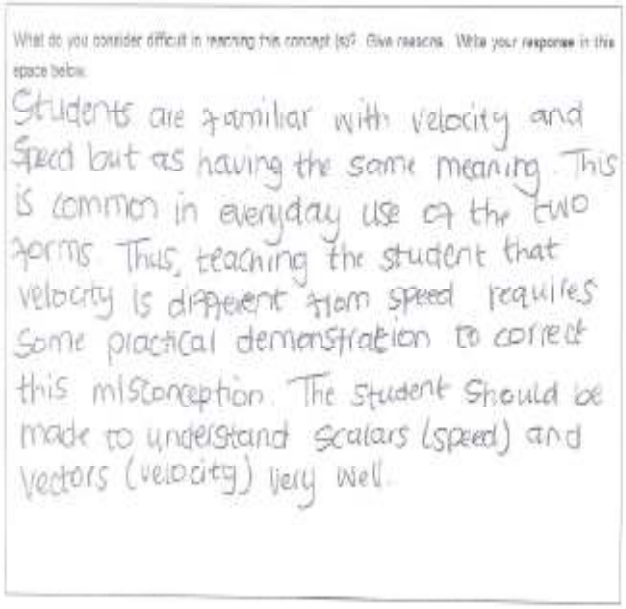
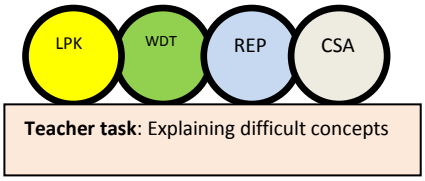
Group 2 – Early in the intervention  	**Typed out extract**: Understanding the concepts of speed and acceleration may be difficult for the student because they usually find it hard to visualize
Group 2 – Latter in the intervention  	**Typed out:** Students are familiar with velocity and speed but as having the same meaning. This is common in everyday use of the two forms. Thus, teaching the student that velocity is different from speed requires some practical demonstration to correct this misconception. The student should be made to understand scalars (speed) and vectors (velocity) very well. **TSPCK Map** 

Figure 4.10: Extract of Group 2 initial and final task on the component of WDT

Similarly, the Group 2 pre-service teachers' last statement as highlighted latter in the intervention in the Figure 4.10 above that is: "*The student should be made to understand scalars (speed) and vector (velocity) very well*" is of the pre-service teachers' knowledge of what is important to teach, an aspect of the TSPCK component curricular saliency (**CSA**). From the

whole response, the pre-service teachers seemed to have demonstrated interactive understanding of the knowledge components **LPK**, **WDT**, **REP** and **CSA**. The TSPCK Map as shown in the Figure 4.10 above visually describes the interrelatedness of the TSPCK components.

While in the two above final responses, there is evidence of drawing on more than three components of TSPCK in the pre-service teachers' formulated responses, on the whole there are more examples drawing on with three components than on four, supporting the allocation of the cohort an average score of '3' corresponding to the 'Developing Category' according to the TSPCK rubric. Having examined the pre-service teachers' written responses on the TSPCK component of what is difficult to teach, the component of 'conceptual teaching strategies' is also looked at for additional evidence of TSPCK improvement.

● ***A sample response based on the component of 'Conceptual teaching strategies' (CTS)***

In this section, the pre-service teachers were majorly required to examine the velocity-time graph given, study a learner's response and then describe specific strategies they would employ to bridge the learner's conceptual gaps. The Figure 4.11 below displays a sample TSPCK tool on this TSPCK knowledge component of CTS.

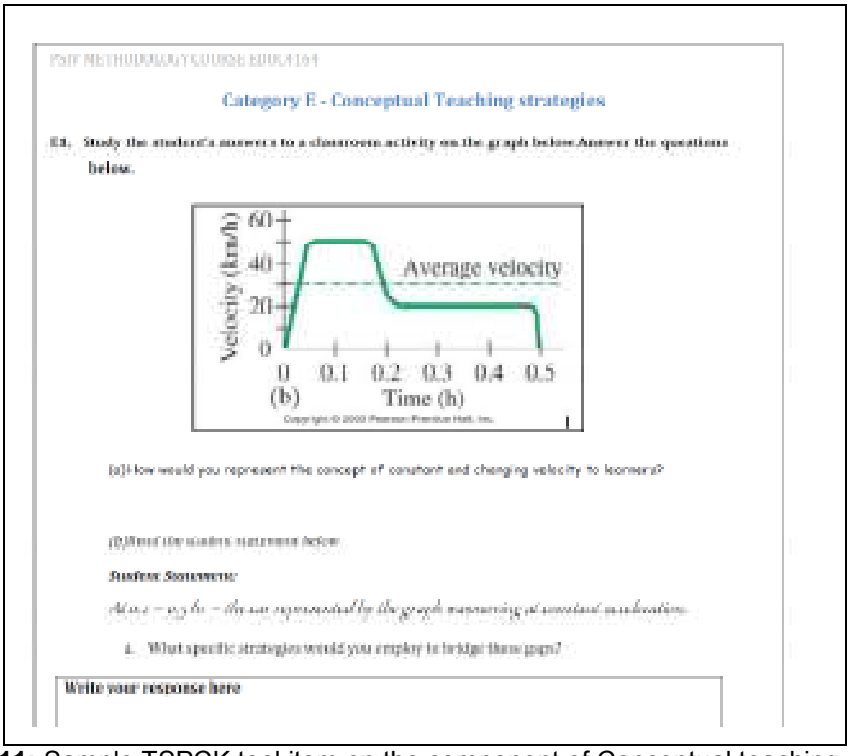
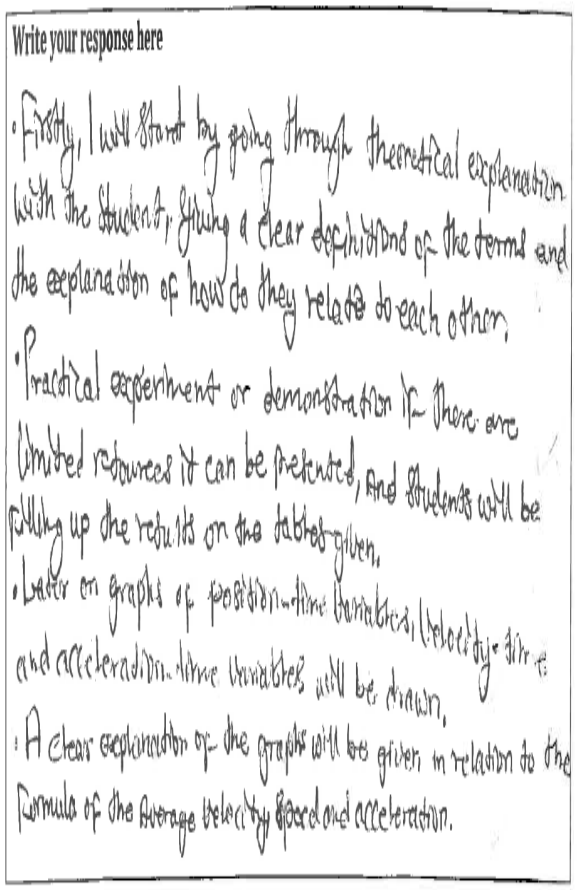
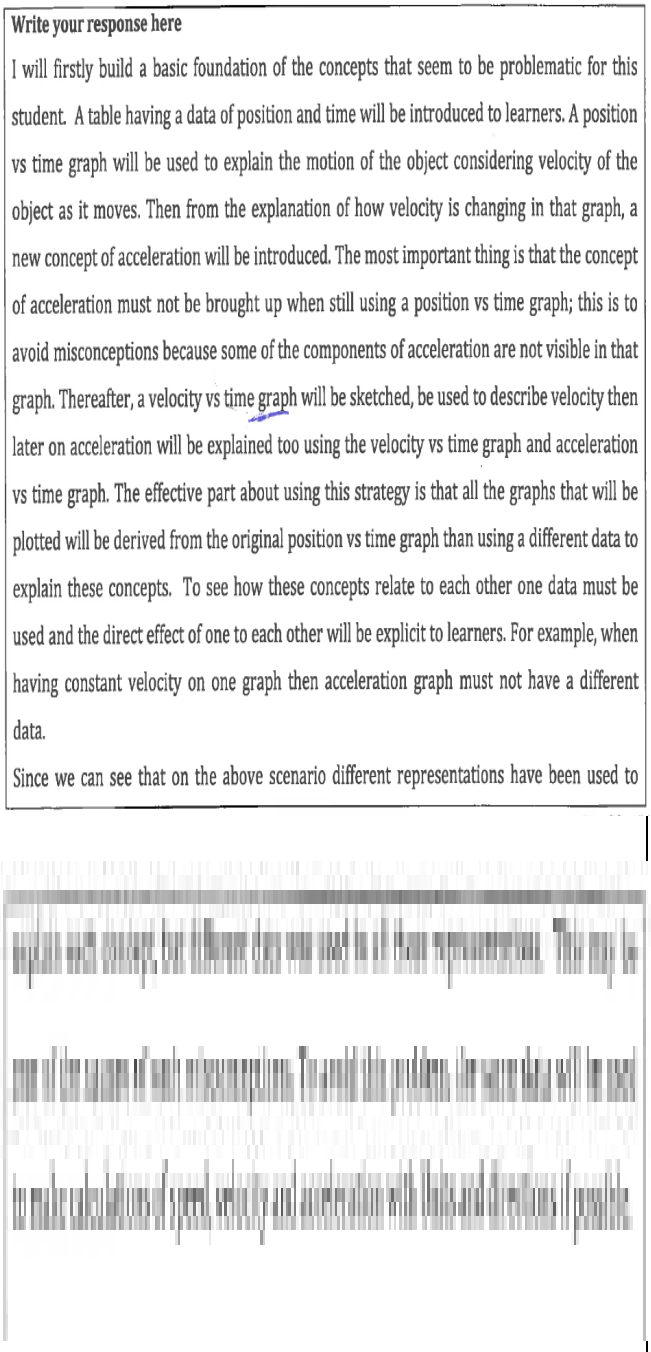


Figure 4.11: Sample TSPCK tool item on the component of Conceptual teaching strategies

An example of pre-service teachers' written response which shows evidence of developing quality of TSPCK with respect to the component CTS is that of pre-service TISI discussed in the Figure 4.12 below.

Pre-test	Post-test
	

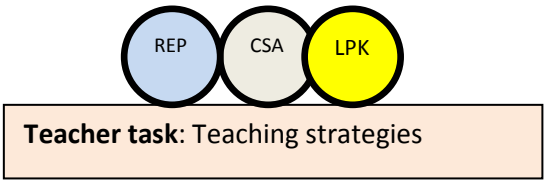
Typed out extract:	**Typed out extract:**
-Firstly, I will start by going through theoretical explanation with the student, giving a clear definitions of the terms and the explanation of how do they relate to each other. - Practical experiment or demonstration if there are limited resources it can be presented, and students will be filling up the results on the table given. - Later on graphs of position-time variables, velocity-time and acceleration-time variables will be drawn - A clear explanation of the graphs will be given in relation to the formula of the average velocity, speed and acceleration.	I will first build a basic foundation of the concepts that seem to be problematic for this student. A table having a data of position and time will be introduced to learners. A position vs time graph will be used to explain the motion of the object considering velocity of the object as it moves. Then from the explanation of how velocity is changing in that graph, a new concept of acceleration will be introduced. The most important thing is that the concept of acceleration must not be brought up when still using a position vs time graph; this is to avoid misconceptions because some of the components of acceleration are not visible in that graph. Thereafter, a velocity vs time graph will be sketched, be used to describe velocity then later on acceleration will be explained too using the velocity vs time graph and acceleration vs time graph. The effective part about using this strategy is that all the graphs that will be plotted will be derived from the original position vs time graph than using a different data to explain these concepts. To see how these concepts relate to each other one data must be used and the direct effect of one to each other will be explicit to learners. For example, when having constant velocity on one graph then acceleration graph must not have a different data. Since we can see that on the above scenario different representations have been used to explain each concept, but different data was used n all these representations. This may be one of the causes of such misconceptions. To avoid this problem, the same data will be used to make calculations of speed, velocity and acceleration with units and directions if possible. **TSPCK Map** 

Figure 4.12: Extract of pre-service teacher TISI's pre and post-test responses

As shown in the Figure 4.12 above, in the pre-test the pre-service teacher (TISI) pointed out the need to first bring up theoretical explanations of the concepts and their relationship. This is followed by the idea of taking students through practical experiment or demonstration. Also to that is the use of graphs that explain relationship between important concepts like position-time, velocity-time and acceleration-time variables. Likewise, TISI made a reference to the use of mathematical formula in explaining the 'concept of velocity, speed and acceleration' (Lichtenberger & Wagner, 2014). It could be observed from the discussion that the pre-service teacher demonstrated understanding of important concepts which describes knowledge of the component 'curricular saliency' (**CSA**). This is coupled with the use of representations (REP) like practical experiment (macroscopic representation) and mathematical formula (symbolic representation) (Carrejo & Marshall, 2007). The pre-service teacher could be said to have interactively demonstrated knowledge of the components **CSA** and **REP**. However, while examining the TISI's response in the post-test, there seemed to be an improved perspective. He began by showing awareness of problematic concepts and the need to build a basic foundation with reference to the 'concepts of position, time and velocity' (Eriksson, 2014) as indicated in the statements "*I will first build a basic foundation of the concepts that seem to be problematic for this student. A table having a data of position and time will be introduced to learners. A position vs time graph will be used to explain the motion of the object considering velocity of the object as it moves*". Together with this awareness of concepts which appeared difficult to the student is the use of graphical representation (Carrejo & Marshall, 2007) for an explanation. The pre-service teacher could be observed to have demonstrated an understanding of an aspect of the TSPCK components 'what is difficult to teach or understand' (**WDT**) and 'representations' (**REP**). In connection to that, TISI gave an idea of using the graph to explain the concept of velocity and introduce the concept of acceleration. These two concepts could be considered fundamental and important for the student to know (Lichtenberger & Wagner, 2014) and hence suggesting that describes the TISI's knowledge of the TSPCK component 'curricular saliency' (**CSA**). Following that is the TISI's understanding of the TSPCK component 'learner prior knowledge including misconception' (**LPK**) as pointed out in the statement "*the concept of acceleration must not be brought up when still using a position vs time graph; this is to avoid misconceptions because some of the components of acceleration are not visible in the graph*". The rest statements further describe TISI understanding of the graphical representation in

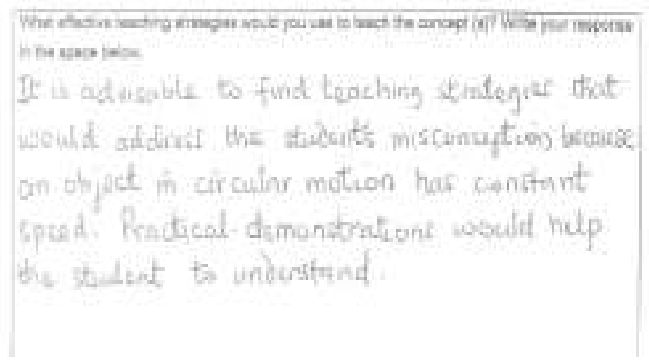
explaining important concepts like velocity-time graph and acceleration. In all, the pre-service teacher's written response revealed understanding of interactive use of three knowledge components **WDT**, **REP** and **CSA** as shown in the TSPCK map above. This describes the improved quality of TSPCK in kinematics with regards to the component of CTS following an intervention.

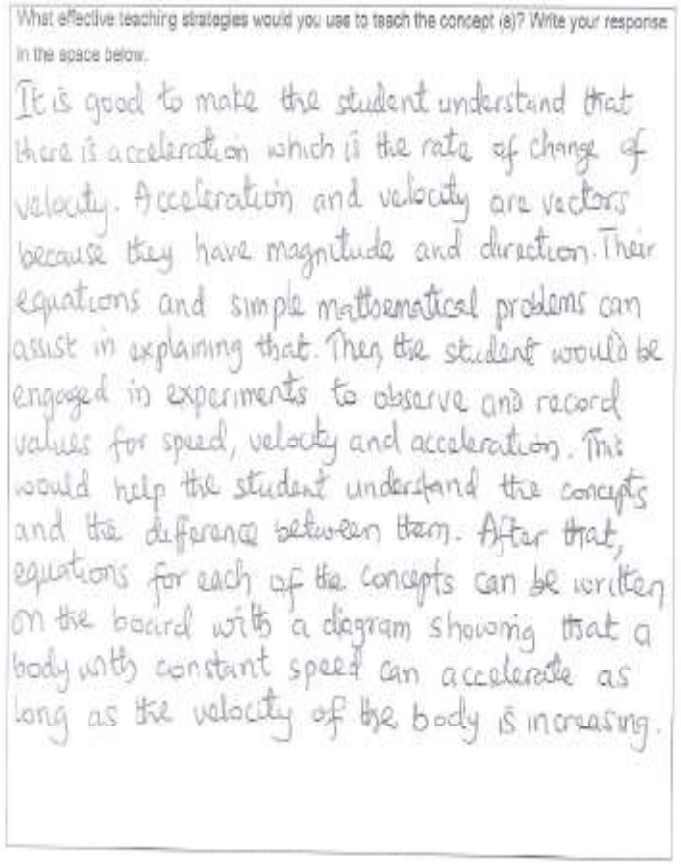
Similar to what was done on the two above TSPCK components; the previous teachers' group discussions were analyzed on this component of CTS as well for possible evidence of improved quality of TSPCK. This is discussed in the next section below.

An example from group discussions (early in the intervention vs later in the intervention)

In correcting the student's assumption that, when an object is in circular motion since the speed is constant there is no acceleration or acceleration is zero, the pre-service teachers were asked to describe appropriate teaching strategies to help such a student. An extract of the Group 1 pre-service teachers' initial and final written responses is given in the Figure 4.13 below. The Figure shows the pre-service teachers' discussions on the possible teaching strategies to address learner conceptual gaps regarding speed and acceleration of an object in circular motion. While the pre-service teachers were responding in the pre-test, they showed an understanding of learner's misconception and suggested practical demonstrations in assisting the learner but there seemed to be no explicit discussions with regards to the strategies. However, while the pre-service teachers were responding in the post-test, they seemed to have an improved and a better approach. For instance, they started by mentioning two important things the learner needs to understand: acceleration as the rate of change of velocity; and acceleration and velocity as vectors because of their magnitude and directional property (Lichtenberger & Wagner, 2014). These are considered basic and important for the learner and thus making reference to such could be describing the pre-service teachers' understanding of the TSPCK component of 'curricular saliency' (**CSA**). On this, the pre-service teachers built the second highlighted statement which suggested the use of equations and practical demonstration. While the use of equations in teaching concepts represent a form of 'symbolic representation', 'practical demonstration' described involves the use of concrete objects and hence, a form of 'macroscopic representation'

(Carrejo & Marshall, 2007). This describes the pre-service teachers' knowledge of the TSPCK component 'representation' (**REP**) in teaching important concepts (**CSA**).

<table>
<tr>
<td>Group 1– Early in the intervention
 
What effective teaching strategies would you use to teach the concept (s)? Write your response in the space below.
It is advisable to find teaching strategies that would address the student's misconceptions because an object in circular motion has constant speed. Practical demonstrations would help the student to understand.</td>
<td>Typed out extract:

It is advisable to find teaching strategies that would address the student's misconception because an object in circular motion has constant speed. Practical demonstrations would help the student to understand.</td>
</tr>
<tr>
<td>Group 1 – Latter in the intervention
 
What effective teaching strategies would you use to teach the concept (s)? Write your response in the space below.
It is good to make the student understand that there is acceleration which is the rate of change of velocity. Acceleration and velocity are vectors because they have magnitude and direction. Their equations and simple mathematical problems can assist in explaining that. Then the student would be engaged in experiments to observe and record values for speed, velocity and acceleration. This would help the student understand the concepts and the difference between them. After that, equations for each of the concepts can be written on the board with a diagram showing that a body with constant speed can accelerate as long as the velocity of the body is increasing.</td>
<td>Typed out extract:

It is good to make the student understand that there is acceleration which is the rate of change of velocity. Acceleration and velocity are vectors because they have magnitude and direction. Their equations and simple mathematical problems can assist in explaining that. Then, the student would be engaged in practical demonstration to observe and record values for speed, velocity and acceleration. This would help the student understand the concepts and the difference between them. After that, equations for each of the concepts can be written on the board with a diagram showing that a body with constant speed can accelerate as long as the velocity of the body is changing.

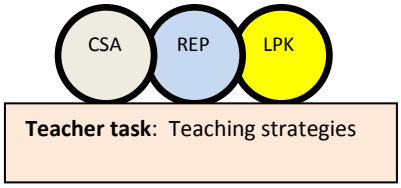
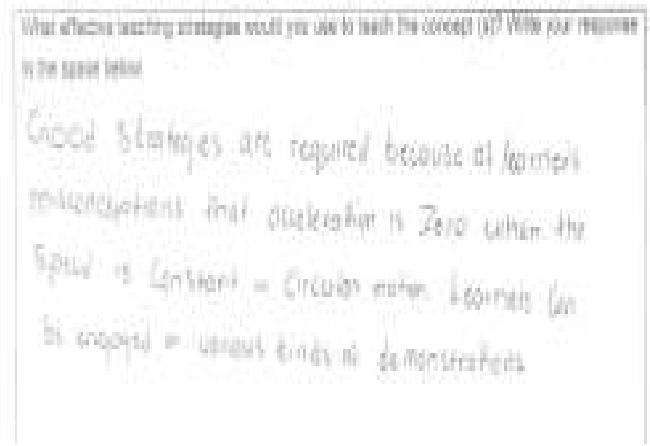
TSPCK Map
 
</td>
</tr>
</table>

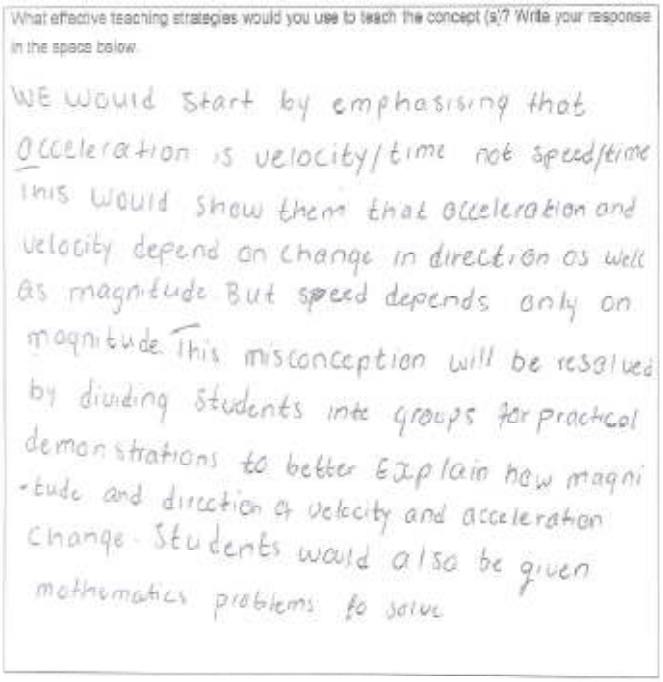
Figure 4.13: Extract of Group 1 initial and final task on the component of CTS

Likewise, the pre-service teachers' last statement as shown in the Figure 4.13 above, in connection to the previous, re-emphasized the use of equations (**REP**) and then an important sentence. The highlighted sentence "*showing that a body with constant speed can accelerate as long as the velocity of the body is changing*" shows teachers' awareness of the learner difficulty (TSPCK component **WDT**) that object in circular motion with constant speed has acceleration. The learner lack of this understanding leads to the misconception (TSPCK component **LPK**) that acceleration of such an object is zero. The TSPCK component LPK could be noticed to be hidden in the knowledge component WDT which the statement denotes. Thus, in the entire response, the pre-service teacher could be observed to have interactively used the knowledge components CSA, REP, WDT and LPK. The TSPCK Map in the Figure 4.13 above shows the interrelatedness of these TSPCK components, broken circular lines used for LPK it seems to be hidden in WDT. This is an improved discussion which describes the pre-service teachers' developing quality of TSPCK in kinematics with reference to the component CTS.

Similarly, the pre-service teachers in Group 2 showed an extent of improvement in their TSPCK as they formulated their response in the final task. An extract of the pre-service teachers' written group discussions is displayed in the Figure 4.14 below. As shown in the Figure, the Group 2 pre-service teachers' explanations in the initial task identified the learner's misconception with a suggestion that learners can be engaged demonstrations to address such. However, the pre-service teachers seemed to have an explicit discussion as they responded in the final task. The first highlighted statement addressed the learner misconception as indicated "*emphasising that acceleration is velocity/time not speed/time*". This describes the pre-service teachers' understanding of the TSPCK component learner prior knowledge (**LPK**). This is connected to what is important for student to understand as in the statement "*This would show them that acceleration and velocity depend on change in direction as well as magnitude. But speed depends only on magnitude*" demonstrating the pre-service teachers' understanding of TSPCK component 'curricular saliency' (**CSA**). There is also evidence of the use of macroscopic and symbolic representations as the pre-service teachers' practical demonstration and solving mathematical problems respectively. This describes pre-service teachers' understanding of the TSPCK component 'representation' (**REP**) in teaching and addressing learner's misconception. In formulating the entire final task responses, the pre-service teachers could be observed to have interactively used the TSPCK knowledge components LPK, CSA and REP. This visual

description of the knowledge components is displayed as the TSPCK Map in the Figure 4.14 below.

<table>
<tr>
<td>Group 2– Early in the intervention
  </td>
<td>Typed out extract:

Good strategies are required because of learner's misconception that acceleration is zero when the speed is constant in circular motion. Learners can be engaged in various kinds of demonstrations.</td>
</tr>
<tr>
<td>Group 2 – Latter in the intervention
 
What effective teaching strategies would you use to teach the concept (s)? Write your response in the space below.
WE would start by emphasising that Acceleration is velocity/time not speed/time This would show them that acceleration and velocity depend on change in direction as well as magnitude But speed depends only on magnitude This misconception will be resolved by dividing students into groups for practical demonstrations to better Explain how magni-tude and direction of velocity and acceleration change. Students would also be given mathematics problems to solve</td>
<td>Typed out:
We would start by emphasising that acceleration is velocity/time not speed/time. This would show them that acceleration and velocity depend on change in direction as well as magnitude. But speed depends only on magnitude. This misconception will be resolved by dividing students into groups for practical demonstration to better explain how magnitude and direction of velocity and acceleration change. Students would also be given mathematics problems to solve.

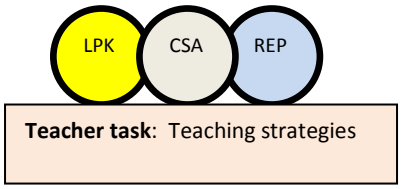
TSPCK Map
 
</td>
</tr>
</table>

Figure 4.14: Extract of Group 2 initial and final task on the component of CTS

To sum up the discussions above so far, I have first shown how the group of pre-service teachers in this study has on the whole improved their TSPCK as a result of the intervention. To do this I have shown scored category of the quality of TSPCK before and after the intervention using the responses from the TSPCK Kinematics tool. I have further shown evidence drawn from qualitative data, both from the tool and data collected during the intervention, with selective components of TSPCK how their knowledge was developing during the intervention. All the above responded to the impact of the intervention on the quality of the TSPCK in the topic. The evidence of improvement in the quality of TSPCK is more evident where the pre-service teachers were able to formulate responses to teacher tasks that draw on three components of TSPCK interactively in most cases and four components in few instances. However, it is also important in this study to demonstrate how dramatically or significant the qualitative observed improvement is. In an effort to establish the extent of the observed improvement, quantitative analysis of the data was carried out. To this end, the Rasch statistical model was used to generate means of the scores that could be compared for difference. This is presented in the next section below.

4.2.2 Quantitative measurement of the observed TSPCK improvement in Kinematics – Rasch Model Analysis

The quantitative analysis of the pre-service teachers' responses to the TSPCK Kinematics was done using Rasch Model Analysis (RMA). This is a kind of statistical analysis that could be used in establishing the validity and reliability of research findings. In this study, the Rasch analysis was done with a computer program software Winsteps MINISTEP 3.90.2 version (Linacre, 2015). As a type of analytical model, Rasch Model Analysis gives two categories of reliability measurement: One for the person to whom the instrument is administered; and the other for the items that the instrument contains. With this, Rasch measurement describes connective likelihood in which both item difficulty and person ability are placed along a single continuum in logits (Bond & Fox, 2015). The '*logit*' as used here refers to the unit of measurement used in expressing person measures and item difficulties (Bond & Fox, 2015). Boone *et al*. 2014) added that "*because persons and items have the same unit, and because logits are equal-interval units, persons can be compared to other persons, items can be compared to other items…..also items and persons can be compared*" (p. 70). This implies that using Rasch

measurement in this study enables the calibration of item difficulty measures and person ability by standardized intervals of estimation along a common continuum in contrast to raw scores that give imprecise intervals (Boon *et al*. 2011). Rasch measurements help to avoid non-linearity of rating scales as well as the non-linearity of raw test data (Boone *et al*. 2014). It gives a more accurate representation of participant performances as argued by Boon et al. (2011). Bond and Fox (2015) further added by referring to Rasch model as a unique one that offers the essential objectivity with a scale which is independent of the distribution of traits that the persons it measures possess. Thus, using Rasch person measure in this study added more thorough analysis with accuracy and value achieving the assumption of scale linearity. Likewise, Rasch Model Analysis does its conversion of raw scores (i.e. ordinal data) to linear measurements on an equal interval scale with undimesionality as the underlying assumption (Boone et al. 2014). The underlying assumption builds on the argument that all items in a tool work together to measure a single construct, thereby demonstrating the validity of the measurements. Thus, using Rasch Model in this study helps in verifying if the identified five knowledge components that enhance transformation of CK work jointly to measure TSPCK as a construct. In all, this helps in estimating person reliability as well as item reliability with the establishment of validity through the generated fit statistical figures. The TSPCK raw data in the Table 4.1 were subjected to Rasch Analysis to estimate item difficulty measure and person ability measure. The Table 4.2 below gives the summary of the Rasch generated person measures and fit statistics (see appendix IX and X for the original version).

Table 4.2: Person measures order (N=19)

	Pre-test TSPCK Kinematics			Post-test TSPCK Kinematics		
Person	Rasch measures	Fit statistics for Persons IN.ZSTD	OUT.ZSTD	Rasch measures	Fit statistics for Persons IN.ZSTD	OUT.ZSTD
TMAM	0.46	0.0	-0.1	5.02	0.4	0.5
TANA	0.46	0.2	0.3	2.05	-1.7	-1.6
TEMA	-0.09	0.1	-0.1	3.96	-0.9	-0.4
TISI	-0.09	-0.6	-0.5	3.96	-0.9	-0.4
TOSM	-0.09	-1.5	-1.5	1.11	1.8	2.0
TNAH	-1.31	1.2	1.3	2.05	-1.7	-1.6
TAKA	-1.31	0.3	0.3	1.11	-1.1	-1.1
TCMM	-1.31	0.5	0.6	5.02	0.8	0.6
TUMA	-1.31	0.2	0.2	3.96	-0.9	-0.4
TMAT	-1.31	0.5	0.6	1.11	1.8	1.7
TSZO	-1.31	0.2	0.2	2.05	-1.7	-1.6
TAZU	-1.31	-0.7	-0.7	1.11	1.1	1.2
TUMO	-1.98	0.7	0.7	6.67	-0.8	-0.6
TIFA	-2.68	0.5	0.5	2.05	0.5	0.4
TIGO	-3.47	-0.5	-0.5	0.28	0.3	0.3
TLMO	-4.53	0.6	0.6	0.28	1.9	1.7
TLEM	-4.53	0.5	0.3	1.11	-1.1	-1.1
TSIU	-5.98	Minimum measure		0.28	0.28	-0.2
TSMO	-5.98	Minimum measure		2.05	-1.7	-1.6
Mean	**-1.98**			**2.38**		
Validity measured through fit statistics		All ZSTD values are within the acceptable range of +2 and -2		All ZSTD values are within the acceptable range of +2 and -2		

Note: The order in which the pre-service teachers are presented in the table above is based on descending order of Rasch measures in pre-test

As shown in the Table 4.2 above, the first column tagged 'person' represents the assigned codes to the pre-service teachers for reporting in this study. The generated Rasch measures for pre- and post-test for kinematics are given in the second and fifth column respectively highlighted in yellow. These represent Rasch calculated person ability for the persons (pre-service teachers). The fact that Rasch Analysis put these person measures on 'an equidistant scale' (Boon *et al.*

2011) ranking individual pre-service teachers' ability that took the test is a now a possibility. Conventionally, increase in the positivity of Rasch measures implies high person ability while increase in the negativity of the values indicates high person difficulty on the items on the instrument (Boone et al. 2014). That is, the higher the person measure the more the better the performance of the participant. This is because according to the coding of the rubric used, '1' is for limited (more difficulty, low ability) and '4' for exemplary (less difficulty, high ability). Thus, in the Kinematics pre-test, only two pre-service teachers (TMAM and TANA) were observed to have the highest person ability with positive Rasch measure of 0.46 each. The negative Rasch measures of varying degrees were noticed with the remaining seventeen other pre-service teachers to indicate individual level of difficulties. Meanwhile, significant improvement appeared to have emerged in the post-test as the analysis generated positive Rasch measures for all the pre-service teachers though at varying degrees. The pre-service teacher TUMO appears to have demonstrated the highest person ability with a Rasch measure of 6.67 while three pre-service teachers (TIGO, TLMO and TSIU) the lowest person ability with an individual Rasch measure of 0.28. Other pre-service teachers have their Rasch measures in-between the highest and the lowest. The fact that positive Rasch measures are generated for the post-test is an indication of an improved pre-service teachers' understanding of TSPCK component following an intervention. This supports earlier qualitative analysis which indicates pre-service teachers moved from a lower overall group score of '2' (denoting basic level of TSPCK) to a higher overall average score of '3' (i.e. Developing).

● ***How the Rasch model determines validity***

In addition to the Rasch measures, the z-standardized values are equally of great importance in this quantitative analysis. These are IN ZSTD and OUT ZSTD which represent the Infit z-standardized indices and Outfit z-standardized indices respectively. These statistical indices are referred to as the 'fit statistics'. They describe how well data conform to the Rasch Model Analysis. According to Boone et al. (2014), "*we identify respondents with ZSTD values of 2.0 or higher, and those with a ZSTD values of -2 or lower, as worthy of further investigation*" (p. 173). As a result, by convention +2 and -2 represent the boundary, an acceptable fit range within which the generated statistical indices perfectly match the Rasch Analysis Model. Having fit statistical indices generated for a set of data establishes the validity of the measures and hence the

instrument (Linacre, 2015). Thus, if the person and item fit statistics are found in the acceptable range, then both person measure and item measure work together to measure a single construct, constituting a valid measure (Boone et al. 2014). Thus, in the Table 4.2 above, the two headings 'IN ZSTD and OUT ZSTD' represent the Infit and Outfit z-standardized values. All statistical indices for pre-test and post-test in kinematics are within the range of +2 and -2. These are considered fitting statistical indices that uniformly measure TSPCK as argued theoretically in the Literature Review, Chapter 2, as a single construct and hence establishing construct validity.

- ***How Rasch determines reliability***

In spite of the establishment of validity illustrated above, determining the reliability of the measures is also vital. As described by Ihantola and Kihn (2011), reliability in quantitative analysis refers the possibility of having results being replicated or repeated, which in returns tells on the internal consistency of the measurement. The Rasch Model Analysis generates reliability values for both the items and persons. These are referred to as the item reliability and person reliability. The Table 4.3 below gives the summary of the reliability values. For the original version see appendix XI and XII.

Table 4.3: Person and Item reliabilities for pre and post-TSPCK kinematics

	Pre-test	**Post-test**
Person reliability(MODEL RMSE)	0.73	0.60
Item reliability(MODEL RMSE)	0.72	0.94
Cronbach ALPHA (KR-20)	0.73	0.59
Validity measured through fit statistics	All ZSTD values are within the range of +2 and -2	All ZSTD values are within the range of +2 and -2

As shown in the Table 4.3 above, the item reliabilities for pre-test and post-test were 0.72 and 0.94 respectively which are generally not less than the acknowledged 0.7 for Cronbach's Alpha (KR-20) used in estimating the degree of internal consistency of the measurement (Boone et al. 2014). This implies that the items in the TSPCK Kinematics tool are replicable. Also, the person reliability vales of 0.71 and 0.60 for pre-test and post-test respectively are well above 0.5 and hence within the range 0 and 1 (Boone et al. 2014). This provides an estimate on the pre-

service teachers' ability in responding to the items in the tools which could be seen to be reliable. Having these person reliability values moderately high could also imply there were enough items spread along the continuum and enough spread of ability among persons (Bond & Fox, 2015). Meanwhile, such person reliability values could be enhanced by adding to the number of persons as well as ensuring participation of persons with high ability. Likewise, the higher the number of items completed by an individual who participated in the study the higher the person reliability. As a result, low person reliability indicates more persons of better ability are needed to complete the items (Linacre, 2015).

- ***Comparison for significant difference***

There is an understanding that for an accurate comparison of item or person measures, it is important for the scales to be equated (Wright, 1996). This is because Rasch analysis, for each of item and person measure in the test, generates its own common scale (Wright, 1996). Thus, Morrison and Fitzpatrick (1992) suggested anchoring as a method of equating scales whenever Rasch analysis is used in research. The method of anchoring calls for the calibration of the base test (e.g. pre-test scores) and then calibrating the current test (e.g. post-test) by fixing the item difficulty parameters for the common items obtained from the calibration of the base test (Morrison & Fitzpatrick, 1992). The test that has been anchored (e.g. pre-test) could then be used for equating the post-test scores as well as the transfer scores as the case may be. This was done in this study to accurately compare means of the tests for evidence of significant difference. The Table 4.4 below summarizes the results of the anchored kinematics pre-test scores in comparison with the post-test in kinematics as originally shown in the appendix XIII and XIV. In the case, the pre-test that has been anchored was used for equating the post-test scores in Kinematics. Considering the mean for pre-test person measures (i.e. -1.98) to that of the post-test person measures (i.e. 1.42), a very wide significant difference could be observed. This implies pre-service teachers' increase in knowledge and skills of using TSPCK components interactively with respect to making the teaching of kinematics concepts understandable in planning context.

Table 4.4 Stacked data – Person Measures from anchored TSPCK kinematics

Pre-service teachers	Pre-test Person Rasch measure	Measures Error	Post-test Person Rasch measure	Measures Error
TMAM	0.46	0.73	3.11	0.90
TANA	0.46	0.73	1.17	0.74
TEMA	-0.09	0.75	2.38	0.82
TISI	-0.09	0.75	2.38	0.82
TOSM	-0.09	0.75	0.64	0.72
TNAH	-1.31	0.81	1.17	0.74
TAKA	-1.31	0.81	0.64	0.72
TCMM	-1.31	0.81	3.11	0.90
TUMA	-1.31	0.81	2.38	0.82
TMAT	-1.31	0.81	0.64	0.72
TSZO	-1.31	0.81	1.17	0.74
TAZU	-1.31	0.81	0.64	0.72
TUMO	-1.98	0.83	4.11	1.13
TIFA	-2.68	0.86	1.17	0.74
TIGO	-3.47	0.93	0.14	0.70
TLMO	-4.53	1.16	0.14	0.70
TLEM	-4.53	1.16	0.64	0.72
TSIU	-5.98	1.91	0.14	0.70
TSMO	-5.98	1.91	1.17	0.74
Mean	**-1.98**		**1.42**	

Note: The order in which the pre-service teachers are presented in the table above is based on descending order of Rasch measures in pre-test (see Table 4.3 above)

Now, subjecting the Rasch measures of the stacked data in the Table 4.4 above to further analysis using Wilcoxon Paired Signed Rank test of QI Macros (Whitley & Ball, 2002) (version 2015), statistical values in the Figure 4.15 below were generated. Using Wilcoxon paired signed rank test for non-parametric data was majorly to determine significant difference (Whitley & Ball, 2002) between the participant pre-test scores and post-test scores. This is preferable to a paired-sample t-test in the study because of its appropriateness for non-parametric data of small sample size (N=19).

Pre-test Person Measures	Post-test Person Anchored Measures	Diff= (Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	190
0.46	3.11	2.65	2.65	10.00	10	n=	19
0.46	1.17	0.71	0.71	1.00	1	σ(T)	49.69909
-0.09	2.38	2.47	2.47	6.50	6.5	α	0.05
-0.09	2.38	2.47	2.47	6.50	6.5	Action(L)	-97.4
-0.09	0.64	0.73	0.73	2.00	2	Action(U)	97.4
-1.31	1.17	2.48	2.48	8.50	8.5	z	3.8
-1.31	0.64	1.95	1.95	4.00	4	Reject Null at 0.05	
-1.31	3.11	4.42	4.42	14.00	14	*p*	0.000
-1.31	2.38	3.69	3.69	12.00	12		
-1.31	0.64	1.95	1.95	4.00	4		
-1.31	1.17	2.48	2.48	8.50	8.5		
-1.31	0.64	1.95	1.95	4.00	4		
-1.98	4.11	6.09	6.09	17.00	17		
-2.68	1.17	3.85	3.85	13.00	13		
-3.47	0.14	3.61	3.61	11.00	11		
-4.53	0.14	4.67	4.67	15.00	15		
-4.53	0.64	5.17	5.17	16.00	16		
-5.98	0.14	6.12	6.12	18.00	18		
-5.98	1.17	7.15	7.15	19.00	19		
		#N/A			#N/A		

Figure 4.15: Summary statistics for pre and post-TSPCK significant difference

The analysis as shown in the Figure 4.15 above was done at a significance level (α) of 0.05. The analysis shows that at the significance level (α) of 0.05, the estimated value of p (= 0.000) is much more less than the significance level, α = 0.05 (Whitley & Ball, 2002). This shows a significance difference between the pre-service teachers' pre-test and post-test and so we reject null hypothesis. This implies that the participant pre-service teachers experienced a significant improvement in their engagement with the TSPCK components in the planning context of Kinematics after the intervention. The highest improvement is observed on three components: What is difficult to teach (WDT); Representations (REP); and Learner Prior Knowledge (LPK) as shown in the Table 4.5. These components were also seen as most evident and mostly used by the pre-service teachers in formulating effective teacher responses.

The discussions above, was aimed at presenting evidence to the first major finding, that the intervention had a dramatically, significant improvement of the quality of TSPCK in the topic of intervention which was kinematics. This finding is important to the discipline of physics as it signals operational implications, discussed in detail in the next chapter, to the way future physics teachers maybe taught. The second major finding is linked to the observation that, the process of acquiring the observed improvement in TSPCK in the topic of intervention was not just

automatic, but requiring rigorous engagement even though the components of TSPCK were taught explicitly in the topic. These findings are discussed below.

4.3 Evidence of engaging TSPCK components

In addition to the discussed pre-service teachers' TSPCK improvement in the topic of kinematics, there is also evidence that the process of acquiring the improvement was a rigorous engagement with the knowledge components, which in-turn reflects the quality of TSPCK in the topic. This observation is interesting. Given that the topic of intervention singularly received extensive attention by virtue of its status as a topic used in the intervention, one is prone to actually be expectant of the observed improvement in TSPCK, and also that the demonstration of knowledge in the components would be easy for the participating pre-service teachers. However, the analysis suggests a differentiated pattern in the averaged group score measures of improvement in each TSPCK component across the pre- and the post-TSPCK tests.

With reference to the Table 4.1 above, the pre-service teachers seemed to improve two categories up on the TSPCK component 'what is difficult to teach' (**WDT**) as seen from the average group score of '2' in the pre-test and '4' in the post-test. The process of rigorous engagement responsible for this jump was observed in the pre-service teachers' ability to provide reasons linking to specific gate keeping concepts which when not fully understood add to the difficulty of a concept in the post-test different from just identifying specific concepts with broad reasons as seen in the pre-test. Likewise on the TSPCK component 'learner prior knowledge' (**LPK**), the pre-service teachers improved a category up with average score of '2' in the pre-test and '3' in the post-test. The engagement was observed as the pre-service teachers' made effort of expanding and re-phrasing explanations to confront misconceptions in the post-test than just acknowledging misconception with standardized knowledge but with no expansion as in the pre-test. Similarly, on the component of 'representations' (REP), the improvement was a category up with average score of '2' and '3' in the pre and post-test respectively. The engagement took place in the post-test as the pre-service teachers' logical discussions showed conceptual orientation of the use of the model than just listing concepts with no explanation as the pre-test. Also, on the TSPCK component 'conceptual teaching strategies' (CTS) with average score of '2' in the pre-test and '3' in the post-test, the engagement occurred as the pre-service teachers

confronted student misconceptions by considering at least an aspect related to curriculum saliency using two or more different representations to enforce an aspect of the concept.

In contrast to the above pattern, there seemed to be not such observation on the component of 'curricular saliency' (CSA) as same average score of '2' was calculated for both the pre and post-test. This is shown in the Table 4.5 above.

Further trends of engagement with TSPCK components were observed from the Rasch analysis measurements.

● ***Item Rank Order***

When comparing Item measures order of TSPCK components in the pre-test to that of the post-test there could be observed to exist, evidence of different levels of engagements with the components. The Table 4.5 below gives the summary of the Rasch analysis generated item rank order for pre-test (see appendix XV) and post-test (see appendix XVI).

Table 4.5: Item Rank Order for pre and post-TSPCK test in kinematics

Item measures – Prior to the intervention (pre-TSPCK test)					
Component	LPK	CSA	WDT	CTS	REP
Rasch measure	-1.38	-0.33	0.07	0.48	1.15
Item measures – Immediately after the intervention (post-TSPCK test)					
Component	WDT	REP	LPK	CTS	CSA
Rasch measure	-3.19	-0.59	-0.32	0.65	3.45

Key words: LPK = Learner Prior Knowledge; CSA = Curricular saliency; WDT = What is difficult to teach; CTS = Conceptual teaching strategies; REP = Representations

As shown in the Table 4.5 above, in the pre-test the lowest Rasch measures of -1.38 and -0.33 were generated for the knowledge components 'learner prior knowledge' (LPK) and 'curricular saliency' (CSA) respectively. This implies that the pre-service found those two components easy to engage as the values were below zero. This is because, interpretatively the higher the item Rasch measure the more the difficulty the participant encounter in engaging with such an item (Boone *et al*. 2014). The remaining three knowledge components 'what is difficult to teach' (WDT), 'conceptual teaching strategies' (CTS) and 'representations' (REP) have the Rasch

measures of 0.07, 0.48 and 1.15 respectively with REP as the most difficult. However, there observed to be a shift in the ranking order of the items in the post-test. The pre-service teachers demonstrated higher engagement of improved understanding with three knowledge components 'what is difficult to teach' (WDT), 'representations' (REP) and 'learner prior knowledge' (LPK) with Rasch measures -3.19, -0.59 and -0.32 respectively indicating WDT as the easiest. The remaining two knowledge components 'conceptual teaching strategies' (CTS) and 'curricular saliency' (CSA) with Rasch measures 0.65 and 3.45 respectively were found difficult indicating CSA as the most difficult.

Efforts were made in this study to investigate the difficulties pre-service teachers encounter with the component CSA which was easy in the pre-test but became the most difficult in the post-test. Three important reasons were gathered from a number of pre-service teachers who were available for the interview. The first identified reason responsible for the difficulty according to the pre-service teachers TAKA and TEMA was the similarities and interrelatedness of the kinematics concepts listed, out of which the pre-service teachers were asked to choose those they considered as Big Ideas.

> TAKA: *The concepts are interrelated and that made it difficult for me to decide on how to rank them. Sequencing too was difficult for this reason.*
> TEMA: *The challenge is that many concepts might form a foundation of kinematics. However asking us to choose only three out of the stated concepts leaves one feels like justice is not done. Sequencing the concepts was less challenging as one knows that distance is the fundamental concept that together with time they give rise to speed.*

The second identified reason for the difficulty was related to the content knowledge. The responses supporting this are as follows:

> TIFA: *The challenge is that I know how the concepts in the topic follow each other, but it is difficult to choose which is more important than others. It might be that I needed to understand the topic and its concepts better.*
> TMAM: *Kinematics has always been a challenging topic for me and without finding more and researching about the topic I couldn't have succeeded in answering and arranging the topics.*

TANA: *Selecting the big ideas was difficult because identifying concepts and subconcepts of those concepts requires deep knowledge of the entire topic and how concepts link.*

The third reason identified was the lack of teaching experience which only a pre-service teacher (TIFA) mentioned. Although all the pre-service teachers available for the interview were asked to indicate if they had an experience of teaching the topic of kinematics, none of them gave 'yes' as an answer to the question. The pre-service teacher TIFA's response is as follows:

TIFA: *The difficulty in sequencing was that I have no experience teaching the content of this topic and to what extent should I go in teaching the topic.*

With all the issues discussed above, having Item rank order in the post-test different from the pre-test is of the implication that the pre-service teachers' improvement in the quality of TSPCK was not just an automatic process of simply recalling or regurgitation of learnt knowledge in the intervention rather it was a rigorous engagement with each knowledge component at varying degrees. This means there were reasoning processes going on as the pre-service teachers engaged with the components of TSPCK in transforming kinematics concepts. These could be associated with a cognitive pedagogical transformation process which goes beyond direct application of learned pedagogical transformation competence during the intervention. Investigating the development of such competence using five knowledge of TSPCK is the target and achievement of this study. Likewise, the order of item difficulty after the intervention further establishes topic specificity of PCK in kinematics as different from other topics like chemical equilibrium (Mavhunga & Rollnick, 2013) and particulate nature of matter (Judith, 2014). The order of difficulty in these chemistry topics was observed different to each other and to the one now established in kinematics. In all, the pre-service teachers differently engaged with the TSPCK knowledge components which positively affected their quality of TSPCK in the topic of kinematics.

4.4 Conclusion

This chapter presented the analysis of data collected on the intervention topic of kinematics. The analysis revealed two major important findings: the participating pre-service teachers improved in the quality of their TSPCK following the intervention; and the improvement in the quality of TSPCK was observed to be a process of engagement with the knowledge components but not

just an automatic process of simply recalling or regurgitation of learned pedagogical transformation competence. The qualitative analysis of data indicated improved pre-service teachers' TSPCK with better understanding of engaging interactively three or more knowledge components in formulating responses. The quantitative as well gave the picture of the extent of this engagement by providing ranking order of TSPCK components. Following the intervention, the pre-service teachers were observed to have better understanding in engaging the components of learner prior knowledge, what is difficult to teach and representations although the lack of shift in the curricular saliency is of concern. The quantitative analysis also established the validity and reliability of the newly developed TSPCK kinematics tool used in this study through acceptable statistical indices. With all that, there is still the need to investigate the extent to which pre-service teachers can transfer the learned pedagogical transformation competence to a new physics topic in a planning context and in actual classroom teaching as part of the targets of this study. Hence, the next chapter discusses the analysis of data collected on a new physics topic (electricity) and records of pre-service teachers' classroom teaching.

CHAPTER FIVE

5. MEASUREMENT OF TRANSFERABILITY OF PEDAGOGICAL TRANSFORMATION COMPETENCE

In this chapter I present discussions on the pre-service teachers' transferability of learnt pedagogical transformation competence to the topic of electricity. This was observed both in the pre-service teachers' written responses to the validated TSPCK tool (in electric circuits) and in the actual classroom teaching of electricity. The conclusive remarks end the chapter with a projection to the next chapter.

5.1 Introduction

The analysis of data collected on the topic of intervention was started in the previous chapter. That was done in answering the first research question which was examining the improvement in the quality of TSPCK following an intervention that taught the competence to transform content knowledge. Following that, this chapter presents discussions on the pre-service teachers' transferability of learned pedagogical transformation competence to a new physics topic of electric circuits. Aydin et al. (2014) argued that while investigating a particular teachers' PCK for a topic provides useful information, concentrating on the same group of teachers' PCK for different topics in the same discipline helps in understanding better the nature of PCK and I thereby point the same for TSPCK. As a result, it was of interest in this study to examine pre-service teachers' TSPCK in a different physics topic (electricity) not discussed in class during the intervention. This is done with the primary purpose of answering the second research question guiding this study - To what extent is the pre-service teachers' learnt pedagogical transformation competence transferable to the development of TSPCK in a new physics topic - electricity?

There is acknowledgement in this study that PCK is a kind of tacit knowledge that teachers gain in the actual classroom teaching (Kind, 2009) and hence not transferable. The same applies to TSPCK, a new version of PCK focused at a topic level, used in this study. However, while pre-service teachers learn techniques of transforming concepts in a topic through five knowledge components of TSPCK, they develop pedagogical transformation competences (Mavhunga &

Rollnick, 2013). These learned pedagogical transformation competences consist of both knowledge and skills required to reason through a topic and transform the concepts for understanding by learners. With this, Rollnick and Mavhunga (2015) argued that "*what is transferable to another topic is the ability to use the five TSPCK components, where successful engagement with the concepts of the new topic is still needed to improve TSPCK in the new topic*" (Rollnick & Mavhunga, 2015, p. 142). This implies that transferability of the learnt pedagogical transformation knowledge and skills comes to play as the pre-service teachers demonstrate ability to formulate explanations using knowledge components of TSPCK interactively. Thus, evidence of pre-service teachers' extent of transferability of learned pedagogical transformation competence in this study was gathered in the context of interactive use and engagement with TSPCK knowledge components.

5.2 The extent of transferability of learnt pedagogical transformation competence

To examine the extent to which pre-service teachers were able to transfer learnt pedagogical transformation competence for the development of TSPCK, a new physics topic was considered. The topic chosen was electricity. The reason was that, pre-service teachers were exposed to electricity as a topic in the content course in their third year of study, thus reasonable to assume familiarity with content knowledge of the topic. The criterion for familiarity with content knowledge is based on the understanding that content knowledge is needed as a pre-cursor for the development of PCK (Kind, 2009), and by association to TSPCK. The content course is a separate course focusing on developing content knowledge; it runs parallel to the methodology courses which have a different focus – developing the knowledge to teach topics. So, electricity as a topic was not discussed in any methodology course in any kind of format.

The data in electricity was collected using a TSPCK tool in electric circuits. The collected data were analyzed qualitatively and quantitatively. Also, a few records of actual classroom teaching of pre-service teachers, who taught electricity after the intervention, during a teaching school experience, were analyzed qualitative as supporting evidence. One important finding emerged from the analysis of TSPCK data collected in the topic of electric circuits. It was found out that the pre-service teachers, like in the topic of intervention, portrayed a 'developing' category of TSPCK which portrays understanding of three knowledge components used interactively. This finding is discussed in the sub-sections below.

5.2.1 Evidence supporting developing TSPCK in electricity in the planning context

For the purpose of positioning the context in which the analysis of TSPCK data was done, this discussion briefly recaps what has been explained in chapter three regarding the tool and methods of analysis. It is in this context that the trends observed in the data are explained. As alluded to in the methodology chapter, chapter 3, a validated TSPCK tool in electric circuits (Zimmerman, 2015) was used to examining the pre-service teachers' quality of TSPCK in electric circuits. The tool has the same structure with other existing TSPCK tools, such as that used for kinematics the topic of intervention, in terms of the TSPCK components except that the contents are based on the topic of electric circuits. The TSPCK tools consisted of five categories, A to E. Each of the categories corresponds to a knowledge component of TSPCK construct which serves as the theoretical framework for this study. The detailed sample tool is attached (see appendix VI). The tool was administered to the pre-service teachers as a take home examination equivalent assignment, three weeks after the intervention. The pre-service teachers had no prior knowledge that electric circuits would be the topic of assessment. However, the fact that it was administered as a task equivalent to an examination, it meant that they will demonstrate their best effort. They were instructed not to discuss answers or exchange ideas with their colleagues. An online university platform known as SAKAI was created for the submission of the task with specific date after which submissions were no longer allowed. The pre-service teachers were given a week to complete and submit the task on SAKAI. Nineteen (N=19) pre-service teachers collected the take home assignment and submitted at the stipulated time. After receiving the completed TSPCK Electric circuits tools, the pre-service teachers' responses were marked using a 'validated TSPCK four points (1-4) scale rubric' (Mavhunga, 2012) similar to the topic of kinematics. With the 4-point scale rubric used, a pre-service teacher could only score 1, 2, 3 or 4 point on a particular knowledge component (item). '1' point stands for 'Limited'; '2' stands for 'Basic'; '3' stands for 'Developing' and '4' stands for 'Exemplary'. That means the lowest score a pre-service teacher could get on a component of TSPCK is 1 and the highest is 4. The criteria specified according to the rubric were used in marking pre-service teachers' responses on each TSPCK component. Myself (as the researcher) and the course lecturer individually marked and scored the pre-service teachers' responses to the tools. Thereafter, we meet to discuss our individual scoring to ascertain consistencies in the marks.

Where there were differences, we looked again at the pre-service teachers' responses in accordance with the rubric, discussed and reached an agreement on the final scores.

The Table 5.1 below gives the final the pre-service teachers' raw scores in the transfer task (electricity). The first column displays the codes assigned to each pre-service that participated in this study. The remaining five columns represent the five knowledge components of TSPCK under which items in the TSPCK tool were grouped. The last column gives the mean score for each pre-service teacher scores on the five knowledge components. Calculated at the bottom are the average of mean scores for pre-service teachers and the average score per TSPCK component.

Table 5.1: Raw scores for pre-service teachers' transfer task in electricity (N=19)

Pre-service teachers	Learner Prior Knowledge (LPK)	Curricular saliency (CSA)	What is difficult to teach (WDT)	Representations (REP)	Conceptual teaching strategies (CTS)	Mean score for Pre-service teacher
TIGO	3	4	4	3	2	3.0
TNAH	4	4	4	3	3	4.0
TAKA	3	2	4	3	2	3.0
TSIU	1	2	3	3	2	2.0
TCMM	4	4	4	4	4	4.0
TEMA	3	3	4	3	3	3.0
TLMO	4	3	4	3	3	3.0
TMAM	3	3	3	3	3	3.0
TSMO	4	2	4	3	2	3.0
TLEM	4	3	4	3	3	3.0
TUMO	4	4	4	3	4	4.0
TUMA	4	4	3	3	4	4.0
TANA	4	4	4	4	3	4.0
TISI	3	3	4	4	2	3.0
TOSM	3	3	4	4	3	3.0
TMAT	4	4	4	3	2	3.0
TIFA	3	3	4	4	3	3.0
TSZO	4	3	4	3	3	3.0
TAZU	3	4	4	4	3	4.0
					Average of mean score for Pre-service teachers	**3.0**
Average score	3	3	4	3	3	
					Overall average group for the five components	**3.0**

While the Table 5.1 above presents pre-service teachers' performances in each component, it should be noted that the criteria in the TSPCK rubric actually calls for interaction of each of the components with others see shaded text in Figure 5.1 below.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • Repeats standard definition with reference to any other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Repeats standard definition drawing on one other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two other component of TSPCK interactively	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on three or more other component of TSPCK interactively

Figure 5.1: An extract of the TSPCK rubric for the component of 'learner prior knowledge'

Hence, the average group score was for the five knowledge components altogether as a measure of their possible effect onto each other. With regards to that, Abell (2008) argues PCK is not the sum of the individual components rather their interactions, likewise I do not consider TSPCK be the sum of the mere components but their interactions as also alluded in Aydin et al. (2015). Thus, considering the overall group score for the task which can be seen to be '3' signifying 'Developing TSPCK' according to the rubric, this acquired category implies that, the pre-service teachers were able to provide evidence of responses to teacher tasks drawing on three components of TSPCK interactively. This is similar to what the pre-service teachers experienced in the topic of kinematics following an intervention as discussed in the previous chapter. Meanwhile, in as much as a mathematical calculation may not be sufficient in representing a complex trait such as TSPCK fully, it was used in this study as a proxy measure reflecting the overall interactions and the influence of the components on each. Such components interactions are an indicator of the likely transferability of pedagogical transformation competence that produces TSPCK in the topic of electricity.

To support the calculated group score of 3, which corresponds to the Developing category of TSPCK, in the discussions below I show examples of pre-service teachers' responses that draw on three categories extracted from the transfer task. While the discussions provide evidence on the pre-service teachers' developing TSPCK in the planning context, it is important to develop insight into how that manifests in their actual classroom teaching. Thus, in addition to the pre-service teachers' written responses in the TSPCK transfer task, the records of actual classroom teaching were also analyzed for further evidence of developing TSPCK. It should be pointed at this point that in order to ensure and enhance reliability of the findings in this study, the identification of TSPCK Episodes (that is, moments of interactively use of two or more TSPCK

components) and their component compositions were compared between two raters (Myself as the researcher and the course coordinator). We thereafter calculated the inter-rater reliabilities values of 0.88 and 0.76 for all written responses and analyzed actual classroom teaching respectively. These are discussed in the subsections below.

● ***A sample response based on the component of 'Learner Prior Knowledge' (LPK)***

Figure 5.2 below presents a test item extracted from the TSPCK tool on the component of 'learner prior knowledge' (LPK) where the pre-service teachers were required to provide a feedback response to a learner who has a misconception about the: flow of charges (electric current) across electric bulbs arranged in series and parallel; and effect of increase in resistance on the brightness of an electric bulb. To each of the two questions, a selection of possible teachers' responses were provided, none of which was incorrect. The participant pre-service teachers were expected to select the response they would most likely use in their practice and explain the reason for their response in each case. An extract of the test items (see appendix VI for the full sample) on this component is provided in the Figure 5.2 below in order to provide the context to the responses.

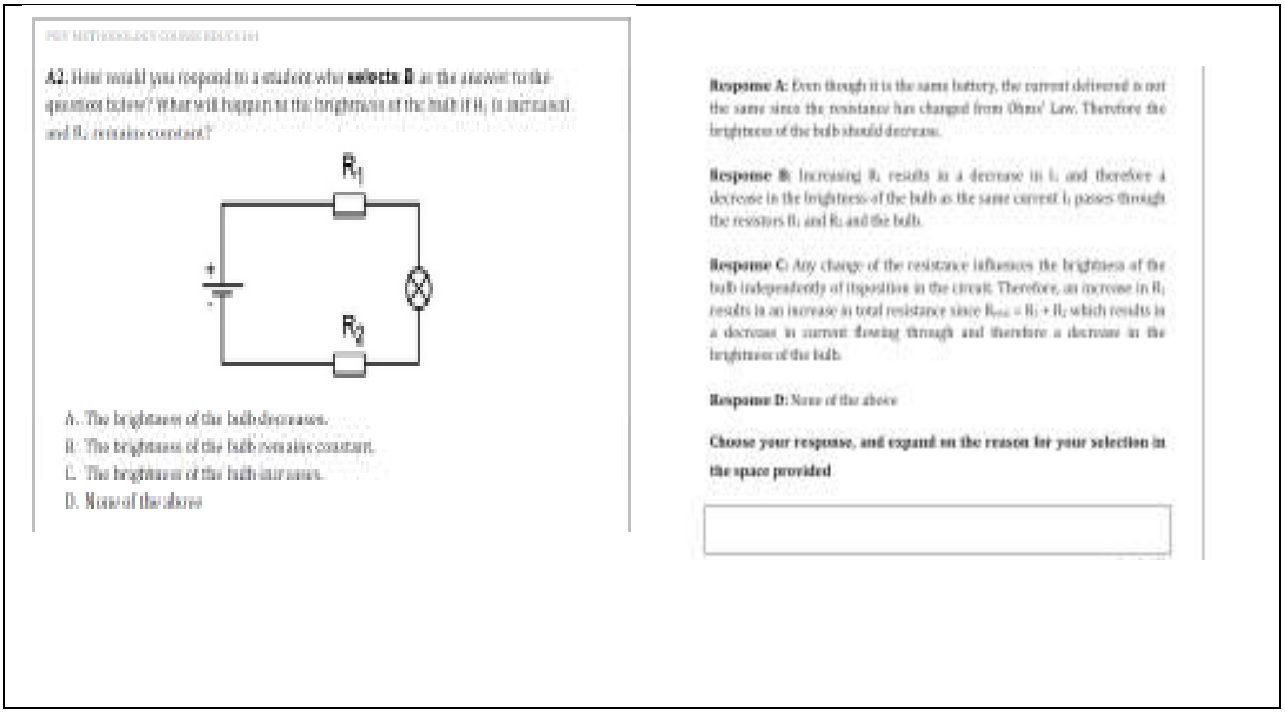
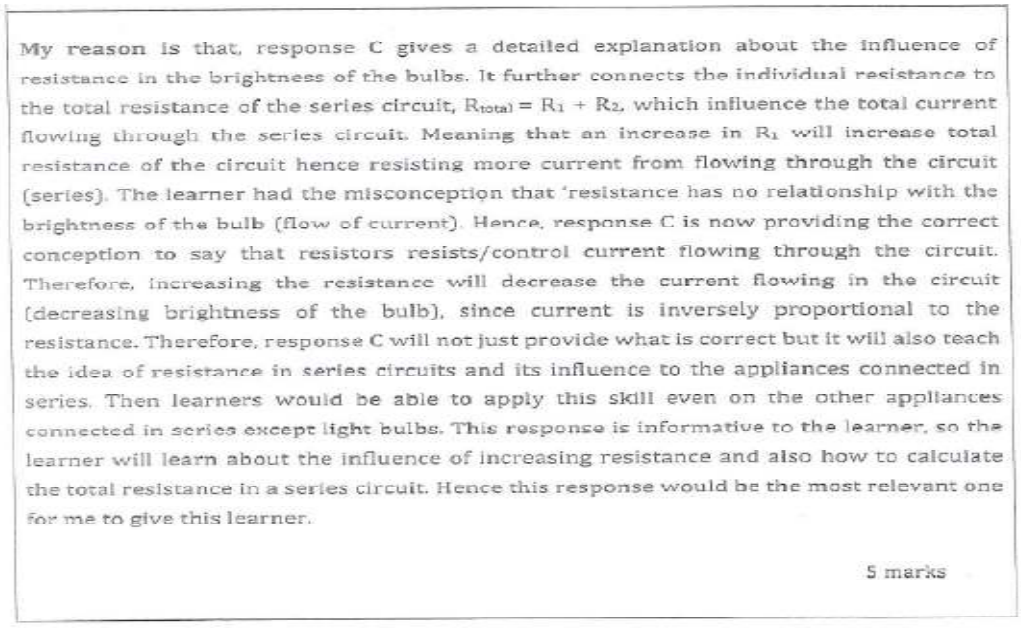


Figure 5.2: Sample TSPCK tool item on the component of LPK

An example of the pre-service teachers' written responses which shows developing TSPCK and interactive use of three or more knowledge components is that of the pre-service teacher TAZU and TANA. An extract of the TAZU's written work is displayed in the Figure 5.3 below.



My reason is that, response C gives a detailed explanation about the influence of resistance in the brightness of the bulbs. It further connects the individual resistance to the total resistance of the series circuit, $R_{total} = R_1 + R_2$, which influence the total current flowing through the series circuit. Meaning that an increase in R_1 will increase total resistance of the circuit hence resisting more current from flowing through the circuit (series). The learner had the misconception that 'resistance has no relationship with the brightness of the bulb (flow of current). Hence, response C is now providing the correct conception to say that resistors resists/control current flowing through the circuit. Therefore, increasing the resistance will decrease the current flowing in the circuit (decreasing brightness of the bulb), since current is inversely proportional to the resistance. Therefore, response C will not just provide what is correct but it will also teach the idea of resistance in series circuits and its influence to the appliances connected in series. Then learners would be able to apply this skill even on the other appliances connected in series except light bulbs. This response is informative to the learner, so the learner will learn about the influence of increasing resistance and also how to calculate the total resistance in a series circuit. Hence this response would be the most relevant one for me to give this learner.

5 marks

Typed out extract:

My reason is that, response C gives a detailed explanation about the influence of resistance in the brightness of the bulbs. It further connects the individual resistance to the total resistance of the series circuit, $R_{total} = R_1 + R_2$, which influence the total current flowing through the series circuit. Meaning that an increase in R1 will increase total resistance of the circuit hence resisting more current from flowing through the circuit (series). The learner had the misconception that 'resistance has no relationship with the brightness of the bulb (flow of current). Hence, response C is now providing the correct conception to say that resistors/control current flowing through the circuit (decreasing brightness of the bulb) since current is inversely proportional to the resistance. Therefore, response C will not just provide what is correct but it will also teach the idea of resistance in series circuits and its influence to the appliances connected in series. Then learners would be able to apply this skill even on the other appliances connected in series except light bulbs. This response is informative to the learner, so the learner will learn about the influence of increasing resistance and also how to calculate the total resistance in a series circuit. Hence this response would be the most relevant one for me to give this learner.

TSPCK Map

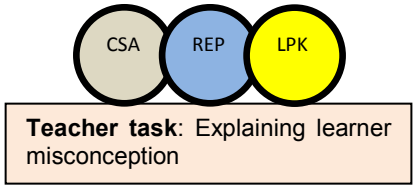
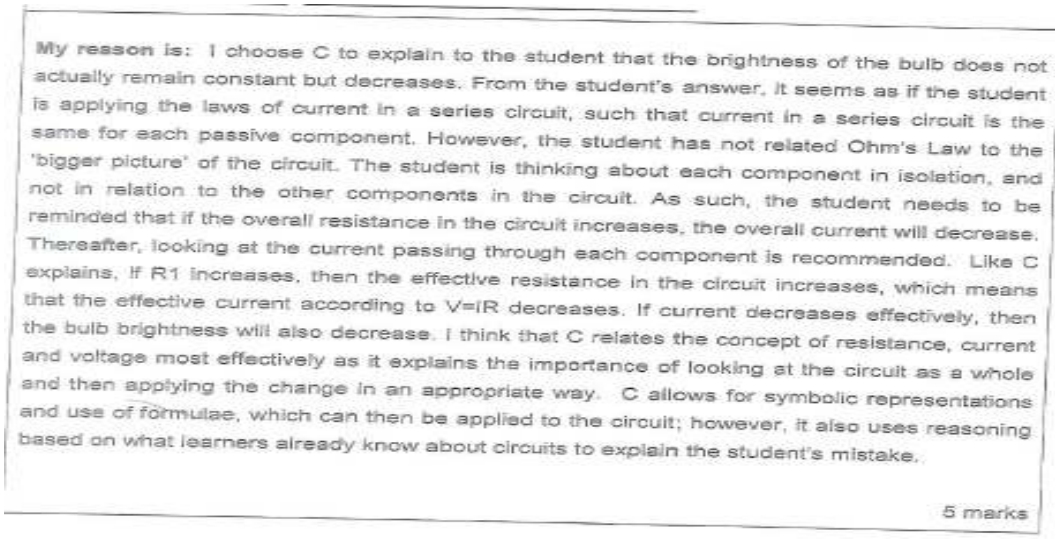


Figure 5.3: Extract of the pre-service teacher TAZU's response on the component LPK

As shown in the Figure 5.3 above, while TAZU was expanding on the option chosen he made a statement highlighted "*influence of resistance in the brightness of the bulbs. It further connects the individual resistance to the total resistance of the series circuit*". This aspect of resistance and how that affects the brightness of the bulbs could be regarded essential for the learner in question to learn (Shipstone & Cheng, 2001) based on his/her answer chosen. This describes TAZU's knowledge of the TSPCK component 'curricular saliency' (**CSA**). In connection to that is the observed symbolic representation, representing the equivalent resistance across resistor R_1 and R_2 present in the circuit (Carrejo & Marshall, 2007). This shows TAZU's knowledge of the TSPCK 'representation' (**REP**) as it relates to current. Linked to that is the TAZU's statement highlighted "*The learner had the misconception that resistance has no relationship with the brightness of the bulb (flow of current)*" describing his understanding of the TSPCK component 'learner prior knowledge' (**LPK**) in which misconception is embedded (İpek *et al*. 2008). The rest highlighted statements further build on what is important for the learner to know, an aspect of **CSA**. In all, the pre-service teacher TAZU could be observed to have interactively engaged three main knowledge components **CSA**, **REP** and **LPK** in formulating response. The TSPCK Map shown in the Figure 5.3 above describes the interrelatedness of these knowledge components.

Similar, the pre-service teacher TANA's written response on this component of LPK is displayed in the Figure 5.4 below.



My reason is: I choose C to explain to the student that the brightness of the bulb does not actually remain constant but decreases. From the student's answer, it seems as if the student is applying the laws of current in a series circuit, such that current in a series circuit is the same for each passive component. However, the student has not related Ohm's Law to the 'bigger picture' of the circuit. The student is thinking about each component in isolation, and not in relation to the other components in the circuit. As such, the student needs to be reminded that if the overall resistance in the circuit increases, the overall current will decrease. Thereafter, looking at the current passing through each component is recommended. Like C explains, if R1 increases, then the effective resistance in the circuit increases, which means that the effective current according to V=IR decreases. If current decreases effectively, then the bulb brightness will also decrease. I think that C relates the concept of resistance, current and voltage most effectively as it explains the importance of looking at the circuit as a whole and then applying the change in an appropriate way. C allows for symbolic representations and use of formulae, which can then be applied to the circuit; however, it also uses reasoning based on what learners already know about circuits to explain the student's mistake.

5 marks

Typed out extract:

My reason is: I choose C to explain to the student that the brightness of the bulb does not actually remain constant but decreases. From the student's answer, it seems as if the student is applying the laws of current in a series circuit, such that current in a series circuit is the same for each passive component. However, the student has not related Ohm's Law to the 'bigger picture' of the circuit. The student is thinking about each component in isolation, and not in relation to the other components in the circuit. As such, the student needs to be reminded that if the overall resistance in the circuit increases, the overall current will decrease. Thereafter, looking at the current passing through each component is recommended. Like C explains, if R1 increases, then the effective resistance in the circuit increases, which means that the effective current according to V=IR decreases. If current decreases effectively, then the bulb brightness will also decrease. I think C relates the concept of resistance, current and voltage most effectively as it explains the importance of looking at the circuit as a whole and then applying the change in an appropriate way. C allows for symbolic representations and use of formulae, which can then be applied to the circuit, however, it also uses reasoning based on what learners already know about circuits to explain the student's mistake.

TSPCK Map

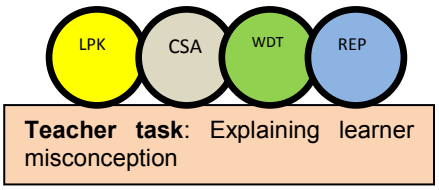


Figure 5.4: Extract of the pre-service teacher TANA's response on the component LPK

As shown in the Figure 5.4 above, the issue as highlighted in the first statement ("*the brightness of the bulb does not actually remain constant but decreases*…..") seems to be acknowledging the learner's misconception (İpek *et al*. 2008) indicating TANA's understanding of the TSPCK component **LPK**. Building on that is the emphasis on what the learner in question needs to know as in the statement "*the student needs to be reminded that if the overall resistance in the circuit increases, the overall current will decrease. Thereafter, looking at the current passing through each component is recommended*" (Shipstone & Cheng, 2001) describing TANA's knowledge of the TSPCK component **CSA**. In relation to that is the TANA's highlighted statement "*if R1 increases, then the effective resistance in the circuit increases*" which could be touching an aspect of what is difficult for the learner to understand (TSPCK component **WDT**) as Dupin and Johsuam (1987) argued. While discussing that, the pre-service teacher TANA made a reference to symbolic representation (describing TSPCK component **REP**) as in the highlighted statement "*which means that the effective current according to V=IR decreases*". Additional evidence of TANA's understanding of TSPCK components **CSA** and **REP** can be observed from the last two statements talking about important concepts - resistance, current and voltage - (Duit & von Rhoneck, 1997) and use of symbolic representations and formulae (Cheng & Gilbert, 2009). In all, the TSPCK Map in the Figure 5.4 shows the interaction of four TSPCK knowledge components (LPK, CSA, WDT and REP) in the pre-service teacher's (TANA) formulation of response.

● A sample response based on the component of What is difficult to teach/understand (WDT)

This category is based on the TSPCK component WDT. The pre-service teachers were asked to list five most difficult concepts in electric circuits with reasons. Three concepts were given as examples; the emphasis was in the reasons ascribed to difficulty. The second part of the question required that pre-service teachers write five terminologies in electric circuits that pose most difficulty for students with reasons. An extract of the test items on this component is provided in the Figure 5.5 below in order to provide the context to the responses.

PSIV METHODOLOGY COURSE EDUC4164

Category C - What is difficult to teach?

C1. What **five** electric circuits concepts, in your experience, are the most difficult to present effectively to students and what do you think the reason for this is? Some **examples** are provided, which you may use, or choose not to use, as a basis for your response if you rephrase them but rather **give your own ideas. (Only give reasons for five concepts).**

Fill in your response in the table below (1 mark for each concept and 2 mark for each reason)

Concept 1 – Ohms' law, the relationship between current and voltage	**Reason**……
Concept 2 – What is meant by voltage or potential difference	**Reason**……
Concept 3 – total resistance in a parallel circuit is less than the individual resistances	**Reason**……
Concept 4 –	**Reason**……

Figure 5.5: Sample TSPCK tool item on the component of WDT

An extract of the pre-service teacher TUMA's written work as an example of a response which draws on three knowledge components is given in the Figure 5.6 below. As shown in the Figure, while the pre-service teacher TUMA was explaining why the concept is regarded difficult (indicating TSPCK component **WDT**), he made reference to the microscopic level (Cheng & Gilbert, 2009) which describes his understanding of the TSPCK component 'representation' (**REP**). This was observed to be connected to the second highlighted statement "*For example at high temperature the particles vibrate more than at lower temperature hence colliding with electrons*" describing the very important concept the learner needs to understand at the microscopic level (Korganci *et al*. 2015). This describes TUMA's knowledge component 'curricular saliency' (**CSA**). The following statement further emphasized why the concept is difficult (indicating knowledge component **WDT**) and the last statement referred to an important

concept Ohm's law in which both resistance and current are embedded (Metioui & Trudel 2012), pointing to TUMA knowledge of **CSA** again.

Concept 2 – how can we explain the relationship between the temperature and resistance of the filament in a bulb using ohm law?	It is difficult because it requires an explanation that is based on microscopic level. For example at high temperature the particles vibrate more than at lower temperature hence colliding with electrons. Second, it's difficult to explain convincingly about a light bulb made of a thin filament to produce resistance that can lead the bulb to glow and give light energy. Moreover, in the case of the bulb, when current becomes larger the bulb starts to glow and give out light and heat meaning that Ohm's law is not obeyed because temperature of the wire is increasing

Typed out extract:

It is difficult because it requires an explanation that is based on microscopic level. For example at high temperature the particles vibrate more than at lower temperature hence colliding with electrons. Second, it's difficult to explain convincingly about a light bulb made of a thin filmanet to produce resistance that can lead the bulb to glow and give light energy. Moreover, in the case of the bulb, when current becomes larger the bulb starts to glow and give out light and heat meaning that Ohm's law is not obeyed because temperature of the wire in increasing.

TSPCK Map

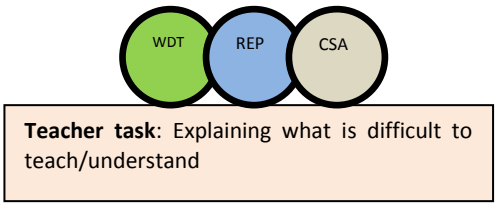


Figure 5.6: Extract of TUMA's written response on the component WDT

The TSPCK Map shown in the Figure 5.6 above shows the TUMA's interactive engagement of the knowledge components REP, WDT and CSA in formulating response.

Similarly, an example of a written drawing on more than three knowledge components, starting from a prompt on knowledge of what is difficult to understand, is that of the pre-service teacher TLEM given in the Figure 5.7 below.

Concept 5 – **A cell or battery provides energy to the circuit; not a continuous flow of current.**	**Reason**…….the battery is usually thought of as an electron 'reservoir' where electrons are stored, produced when the battery is connected and then used up as they come across resistors. This is a misconception that is difficult to dispel especially because this is happening at the microscopic level and as such, cannot be observed. To teach students that the battery is an energy source with a potential difference becomes meaningless as students cannot see this, thus it is not concrete. Since current is the flow of charge, students reason that charge is coming from inside the battery and flowing around the circuit. It needs to be explained that the charges are continually looping around the circuit; and that there are many charges at each point in a circuit, not simply a bunch of charges emanating from the source. Thus, even when the battery is off, the charge is still at each point in the circuit, but it has stopped flowing at a rate which is why electricity is not generated. The ideas here are very precise, and students may get bogged down by the many different ideas and visualisations that are required, which makes this a difficult concept to teach. This also draws on the idea of the conservation of charge and energy.

Typed out extract:

Reason …. The battery is usually thought of as an electron 'reservoir' where electrons are stored, produced when the battery is connected and then used up as they come across resistors. This is a misconception that is difficult to dispel especially because this is happening at the microscopic level and as such, cannot be observed. To teach students that the battery is an energy source with a potential difference becomes meaningless as students cannot see this, thus it is not concrete. Since current is the flow of charge, students reason that charge is coming from inside the battery and flowing around the circuit. It needs to be explained that the charges are continually moving around the circuit; and that there are many charges at each point in a circuit, not simply a bunch of charges emanating from the source. Thus, even when the battery is off, the charge is still at each point in the circuit, but it has stopped flowing at a rate which is why electricity is not generated. The ideas here are very precise, and students may get bogged down by the many different ideas and visualizations that are required, which makes this a difficult concept to teach. This also draws on the idea of the conservation of charge and energy.

TSPCK Map

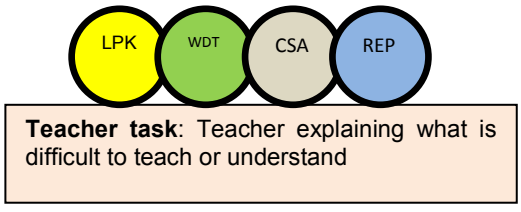


Figure 5.7: Extract of the pre-service teacher TLEM's written response on the component WDT

As shown in the Figure 5.7 above, the pre-service teacher TLEM's first statement seems to be acknowledging the learner's misconception as in the highlighted statement "*The battery is usually thought of as an electron reservoir where electrons are stored, produced when the battery is connected and ten used up as they come across resistors. This misconception*". This describes the TLEM's understanding of an aspect of TSPCK component 'learner prior knowledge' LPK with regards to misconceptions in electricity (Urban-Woldron, 2014). In connection to that is the TLEM's awareness of aspects about the battery as a source of energy that are difficult for learners to understand (Urban-Woldron, 2014) therefore meaningless if taught without some kind of transformation, this is an aspect of what is difficult to teach (**WDT**). This aspects is confirmed in the highlighted statement "*that is difficult to dispel especially because this is happening at the microscopic level and as such, cannot be observed. To teach students that battery is an energy source with a potential difference becomes meaningless as students cannot see this, thus it is concrete*". The place of TLEM's understanding of the TSPCK components **REP** and **WDT** is seen in this statement. In relation to that is the TLEM's explanation of the need to explaining movement of charges as it relates to the battery and the fact that the charges are available at every point of the circuit. These explanations reveal TLEM's knowledge of the most key aspects to be understood when it comes to understanding current as a flow of charges (Metioui & Trudel 2012), an aspect of TSPCK component 'curricular saliency' (**CSA**). We also see in her closing statement a reference to prior knowledge that should be in place when discussing electricity, this is the principle of conservation of energy seen here identified as prior concepts needed. The knowing of concepts needed prior to teaching a particular aspects is also an element of 'curricular saliency' (**CSA**), a slightly different element from knowing key aspects to be learnt in a particular topic. Thus we see, a slightly sophisticated episode where there is a repeat of the component of **CSA** coming through revealing different elements of the component but all important for transforming content knowledge.

- ***A sample response based on the component of Conceptual teaching strategies (CTS)***

The pre-service teachers were expected to formulate a teaching strategy which draws on other TSPCK components in bridging a student's conceptual gaps as he/she answers questions related to the flow of charges in a series circuit. An extract of the test items on this component is provided in the Figure 5.8 below in order to provide the context to the responses.

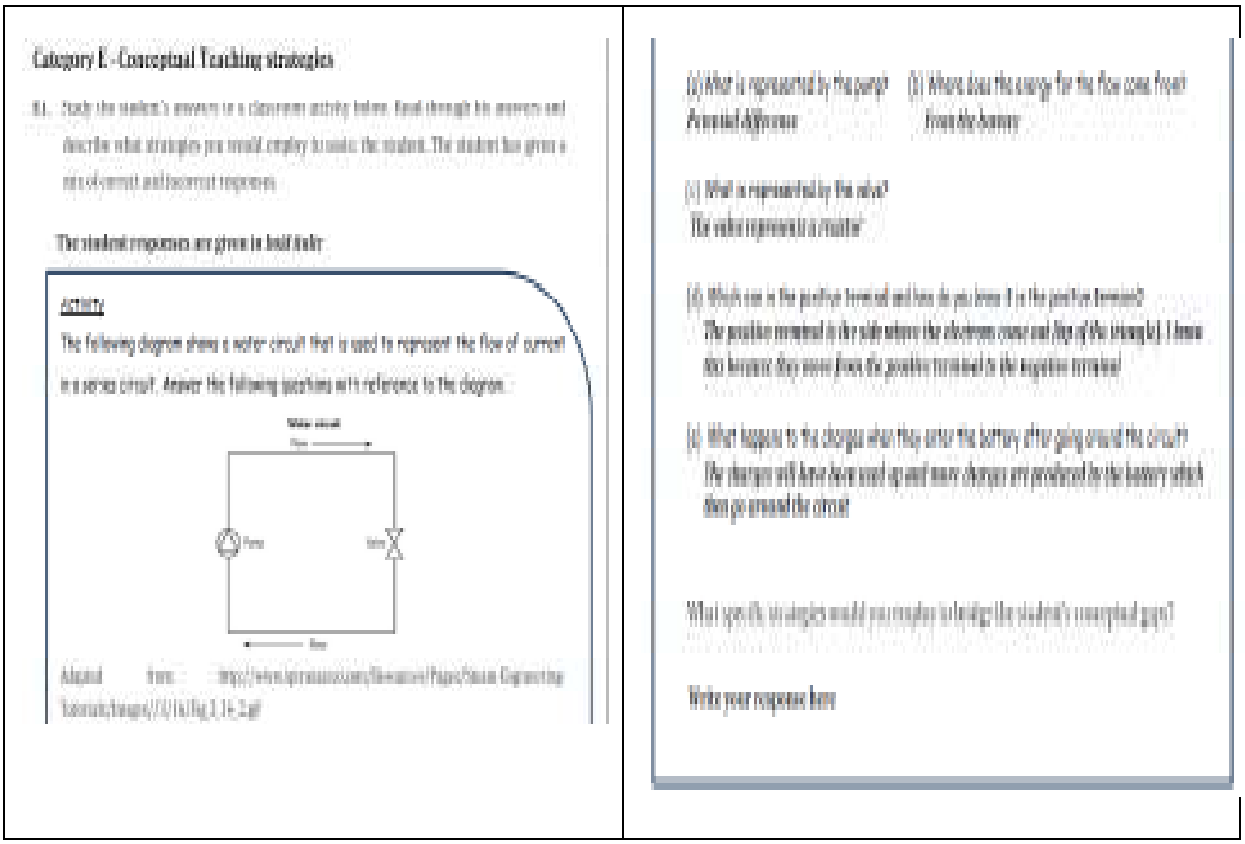


Figure 5.8: Sample TSPCK tool item on the component of CTS

An extract of the pre-service teacher TIFA's written work as an example of a response which draws on three knowledge components is given in the Figure 5.9 below. As shown in the Figure, while TIFA was explaining why the learner needs to understanding difference between the concept of emf and potential difference, he made reference to the use of circuits and components. It is important to point out that emf, which is 'electromotive force' is the potential difference across the terminal of a cell when it is not delivering current. This means that TIFA would have been explicit by referring to 'emf' and terminal potential difference; however this is not clear from the extract. Notwithstanding the place of awareness of important concepts like electromotive force, emf (Kucukozer & Kocakulah, 2007) and use of macroscopic representation (Cheng & Gilbert, 2009) could be noticed in TIFA's response. This demonstrates his understanding of TSPCK component curricular saliency (**CSA**) and representation (**REP**). TIFA further demonstrates awareness of common learner misconception that charges are used up (Kucukozer and Kocakulah, 2007) describing his understanding of the TSPCK component **LPK**. Likewise, in the statement "*and to explain the flow of electrons I will use a microscopic representation. The student has to first understand the structure of an atom then understand how*

come other materials are conductors while others are not. Then I would be appropriate to review the attraction between charges" the place of TSPCK component representation (**REP**) could be seen, sequencing of teaching important concept (TSPCK component **CSA**) and possibility recalling on concepts regarded as pre-concepts needed for understanding of charges. The understanding of pre-concept is a element of curricular saliency slightly different from that of sequencing conceptually logically seen in the same extract. Thus we also see another sophistication in the use of the component of CSA revealing its different elements.

Write your response here

For the student to know the difference between emf and potential difference I will use a circuit board and components. I will measure the volts across a battery when the switch is open and the volts again when the switch is closed then the volts across a bulb. I will then use the difference in these readings to explain the difference between emf and potential difference.

To explain why charges are not used up, that they are energised and to explain the flow of electrons I will use a microscopic representation. The student has to first understand the structure of an atom then understand how come other materials are conductors while others are not. Then I would be appropriate to review the attraction between charges. Since electrons are negative their attraction will be towards the positive terminal. By reviewing the structure of the atom one thing to emphasis would be that charges are everywhere since every material is made up of atoms and that an atom consists of electrons and proton not all materials have electrons that can move. The student here basically has to understand that the charges do not get used up but rather they are always there but the use the energy the they have that is given by the battery.

Typed out extract:

For the student to know the difference between emf and potential difference I will use a circuit board and components. I will measure the volts across a battery when the switch is open and the volts again when the switch is closed then the volts across a bulb. I will then use the difference in these readings to explain the difference between emf and potential.

To explain why charges are not used up, that they energized and to explain the flow of electrons I will use a microscopic representation. The student has to first understand the structure of an atom then understand how come other materials are conductors while others are not. Then I would be appropriate to review the attraction between charges. Since electrons are negative their attraction will be towards the positive terminal. By reviewing the structure of the atom one thing to emphasis would be that charges are everywhere since every material is made up of atoms and that an atom consists of electrons and proton not all materials have electrons that can move. The student here basically has to understand that the charges do not get used up but rather they are always there but the use the energy the they have that is given by the battery.

TSPCK Map

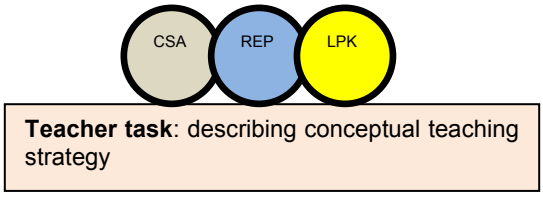


Figure 5.9: Extract of the pre-service teacher TIFA written response on the component CTS

As shown in the Figure 5.9 above, additional evidence of TIFA's knowledge of TSPCK component **CSA** could be observed in his statement "*one thing to emphasis would be that*

charges are everywhere since every material is made up of atoms and atoms consists of electrons and proton". In connection to that is the next highlighted statement which further stressed the earlier indicated learner misconception (TSPCK component **LPK**) that charges are used up in circuits. In all, the pre-service teacher TIFA could be observed to have interactively engaged the TSPCK components REP, LPK and different elements of CSA, as shown in the TSPCK map in the Figure 5.9 above.

Similarly, another example of a written drawing on three knowledge components is that of the pre-service teacher TEMA given in the Figure 5.10 below. As shown in the Figure, TEMA demonstrated an understanding of what learner needs to be taught (knowledge of TSPCK component **CSA**) as in the highlighted statement "*it is evident that the learner needs more attention in terms of understanding the battery and the ideas of a source in a closed circuit and what it entails*". In connection to that is the TEMA's awareness of the necessity to use representations (knowledge of TSPCK component **REP**) at microscopic level to explain how cells supply energy. Additional evidence of TEMA knowledge of TSPCK component **CSA** is noticed as he talked about the need for the learner to understand electrochemical cell. In the last highlighted statement "*we cannot measure current across the battery, and we will show students that only voltage can be measured across the terminals of a battery, using a multimeter*" TEMA could be observed to demonstrate possible learner misconception (indicating knowledge of TSPCK component **LPK**) and use of microscopic representation (knowledge of TSPCK component **REP**) in confronting the misconception. In all, the pre-service teacher TEMA could be observed to have interactively engaged the TSPCK knowledge components CSA, REP and LPK as shown in the TSPCK Map above.

Write your response here

To bridge these gaps, it is evident that the learner needs more attention in terms of understanding the battery and the ideas of a source in a closed circuit and what it entails. Since understanding electricity is at the microscopic and abstract level, representations need to be used to explain the concept that cells supply energy to do work, which enables charge to move from the negative to the positive terminal. This requires some understanding of an electrochemical cell. The processes that occur in the battery between the positive and negative terminal should be shown to the student, by making use of a video. Then, a lemon battery should be made as a demonstration, to show the role of the electrolyte, the positive terminal, and the negative terminal in a cell. From this video and demonstration, learners will gauge that electrons flow from the negative terminal towards the positive terminal around the circuit; and this is how we get current- our rate of flow of charge. However, we cannot measure current across the battery, and we will show students that only voltage can be measured across the terminals of a battery, using a multimeter.

As a result, students will understand that voltage and energy are related, and energy is required for current to flow.

It is as this point, when the conceptual understanding of current and negative charge is strong, that conventional current needs to be explained to students. Here, it would be useful to describe conventional current as a 'mistake' made by early scientists who believed that positive charges flow- this is why they 'got the direction wrong'. This use of language is at the learner level and they will be able to deduce that conventional current flows opposite in direction to actual current;

Typed out extract:

To bridge these gaps, it is evident that the learner needs more attention in terms of understanding the battery and the ideas of a source in a closed circuit and what it entails. Since understanding electricity is at the microscopic and abstract level, representations need to be used to explain the concept that cells supply energy to do work, which enables charge to move from the negative to the positive terminal. This requires some understanding of an electrochemical cell. The processes that occur in the battery between the positive and negative terminal should be shown to the student, by making use of a video. Then, a lemon battery should be made a demonstration, to show the role of the electrolyte, the positive terminal, and the negative terminal in a cell. From this video and demonstration, learners will gauge that electrons flow from the negative terminal towards the positive terminal around the circuit; and this is how we get current – our rate flow of charge. However, we cannot measure current across the battery, and we will show students that only voltage can be measured across the terminals of a battery, using a multimeter.

TSPCK Map

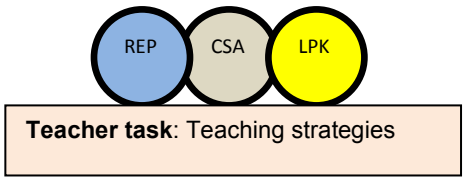


Figure 5.10: Extract of the pre-service teacher TEMA written response on the component CTS

The description of how the pre-service teacher TEMA interactively engaged the knowledge components REP, CSA and LPK is explained above as shown in the Figure 5.10.

In the above discussions, I have shown samples of pre-service teachers' written responses that provide evidence of developing TSPCK based on interactive use of three or more knowledge components and hence transferability of pedagogical transformation competence to a new physics topic of electric circuits, not discussed in class. Meanwhile, Shulman (1987) is of the opinion that PCK requires that teachers "comprehend subject matter for themselves, to becoming able to expose subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be understood by students" (p. 13). In support of that, Baxter and Lederman (1999) added that PCK is not limited to what teachers know but it is as well embedded in "what a teacher does" (p. 158) in teaching a particular topic and hence I point the same for TSPCK. This implies that teachers' PCK and also TSPCK should be investigated at two different stages referred to as the "espoused PCK and enacted PCK" as argued by Aydeniz and Kirbulut (2011, p. 2). As discussed in the literature chapter, chapter 2, espoused PCK serves as guidance to teachers in making decisions that have to teaching a particular concept or topic, choice and use of representations and instructional strategies (Park & Oliver, 2008). It could be said to represent teachers' understanding of pedagogical transformation skill that helps in conceptual teaching strategies to enhance learning. This is similar in this study to exploring pre-service teachers' TSPCK in the planning context. However, Aydeniz and Kirbulut (2011) further argue that teachers have such knowledge does not guarantee the use in the actual classroom teaching. When that kind of knowledge teachers possess in the planning context get enacted and observed in their actual classroom teaching then it is referred to as the enacted PCK (Park & Oliver, 2008) and thus enacted TSPCK in this study. Thus, this study investigated to what extent the pre-service teachers learned pedagogical transformation competence of TSPCK could be observed in their actual classroom teaching. The analysis of few records of actual classroom teaching is presented in the next section below.

5.2.2 Evidence supporting developing TSPCK in electricity from the actual classroom teaching

In order to further examine transferability of pedagogical transformation competence of pre-service teachers, efforts were made to analyze their records of actual classroom teaching. Concentration was on a number of pre-service teachers who taught physics concepts related to

the topic of electricity since this study investigates transferability of learnt competence to that topic. Only three pre-service teachers (**TEMA**, **TLEM**, and **TIFA**) were involved in this analysis. The verbatim transcription of each pre-service teacher's teaching is presented below. In each case, what the specific teacher said and learners' responses (represented as '**Ss**' for all learners and '**S with a number**' for a particular learner) are given. The analysis of classroom teachings is qualitatively discussed below.

Pre-service teacher TEMA

The pre-service teacher TEMA taught the concepts of electric circuits to Grade 10 students for 50 minutes. Based on the number of TSPCK episodes (that is, interactively used of two or more TSPCK components) observed, the lesson has been divided into two segments. The segment 1 concentrated on the first 5 minutes of TEMA's teaching. This teaching segment is transcribed as follows.

> **TEMA**: Today's topic is electric circuit, anyone who can tell me what is electric circuit? Yes I like you to share your ideas with us all.
>
> **Ss**: Murmuring….(Voices not clearly heard)
>
> **S1**: It is a passage in which electric current pass.
>
> **TEMA**: Anyone who wants to say something or add…… (the teacher paused and then continued)……so you all agreed that electric circuit is a passage.
>
> Students: …(no statements heard)……
>
> **TEMA**: Electric circuit is like a passage or a path like he said in which electric charges will flow. There are components or devices that make up a circuit. Such include the connecting wires, an ammeter, a voltmeter, an electric bulb or a resistor. If you look at these components, each of them has a specific symbol which we use for representation whenever we need to perform an experiment. As I have just drawn on the board, this representation is for voltmeter, this is for ammeter and this is for a resistor. Please, don't get confused with these symbols, is that Ok? Now, It is important for you to know that the flow of electric charges constitutes the electric current. We have electric current when charges flow through the circuit. Sometimes you find that we have a closed or an open circuit. If we have open circuit, it means that electric charges cannot flow throughout the circuit so we cannot say there is current. For charges to flow throughout the circuit, we have to close the circuit, right. At times people say charges flow when the circuit is opened in a similar way to everyday happenings. In this case of current in circuits it is not so, ok,

for charges to flow that is for us to say current flows, the circuit must be closed. Is that clear? Looking at the diagrams I have just drawn on the board, That is important. We shall still look at this later on.

As stated above, the pre-service teacher TEMA commenced his teaching by asking learners what they understood by 'electric circuits' with the intention of bringing into play the learners' preconceptions. This could be said to have given the picture of TEMA's understanding of the TSPCK component 'learner prior knowledge' (**LPK**) similar to what Mthethwa-Kunene et al. (2015) observed with the experienced teachers as reported in Chapter 2. Not ignoring the response gotten from a student, TEMA explained electric circuit as the path through which an electric charge flows (Licht & Thijs, 1990). This describes TEMA's knowledge of what is important for learners to know, talking to the TSPCK component 'curricular saliency' (**CSA**). In explaining that, TEMA referred to symbolic representations of apparatus as drawn on the board (Carrejo & Marshall, 2007**)** thereby describing his understanding of TSPCK component 'representation' (**REP**). In explaining that, TEMA further made two noticeable statements highlighted as follows "*If we have open circuit, it means that electric charges cannot flow throughout the circuit so we cannot say there is current....At times people say charges flow when the circuits is opened in a similar way to everyday happenings. In this case of current in circuits it is not so, ok*". These could be seen as addressing common learner misconception (Kucukozer & Kocakulah, 2007), describing TEMA's understanding of TSPCK component **LPK** (including misconception). The statement is highlighted as follows. This interwoven with what TEMA considered important for the learners to know. The TSPCK Map describing the TSPCK components observed in this segment is displayed in the Figure 5.11 below.

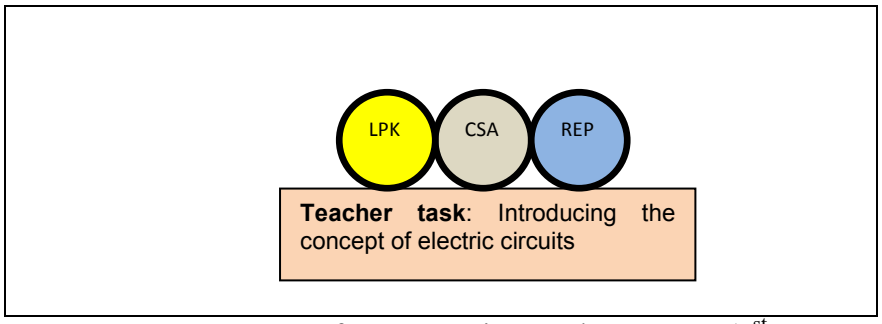


Figure 5.11: TSPCK map for pre-service teacher TEMA (1st segment)

The TSPCK Map shown as shown in the Figure 5.11 above indicates TLEM in segment 1 of his teaching, interactively used three knowledge components **LPK**, **CSA** and **REP** in introducing electric circuits to the learners.

Additionally, another teaching segment of pre-service teacher TEMA tagged '2nd segment' was analyzed. This was in the period of 5.30 – 12.30, about 12 minutes. This teaching segment is transcribed as follows.

TEMA: *In electric circuits, we have what we call potential difference, anyone who can tell me?*

S2: I think it's current.

TEMA: *Potential difference is something else, it is not current.*

S3: It is kinetic energy

TEMA: *Kinetic energy? You said potential difference is kinetic energy?*

S4: No, it is voltage.

TEMA: *So the potential difference is the work done on a charge. This is the work done on a single charge. It is given by P.d = Work done/Charge = W/Q (Joule per Coulomb). Work done is used for moving a charge from one point to another in a circuit. Is that Ok now, fine let's move on.*

TEMA: *Potential difference is measured in volts, right. It is sometimes called voltage but we'll expose as we move forward. There is another one called E.m.f. Ok anyone who understands what an E.mf. is? E.m.f*

S6: Electromagnetic force

TEMA: *Hmmm…..it is Electromotive force, ok. What is an electromotive force? Say for example you have the source, this is the battery. You know battery, right. Here is an example (Teacher showed students a battery). If you take the voltmeter and you measure your voltage across the battery, what your voltmeter is gonna read as long as the circuit is opened is gonna be the e.m.f. Let's try and do that now. You can see that the Emf is the voltage measured across the two terminals of the battery when the circuit is opened, right. It means for example when you have the battery……. (The teacher demonstrated by showing the students how to connect across a cell and then measured using a voltmeter).*

S7: Sorry sir, Emf is electromagnetic force right?

TEMA: *Sorry, Emf is electromotive force, not magnetic. Yah, now if you have a circuit and then you close it, we have the circuit here and we have our cell. When you measure the voltage when the circuit is closed then we have terminal potential difference or terminal voltage.*

As stated in the conversations above, TEMA started by asking learners what they knew about potential difference, describing his understanding of TSPCK component **LPK**. With regards to a response from a learner, TEMA corrected a misconception that 'potential difference is electric current', further indicating TEMA's awareness of **LPK**. Such an interchangeably use of electricity terms and in meaning have been identified as part of learners' misconception (Engelhardt & Beichner, 2004). In connection with the responses from the learners, TEMA defined potential difference signifying what is important for the learners to learn (Kucukozer & Kocakulah, 2007) and hence his understanding of TSPCK component **CSA**. Together with that, TEMA used a mathematical formula to represent potential difference indicating his understanding of TSPCK component **REP**. Additional statements TEMA made as highlighted in the transcription further re-emphasized his understanding what is important to teach (**CSA**), learner prior knowledge (**LPK**) and representation (**REP**). It is however, noted that TEMA missed an opportunity to explain in better detail what Electromotive force is following the question by the learner who asked about electromagnetic force. The pre-service teacher's answer lacked seizing the opportunity to emphasis important aspects of about electromotive force. The TSPCK Map describing the use of these knowledge components is given in the Figure 5.12 below.

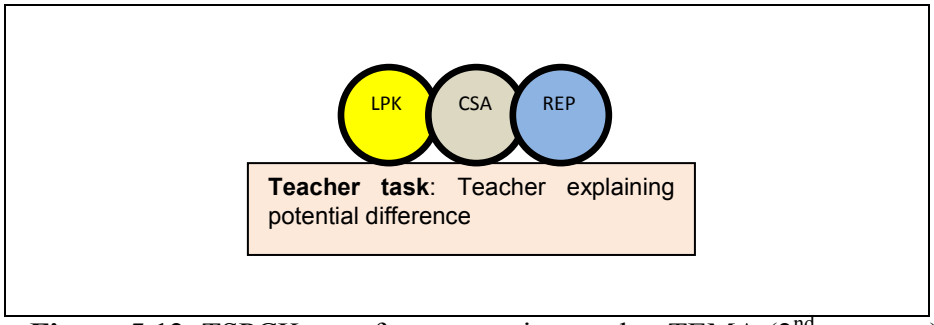


Figure 5.12: TSPCK map for pre-service teacher TEMA (2nd segment)

The TSPCK Map as shown in the Figure 5.12 displays TEMA's interactive engagement with the knowledge components LPK, CSA and REP in explaining potential difference with respect to

what the learners already knew. This as well supports qualitatively, evidence of transferability of pedagogical transformation competence drawing on three knowledge components of TSPCK in teaching an aspect of electric circuits. Similar to TEMA, another pre-service teacher TLEM's teaching segments were analyzed. This is discussed as follows.

Pre-service teacher TLEM

The pre-service TLEM focused on the concept of 'electromotive force with potential difference' in his teaching. The first thirteen minutes of the lesson was examined and considered as segment 1. In this segment, TLEM started by referring to imbalance and movement of charges which he assumed students should have learned in the previous grade. He asked students what an electric current is. By asking students a related or exact thing to what they have learned in the previous lesson or grade could be describing TIFA's awareness of the importance of learner prior knowledge (Aydin & Boz, 2013). TLEM could be said to have demonstrated the TSPCK 'Learner Prior Knowledge' (**LPK**) by so doing. The transcription is given as follows:

> **TLEM**: We gonna be exploring electromagnetic force and potential difference. Remember that we said when a device produces an imbalance of charges, we spoke about charges then connecting the areas of imbalance in a way that allows the charges to move, it would produce an electric current. So now what is an electric current? What can you say about electric current? Think of what you have learned before now, Ok.
>
> Students: Murmuring……(silently heard) the flow of electricity
>
> **TLEM**: It's the flow of electricity, and I would really appreciate if you want to contribute. What is electric current? Our basic background for Grade 19, it is called?
>
> Students: Murmuring ….(voices not clearly heard)
>
> **TLEM**: Yeah, yeah guys eh, hello if you want to contribute by showing your hands, it would be nice. My concern is electric current is the flow of charges. Basically we are also linking up on the concept of charges we have explored earlier on but now we would be using a different procedure but now you don't have to conclude, what is happening now is leading us to discover another thing. I recovered whomever someone said electric current is the flow of charge, he has just said it is the flow of charge but you have to understand it is not just the flow of charge. It is the flow of charges through the medium set-up in electric field along and around the length of the medium. This has got to pass through a conductor because electricity cannot flow without a conductor. So there must be a conductor involved. Remember you could not have learned about charges without

talking about the materials or conductors. It is noted that not any moving charge constitutes an electric current simply because in any moving charges there must be a conductor involved. Please note that it is important to recognize the materials through which charges move. It is also good for you to know that all materials already contain electric charges. So the science of the current is the rate of transfer of charge. There is time involved so the amount of charge that is moving within an electric object per specific time, it can either be in minute but we should note that the basic unit of time is seconds. So electric current is given by this formula Current, I = Charge/time = Q/t. That is the formula for current. This mathematical expression is used for calculating the value of current, you must know It is possible that you can define your current according to the formula as it is being given, we should know that formula is very important. I is the symbol for current and the SI unit is Ampere

As illustrated above, TLEM can be seen to have used LPK as the basis for defining electric current, the flow of electric charges with emphasis on that fact that materials that experience electric current (that is, flow of charges) already contain charges (Duit & von Rhoneck, 1997). This is an important aspect of electric current, making students to realize that materials have charges already. This could be considered an important thing to teach as argued by Duit and von Rhoneck (1997) and hence a feature of TLEM's understanding of the TSPCK component 'curricular saliency' (**CSA**). While TLEM defined electric current, he included the mathematical formula and pointed out its usefulness. The formula in this case represented the pre-service teacher's understanding of symbolic representation (Cheng & Gilbert, 2009), the knowledge of TSPCK component 'representations **REP'** in teaching the concept of electric current. The concept for these knowledge components is shown in the Figure 5.13 below.

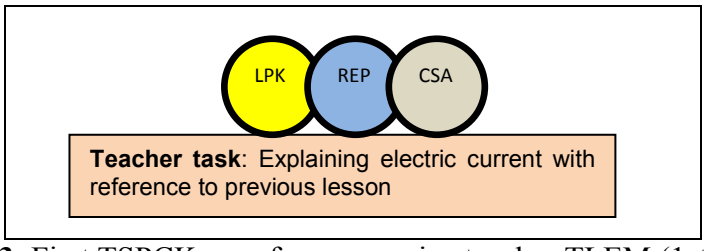


Figure 5.13: First TSPCK map for pre-service teacher TLEM (1st segement)

In the entire conversation for the segment 1, the pre-service teacher TLEM can be seen to have interactively engaged three knowledge components **LPK**, **CSA** and **REP** in explaining the

concept of electric current with reference to the learners' previous lesson. The TSPCK Map as given in the Figure 5.13 describes the interrelatedness of the observed knowledge components.

The second observed segment of the pre-service teacher TLEM's teaching took place between 16.10 and 23.00 (for about 7minutes). While TLEM was trying to describe the direction of current in an electric circuit, he reminded students of the direction of electron flows associated with flow of positive charges. Then, he made mention of the energy available to make charges flow. The conversation is transcribed as follows:

> **TLEM**: We spoke about electric charges in previous grade. This is important for us now to understand concept of electric circuit. How is charges flow and in what direction. By the flow we refer to charge movement. You have to know that any device that provides energy to each charge as it travels around the circuit is said to be the source of E.m.f. What is E.m.f.?
> Students: murmuring…..(voices not heard clearly)
> **S1**: Electrical, electrical
> **TLEM**: Yeah what is E.m.f? I don't appreciate you quiet, yes middle man, what is e.m.f?
> **S2**: Electromotive force
> **TLEM**: Electromotive force. We need to know. In clarifying what has just been mentioned, it is the amount of workdone in moving each unit of charge. The battery or a cell provides the E.m.f. We can say that the E.m.f is the potential per unit charge, very important to note that, ok. For calculations, we write E.m.f is equal to the ratio of workdone to the unit charge that E.m.f equals workdone over charge. That is, E = W/Q. This is the same as the potential difference across the terminals of the battery or cell. The S.I unit for this potential difference is Joules per coulomb which is the same as the volt. Remember, workdone is measured in Joules and charge is measured in coulomb. That is very important.

As revealed in the above conversation, the pre-service teacher TLEM can be seen to have demonstrated the understanding of TSPCK component learner prior knowledge (**LPK**) as he made reference to what the learners have earlier learnt (Urban-Woldron, 2014) in the previous grade. Building on that is the TLEM's explanation of flow of charges constituting electric current leading to the concept of electromotive force, emf (Metioui & Trudel 2012) describing knowledge of important concepts and their sequencing. While explaining electromotive with respect to the battery as the source (Duit & von Rhoneck, 1997), TLEM used a mathematical formula which signifies his understanding of the TSPCK component 'representation' (**REP**) in

teaching what is important for learners to know, indicating his understanding of knowledge component curricular saliency, **CSA**. The TSPCK Map describing TLEM use of the TSPCK knowledge components is given in the Figure 5.14 below.

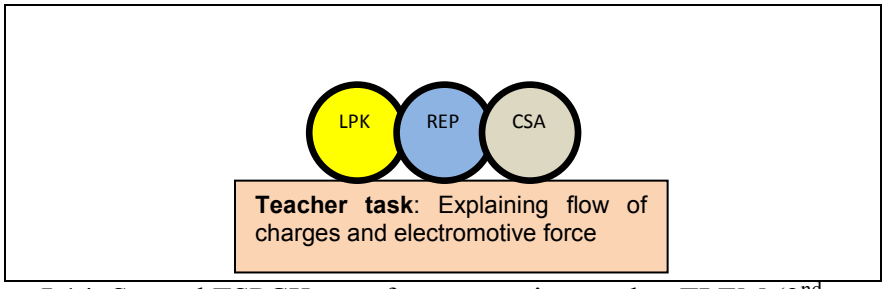


Figure 5.14: Second TSPCK map for pre-service teacher TLEM (2nd segment)

As shown in the Figure 5.14 above, in the second segment of pre-service teacher TLEM's teaching, he could be observed to have interactively used three TSPCK components LPK, REP and CSA in explaining the flow of charges and electromotive force.

The two analyzed teaching segments of the pre-service teacher TLEM describes his quality of TSPCK which majorly draws on three knowledge components in explaining the concepts. This could be said to have described an extent of transferability of learnt pedagogical transformation competence in written context to actual classroom teaching. Additional supporting evidence is drawn from the analyzed teaching segments of pre-service teacher TIFA. This is discussed below.

Pre-service teacher TIFA

The pre-service teacher TIFA likewise taught the topic of Electric circuits. The first 12 minutes (0.00 -12.00) of his teaching was analyzed and tagged as segment 1. The transcription of the conversations is given as follows.

> **TIFA**: Good morning class. Last week we did talk about Emf and Potential difference but I didn't tell you how that potential difference comes about. So this is what I will be telling you about today. What I have with me is the apparatus for our circuit diagrams. I have a voltmeter, here is the voltmeter and connecting wires. I have an ammeter with me as well. Can I just ask, what does a voltmeter measure?
>
> **Ss**: (chorused)….voltage

TIFA: It measures potential difference. Remember, I told you we have what we call terminal p.d and e.m.f. I will show you that just now. Then, I have circuit board with bulbs. The bulbs are the resistors on the circuit board. I want to show you the diagram on the board. Then note that I am connecting the voltmeter across the batteries not to the batteries. So, the voltmeter reading across my battery is 6volts. Now I haven't connected the whole circuit yet. What does that 6volts means?

Ss: ….(silence)……..

TIFA: The 6volts simply means the Emf of the battery. The Emf means the energy that the battery has to drive electric charges through the circuit. Now, if I complete the circuit, my bulb will light up showing that my circuit has been completed. And then now I want to see whether how much potential difference is used across the light bulb. Then I measure the potential l difference across the light bulb which is now 5volts. Then across the batteries on a closed circuit, we have 5volts. Now, shouldn't it be 6volts? So what does that mean?

S2: It was 6 before

TIFA: Yes, it was 6. But look at what happens, I disconnect my light bulb, connect the voltmeter across the battery and then it goes back to 6. So what does that means now? See, if I connect the light bulb, it is 5. So what does that mean?

S3: Emf

S4: It is an open socket.

TIFA: That 5volts mean the terminal potential difference when the cell is delivering current to the circuit. The 6volts we recorded is the E.m.f. of the cell when the cell is not delivering current to the circuit. These are very important for you to understand.

In teaching how a voltmeter measures emf (electromotive force) and terminal potential difference as shown in the conversation above, the pre-service teacher TIFA briefly referred to what learners have previously learnt (Rusznyak & Walton, 2011) describing his understanding of the TSPCK component learner prior knowledge (**LPK**). In connection to that is the use of circuit boards which consist of laboratory equipment for teaching electric circuits (Engelhardt & Beichner, 2004). TIFA asked learners questions on this signifying his knowledge of the TSPCK component 'representation' (**REP**). Further observed in the conversation is TIFA repeatedly asking the learners questions as in the highlighted statements re-emphasizing his knowledge of **LPK**. Also building on that is the evidence of what is important to teach as seen in the TIFA's effort to differentiate between terminal potential difference (of 5volts) and emf (of 6volts)

describing (Kucukozer & Kocakulah, 2007) his knowledge of the TSPCK component 'curricular saliency' (**CSA**). Show in the conversation is the place of interactive use of three knowledge components **LPK**, **REP** and **CSA** as displayed in the TSPCK map (Figure 5.15) below.

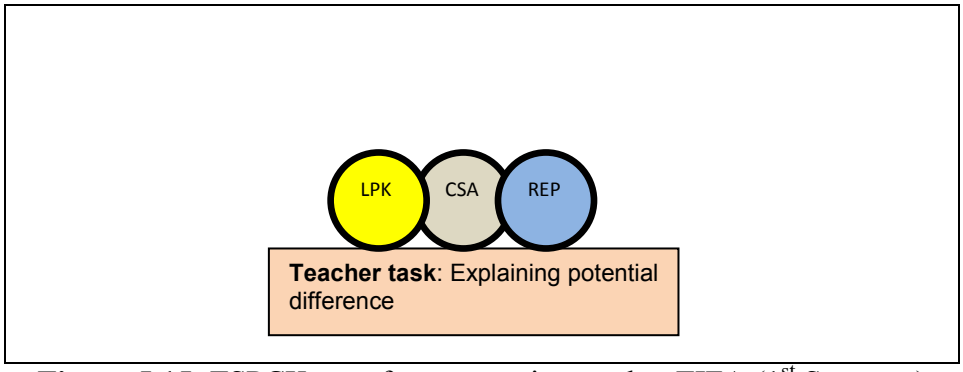


Figure 5.15: TSPCK map for pre-service teacher TIFA (1st Segment)

The Figure 5.15 above shows how interactive use of three TSPCK components LPK, CSA and REP has demonstrated the quality of TSPCK and hence extent of transferability of pedagogical competence in that teaching segment.

Another teaching segment of TIFA's lesson tagged segment 2 was also analyzed. TIFA seemed to concentrate of electric field. The conversation is transcribed as follows:

> **TIFA**: Now with the help of electromotive force from the cell, we can a charge round the circuit, ok? For us to move a positive test charge, assuming we have one large charge at the centre same positively charged then if we want to move this positive charge say from point A to point B where the large charge is, what do you think will happen, it will repel or attract?
>
> Students: murmuring…….. (responses not clearly heard)
>
> **S5**: Yes
>
> **S6**: repel
>
> **TIFA**: Yes, there will be repulsion you know the two charges are both carrying a positive sign, ok? Then the blue lines I drawn now represent an electric field. Does anyone know what an electric field is?
>
> S6: Yes, it's an imaginary line around the magnet
>
> **TIFA**: It's an imaginary line around a magnet? That's a magnetic field. Now we are talking about an electric field, is that ok. We have a charge and we have an electric field that will form around it. In magnetism we talk about magnetic field, but now in electricity we talk about magnetic field.
>
> **S4**: Sir, an electric field is an imaginary line around a charge.

As highlighted in the first statement above, TIFA began by describing the movement of a positive test charge from one point to another. This could be regarded a basic concept on which other concepts can build (Rollnick & Mavhunga, 2014) in teaching electric field thereby describing TIFA knowledge of an aspect of TSPCK component 'curricular saliency' (**CSA**). Based on that is the TIFA's question investigating learners' prior knowledge (TSPCK component **LPK**). Related to that is the diagrammatic representation (Engelhardt and Beichner, 2004) TIFA drew on the board in explaining electric field. This diagrammatic illustration describes TIFA knowledge of TSPCK component 'representation' (**REP**). In further attempts to make the concepts clear, TIFA could be seen asking the learners additional questions (Mthethwa-Kunene *et al*., 2015), re-emphasizing his understanding of the TSPCK component **LPK**. The TSPCK Map showing the interactive use of these knowledge components is given in the Figure 5.16 below.

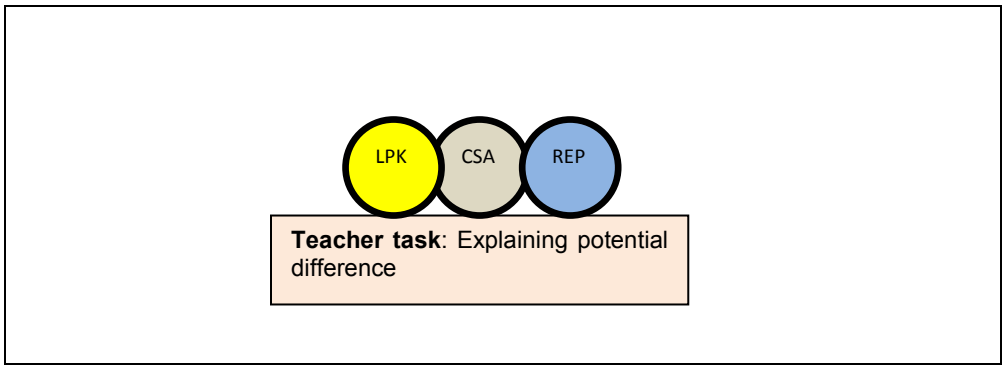


Figure 5.16: TSPCK map for pre-service teacher TIFA (2nd Segment)

The Figure 5.16 above further confirms the pre-service teacher interactive use of three TSPCK components CSA, LPK and REP which seem to describe the quality of TSPCK and hence transferability of pedagogical transformation competence.

To sum it all, the analysis of the selected pre-service teachers' actual classroom teaching discussed above showed interactive use of three TSPCK knowledge components. This is summarized in the Table 5.2 below.

Table 5.2: Summary of the pre-service teachers' interactive use of knowledge components as observed in actual teaching

Pre-service teacher	Number of teaching segments	Number of TSPCK Episodes observed	TSPCK components involved
TEMA	2	2	LPK, REP, CSA
TLEM	2	2	LPK, REP, CSA
TIFA	2	2	LPK, REP, CSA

The Table 5.2 above shows the number of pre-service teachers' teaching segments observed with the number of TSPCK Episodes and components involved. The interactive use of the three knowledge components (learner prior knowledge, LPK; representations REP; and curricular saliency, CSA) further confirms what was observed in the pre-service teachers' written responses to the validated TSPCK tool in the electric circuits.

5.3 Conclusion

The discussions in this chapter showed that the pre-service teachers were able to transfer learnt pedagogical transformation competence to the same extent as that of the topic of the intervention. This was seen in the pre-service teachers' overall group score of '3' (representing 'Developing TSPCK') in the topic of electricity which is similar to the group score in the topic of the intervention (kinematics). This implies that the pre-service teachers in most instances demonstrated understanding of interactive use of three TSPCK knowledge components while formulating responses to teacher tasks and also in the actual teaching. This interactive use of three knowledge components (learner prior knowledge, curricular saliency and representation) was similar to the improvement in the quality of TSPCK that the pre-service teachers experienced in the topic of kinematics following an intervention. This is interesting because the pre-service teachers' observed pedagogical transformation competence is only based on the known background context which is that, they have not been exposed to electricity from a teaching perspective particularly TSPCK. However, I am aware that this study has a limitation of not measuring the quality of TSPCK in electricity before the intervention. This was because I

had limited access to the methodology class and running two pre-tests at the beginning of the intervention time wise, and other demands of the course on pre-service teachers was not possible for me (as the researcher). Nevertheless, the observed "developing" quality in the topic of electricity seen in both planned and enacted TSPCK cannot be ignored given that the exposure to the pedagogy of TSPCK only came through the intervention. Hence, I am encouraged by the implications of these findings which are discussed in the next chapter, the closing chapter.

CHAPTER SIX

6. DISCUSSIONS AND IMPLICATIONS

In this chapter, I provide an insightful summary of the whole study based on the discussions from the preceding chapters. I start by recalling the identified problem statement and rationale as they relate to the theoretical framework used in this study. This is followed by answering the research questions with discussions on the methodological and empirical contributions of this study. Thereafter I give critical reflections on the entire research process. Lastly, limitations of this study are highlighted and recommendations and conclusions are made.

6.1 Overview of the study

The identified problem statement in this study has been in two phases: the issue that much work has been done in demonstrating the TSPCK construct in chemistry topics e.g. chemical equilibrium (Mavhunga & Rollnick, 2013); electrochemistry (Ndlovu, 2014), organic chemistry (Vokwana, 2013) and particulate nature of matter (Pitjeng, 2014) but little is known about the development of the construct in physics topics; and there have been reports on the ineffective teaching of physics leading to learners' unsatisfactory performances (Department of Basic Education, 2015; Spaull, 2013). Some of the difficulties high school learners encountered in understanding physics concepts have been associated with teachers' teaching strategies that are not simply defined and without significant influence on the learners' conceptual understanding (Planinic et al. 2012). Particularly in South African high schools, the difficulties have equally been attributed to the teachers' inadequate content knowledge (Spaull, 2013) and poor pedagogical content knowledge (Rollnick & Mavhunga, 2014) in making the concepts accessible to students. Noticeably, the topic of kinematics has been identified as one of the challenging aspects of physics that learners find difficult to understand as analyzed in the South African Diagnostic Report (Department of Basic Education, 2015). Kinematics serves as an important fundamental aspect of mechanics necessary for understanding some other physics topics (Lemmer, 2013). Thus, the purpose of this study was to examine the development of pre-service teachers' Topic Specific Pedagogical Content Knowledge (TSPCK) in kinematics and

transferability of learnt pedagogical transformation competence to a new physics topic – electricity.

The collation of solutions to physics learners' difficulties has been identified in this study to be rooted in the Shulman's (1986, 1987) initial idea that content knowledge (CK) must be transformed to make teaching effective and enhance students' conceptual understanding. This understanding of pedagogical transformation of content knowledge is also associated with what Geddis and Wood (1997) as well as Ball et al. (2008) argued for in the classroom teaching of science and mathematics respectively. The arguments suggested specialized knowledge components spearheading this pedagogical transformation of content knowledge. Based on that, this study adopted two important theoretical propositions. The first theoretical proposition was that, for pre-service teachers, an intervention, which entails explicit discussions of five content-specific knowledge components in a specific topic, contributes to the development of quality of TSPCK in that topic. The second theoretical proposition was that following such explicit discussions, there is learned pedagogical transformation competence which first is used to develop TSPCK in the topic of the intervention itself, and thus the exploration to determine transferability of this competence to a new topic. Thus, the TSPCK construct (Mavhunga, 2012) has served as a theoretical framework in this study. This construct makes use of five content-specific knowledge components that bring about pedagogical transformation of content knowledge in a specific topic. The knowledge components include: learner prior knowledge; curricular saliency; what is difficult to teach; representations; and conceptual teaching strategies (Mavhunga, 2012). The understanding of these knowledge components in a particular topic and the skill to use them interactively enhances the production of PCK which is specific to that topic. This kind of PCK is termed Topic Specific Pedagogical Content Knowledge, TSPCK which is PCK exclusively in the specific topic of concern (Mavhunga & Rollnick, 2013). While engaging in explicit discussions of these knowledge components, knowledge and skills, which rest in using the components interactively, for pedagogical transformation of CK are learned. This has been termed the 'pedagogical transformation competence' (Rollnick & Mavhunga, 2015). It combines understanding of the knowledge components and their interactive use in explaining a concept in a particular topic. As it has been argued in the literature review chapter, chapter 2, the sought after transfer is however not the transferability of TSPCK developed in the topic of intervention as TSPCK is the product of the rigorous application of the transformation

competence, but the knowledge of both the knowledge of the components of TSPCK and the skill to apply them interactively in engaging concepts in a topic (Rollnick & Mavhunga, 2015). So, what is transferable to a new topic is the learned pedagogical transformation competence (Rollnick & Mavhunga, 2015). Based on these arguments, two research questions were formulated to guide this study and answers to these questions are provided below.

6.2 Answering research questions guiding this study

The explicit intervention which exposed the participating pre-service teachers to the use of five content-specific knowledge components of TSPCK concentrated on the physics topic of kinematics. This topic has earlier been discussed to be a fundamental and core aspect in learning physics at the high school level.

Research Question 1: The first research question guiding this study was stated as – what is the impact of an intervention, which explicitly discusses transformation of content knowledge using five content specific components, on the quality of pre-service teachers' TSPCK in kinematics? The question was about how explicit discussions of the five content-specific knowledge components influenced the quality of pre-service teachers' TSPCK in kinematics. The analysis of the TSPCK data collected indicated that the pre-service teachers moved from a lower overall group score of '2' (which denotes basic level of TSPCK) to a higher overall average score of '3' (which denotes developing level of TSPCK) following the intervention. This newly acquired category '3' (i.e. Developing TSPCK) implies that, following the intervention the pre-service teachers were able to provide evidence of responses to teacher tasks drawing on three components of TSPCK interactively rather than drawing on only one or two as in the beginning (i.e. prior to the intervention). There was also evidence of shifts in the quality of TSPCK components interactions observed early in the intervention from the pre-service teachers' submitted class activity and group discussions compared to those later in the intervention. Such component interactions have been argued to be an indicator of the likely quality of the TSPCK in the topic (Mavhunga, 2014). Hence, the answer to the research question is that following an intervention explicitly focusing on developing transformation competence, the pre-service teachers experienced a significant improvement in their quality of TSPCK in the topic of kinematics.

Research Question 2: The second research question guiding this study stated that - To what extent is the pre-service teachers' learnt pedagogical transformation competencies transferable to the development of TSPCK in a new physics topic - electricity? With this question, the interest was in determining if the pre-service teachers were able to transfer the pedagogical transformation skills and knowledge acquired during the intervention to the planning and actual teaching of a new physics (electricity). Data collected through the validated TSPCK electricity tool, TSPCK rubric and records of pre-service teachers' actual classroom teaching assisted in answering this question. The answer to the research question is that the pre-service teachers showed evidence of using the pedagogical competence learnt in the intervention to develop TSPCK in the new topic of electricity to the same extent as in the topic of intervention – a 'Developing' category of TSPCK. This extent of transferability is the next to the highest extent according to the validated rubric used in this study. With this 'Developing' category of TSPCK, the analysis revealed three knowledge components - learner prior knowledge (LPK), curricular saliency (CSA) and representations (REP) - were commonly interactively used by the pre-service teachers in the new physics topic - electricity. The pre-service teachers would have demonstrated the highest extent of transferability (i.e. the 'Exemplary TSPCK), if they had interactively used four knowledge components consistently in their formulation of responses. Meanwhile, the topic of electricity was considered new from the point of discussion of its teachability, the pre-service teachers only had the opportunities of learning the content in the content course in their third year but not the TSPCK aspect. So, it was impressive seeing the pre-service teachers demonstrating TSPCK in this new physics topic to the same extent as that of the topic of the intervention.

Having provided answers to the research questions guiding this study, there were notable trends observed in the findings. These are discussed below considering the context of the limitations of this study.

6.3 Contributions of this study to New Knowledge

This study makes notable contributions to the PCK studies and classroom teaching and learning of physics through its methodological and empirical findings generated. One of the important aspects of this study is embedded in validating the newly developed TSPCK kinematics tool

used, serving two main purposes. The first purpose was to use to the tool to measure pre-service teachers' quality of TSPCK in the topic of kinematics in planning context. The second purpose was to make the tool served as a contribution to the literature with regards to valid instruments for measuring TSPCK construct. These served as methodological contributions. The generated findings from the analysis of data collected using the tools served as empirical contributions. The discussions in the subsections below provide detailed explanations on the contributions of the findings to new knowledge.

6.3.1 Empirical contributions

There are basically three empirical findings that emerged from this study. The first was that the participating pre-service teachers improved in the quality of TSPCK in the physics topic of kinematics following an intervention. The second finding was that the pre-service teachers' observed improvement in the quality of TSPCK in kinematics was not an automatic process of simply recalling or regurgitation of learnt knowledge in the intervention rather a process of rigorous engagement with each of the knowledge component at varying degrees. The third finding is derived from the observation that the pre-service teachers' demonstrated transferability of learnt pedagogical transformation competence to a new physics topic of electricity. It is worth indicating that the first two findings were not surprising as these findings confirmed reports in some of the previous studies that were done in chemistry topics like chemical equilibrium (Mavhunga & Rollnick, 2013), organic chemistry (Vokwana, 2013), electrochemistry (Ndlovu, 2014). However, the findings remain significant and contributing towards the literature on developing planned TSPCK in different disciplines of science pre-service long before they become teachers. Furthermore, the repetition of the study in another science discipline (physics) adds credibility to the TSPCK construct using key components of the construct itself. This supports argument in the literature that developing PCK in pre-service teachers is done by teaching them the components that make up PCK (Nilsson, 2011). While the observed improvement reflects TSPCK at a planning level rather than enacted, Shulman (1987) has encouraged its development highlighting its influence in explaining and influencing future teacher actions in class. Likewise, the findings in this study could stand to provide a substantial practical example of what Shulman (1987) argued that "*teaching necessarily begins with a teacher's understanding of what is to be learned and how it is to be taught*" (p. 7) and that

reasoning pedagogically in a planning context is as important as the actual classroom teaching. The third finding is of high interest, as it suggests a possible model for a self-driven, independent, spiral development of TSPCK in several topics in a discipline by pre-service teachers. This finding however is presented with caution as there were limitations in the research design of the present study that do not allow for a tight-proof conclusion. Each of the three findings is discussed below in detail.

(i) Improvement in the quality of TSPCK in kinematics

First, as illustrated in chapter 4, the analysis of the data collected indicated that the pre-service teachers had an overall group scores of '2' and '3' on the five knowledge components in the pre-TSPCK test and post-TSPCK test respectively. While a score of '2' corresponds to 'Basic level' of TSPCK, '3' corresponds to 'Developing level' of TSPCK according to the validated TSPCK rubric used (see appendix VIII). The pre-service teachers can be observed to have moved from a lower category '2' (Basic) to a higher category '3' (Developing). Also the Rasch Analysis done as shown in the Table 4.4 in Chapter 4 indicated that: the pre-service teachers had a Rasch person measure of -1.98 in the pre-test; and a Rasch person measure of 1.42 in the post-test. Conventionally, increase in the positivity of Rasch measures implies high person ability while increase in the negativity of the values indicates high person difficulty on the items on the instrument (Boone et al. 2014). That is, the higher the person measure the more the better the performance of the participants. This is because according to the coding of the rubric used, '1' is for limited (more difficulty, low ability) and '4' for exemplary (less difficulty, high ability). Thus, the pre-service teachers' post-TSPCK Rasch measure indicates an improvement in the quality of their TSPCK with respect to the topic of the intervention, kinematics. Second, further analysis was carried out using Wilcoxon Paired Signed Rank test on the pre-service teachers' pre and post-TSPCK Rasch measures. The analysis gave an estimated value of p (=0.000) which was much more less than the significance level ($\alpha = 0.05$) at 99% level of confidence as indicated in the Figure 4.15 in Chapter 4. This indicates such a huge statistical significant difference between the pre-service teachers' performances in the pre-test and the post-test.

Third, it was considered important to develop insight into the struggle and success as the pre-service teachers were developing their TSPCK in the topic of kinematics during the intervention (Mavhunga, 2014). The content analysis of the written group discussions of the class activities

collected towards the end of the intervention indicated evidence of developing TSPCK in the topic as well. For instance, while the two groups of pre-service teachers were engaging and responding on questions on the knowledge component 'what is difficult to teach' (**WDT**) later in the intervention (as in the Figure 4.9 and 4.10 in Chapter 4) it was observed that other components were also emerging in the given responses, particularly the component on the knowledge of important concepts in the topic was demonstrated coupled with the reason for the difficulty. This ability that recognizes important concepts in a topic, talks to the pre-service teachers' understanding of the TSPCK component 'curricular saliency' (**CSA**) (Geddis and Wood, 1997). As shown in the Figure 4.9 the pre-service teachers in group 1 demonstrated understanding of the use of representations (**REP**), identifying important concepts like speed and velocity (signifying an aspect of **CSA**) alongside and emphasizing what makes velocity and speed difficult (signifying an aspect of **WDT**). The interactive use of knowledge components - **REP**, **CSA** and **WDT** - seemed to be evident. Similarly, the group 2 pre-service teachers made a reference to the student familiarity with the meaning of velocity and speed as interchangeably used in everyday language (Sengupta & Farris, 2012) thereby signifying their understanding of the TSPCK component learner prior knowledge (**LPK**). Interactively demonstrated with that was the understanding of the specific concepts considered difficult with reason (indicating knowledge of TSPCK component **WDT**) and use of representations as a strategy (indicating knowledge of TSPCK component **REP**). Building on that was the pre-service teachers' statement "*The student should be made to understand scalars (speed) and vector (velocity) very well*" reflecting what is important to teach and an understanding of the TSPCK component **CSA**. These improved pre-service teachers' responses in the TSPCK kinematics post-test and later submitted class activities revealed their developing quality of TSPCK in the topic following the intervention.

This improvement as discussed above is not without a link to all that happened during the intervention process. As explained in the methodology chapter (Chapter 3), the key feature of the intervention was explicit in discussing the TSPCK and how the constituent components, once understood could be used interactively to transform CK when thinking and planning to teach a topic. As a result, the intervention was made up of carefully planned series of explicit discussions on the understanding of TSPCK components that bring about the transformation of CK. Naturally, while the focus was on the demonstration of one component of TSPCK at a time,

the spontaneous emergence of other components in the explanations was pointed out. In such a moment, an accompanying comment was made whether the emerging component (s) is yet to be discussed in full (in upcoming sessions) or a reminder of its discussion in the previous sessions. However, pre-service teachers were encouraged to make note of how the components interact. Typically sessions that introduced a component would have a mix of teacher and learner cantered discussions. The intervention explained each of the five components of TSPCK using the knowledge concepts of kinematics. Through this program, the pre-service teachers were able to interrogate the content of the topic from the perspective of each of the TSPCK components. Through the support of the lecturer in the process, opportunities for trial and error developed the competency to formulate teacher responses such as explanations that demonstrated the use of components interactively. As discussed in chapter four, in order to measure the nature and the extent of the shifts in the quality of the developing TSPCK in kinematics, the TSPCK kinematics tool was administered prior to the intervention and after the intervention as a pre-test and post-test respectively. In both cases, the tool was administered as take-home tests due to the nature of the test items and the time needed to think through them. After the pre-service teachers handed-in the completed tool for the pre-test, the course lecturer then informed them that another test (the post-test) would be conducted. The date was announced but the nature of the test and its similarity to the pre-test was neither discussed nor included in the announcement. Both pre-test and post-test conducted were of the same contents except for the different cover sheets and the different dates they were written. The efforts made during the intervention and the pre-service teachers' pedagogical transformation competence have collectively worked together, bringing about quality explanations in the post-test pre-service teachers' responses compared to the pre-test.

Thus, in this study, the pre-service teachers' improvement in the quality of TSPCK in kinematics confirms reports in two previous studies. For instance, Mavhunga (2012) investigated the quality of pre-service teachers' TSPCK in the topic of Chemical equilibrium using the same construct as used in this study. She made two important findings, following an intervention: there a significant positive difference between the Rasch measures in the pre vs. post-tests at the 99% level of confidence (Mavhunga, 2012, p. 196); and as the pre-service teachers were focusing on one of the components, they naturally made reference to another (Mavhunga, 2012, p. 196). In another similar study that used the construct of TSPCK, Pitjeng (2014) engaged a

group of novice unqualified graduate teachers (NUGTs) in a 'professional development intervention' (PDI) with a similar intention of developing TSPCK in the topic of particle nature of matter. She found out that: the NUGTs had an improved level of TSPCK in the topic considerably after engaging with the PDI (Pitjeng, 2014, p. 178); and that their collective engagement of TSPCK components enabled the transformation of CK in the topic of the intervention (Pitjeng, 2014, p. 178). Thus, in this study the finding with the topic of kinematics is not surprising but it validates the value of the construct and the model of implementation used in the reported studies with different types of teachers and adds new knowledge with respect to feasibility of the model with physics topics.

(ii) The process of developing TSPCK is rigorous

The second finding was that the pre-service teachers' reported improved quality of TSPCK in kinematics was a rigorous engagement with each of the knowledge component at varying degrees. Given that the topic of intervention singularly received extensive attention by virtue of its status as a topic used in the intervention, one is prone to actually be expectant of the observed improvement in TSPCK, and also that the demonstration of knowledge in the components would be easy for the participating pre-service teachers. However, the analysis suggests a differentiated pattern in the average group score measures of improvement in each TSPCK component across the pre- and the post-TSPCK tests. As indicated in the table 4.1 in Chapter 4, it was first noticed that on the TSPCK component 'learner prior knowledge' (LPK), the pre-service teachers improved one category up with a group score of '2' in the pre-test to a group score '3' in the post-test. The engagement was observed as the pre-service teachers' made effort to expand and re-phrase explanations, confronting misconceptions in the post-test than just acknowledging misconception with standardized knowledge but with no expansion as in the pre-test. This pre-service teachers' engagement on this LPK component seemed to follow the argument by Aydin and Boz (2013) that a teacher with PCK demonstrates its component of learner knowledge when there is awareness of learners' pre-requisite knowledge, difficulties as well as misconceptions and I point the same for TSPCK in this study. However, the pre-service teachers' extent of rigorous engagement on this component could be in line with the opinion of Zhou *et al*. (2015) that since pre-service teachers do not really have many classroom teaching experiences, they could only accumulate an appreciable understanding of students' preconceptions and knowledge

in the course of their teacher education programs, thus the observed improvement in this component is evident of thinking about concepts, even perhaps drawing on own experience as a learner, but it was first time that the pre-service teachers reasoned about misconceptions from a perspective of teaching kinematics. Similarly, on the TSPCK component of 'representations' (REP), the improvement was a category up with average score of '2' and '3' in the pre and post-test respectively. The engagement took place in the post-test as the pre-service teachers' logical discussions showed conceptual orientation of the use of the model than just listing concepts with no explanation as in the pre-test. Also, on the TSPCK component 'conceptual teaching strategies' (CTS) with average score of '2' in the pre-test and '3' in the post-test, the engagement occurred as the pre-service teachers confronted student misconceptions by considering at least an aspect related to curriculum saliency using two or more different representations to enforce an aspect of the concept.

Exceptionally noticed, the average group score per category as shown in the Table 4.1 in Chapter 4 indicated that the pre-service teachers improved two categories up on the TSPCK component 'what is difficult to teach' (WDT) with the score of '2' in the pre-test and '4' in the post-test. The process of rigorous engagement could be said to have been responsible for this jump. This was observed in the pre-service teachers' ability to provide reasons linking to specific gate keeping concepts which when not fully understood add to the difficulty of a concept (Zhou *et al*. 2015). This was accounted for in the post-test better than just identifying specific concepts with broad reasons as seen in the pre-test. This finding was similar to what Mthethwa-Kunene *et al*. (2015) observed with a group of experienced biology teachers following an exploration of the teachers' PCK in a specific of genetics. The authors found out that all the observed teachers were able to identify learners' difficulties related to the terminology in genetics, processes of cell division and abstract nature of some aspects in the topic. In contrast, Zhou *et al*. (2015) found out while investigating pre-service science teachers' PCK in the physics topic of Newton's law of motion that "*majority of pre-service science teachers were not able to accurately spot student learning difficulties: distinguishing interaction forces and balanced forces in gravity associated interaction situations*" (p. 382). Usak *et al*. (2011, p. 416) equally reported, while studying beginning teachers' PCK, that they were unable to give any more-or-less reasonable answers to questions related to learning difficulties and misconceptions of learners. Thus, the pre-service

teachers' reasoning and rigorous engagement with this very TSPCK component was more intense than the remaining four other components.

In contrast to the aforementioned rigorous pre-service teachers' engagement on the TSPCK components, there seemed to be no such observation on the component of 'curricular saliency' (**CSA**) as same average score of '2' was calculated for both the pre and post-test although there was evidence that pre-service teachers' partly applied the knowledge of this component while formulating responses. This finding was slightly similar to that of Park and Chen (2012) who reported while investigating experienced teachers' PCK in a biology topic that "*another salient pattern in the synthesis of the PCK components was that knowledge of science curriculum (KSC) had the most limited connection with other components*" (p. 937). The explanations provided by Park and Chen (2012) for the teachers' difficulty with this KSC included: narrow perspective of curriculum as a collection of topics; and using the curriculum to select topics but hardly referring to its scope and sequence in preparing lesson plans. While interviewing the available pre-service teachers (TAKA, TEMA, TIFA, TMAM and TIFA) as reported in the section 4.3 in Chapter 4, TAKA and TEMA referred to the similarities and interrelatedness of the kinematics concepts listed in the tool from which they were expected to select central concepts. Also, TIFA, TMAM and TANA talked about the need to further work on their content knowledge in the topic of kinematics. TIFA spoke about lack of teaching experience in the topic of kinematics as the factor. These are important factors that should further be looked at in developing pre-service teachers' TSPCK in physics topics. That there was no such pre-service teachers' rigorous engagement with the TSPCK component of CSA, Loughran et al. (2012) raised an important point related to teaching experience as argued that "*expert science teachers use this knowledge and information to shape the manner in which they teach particular concepts*" (p. 13). This could possibly call for thorough and more emphasis on this component in the intervention and further investigating the pre-service teachers' enacted TSPCK which goes beyond planning context (espoused TSPCK).

Moreover, supporting the above was the generated Rasch item rank order in the post-test which was noticed to be different from the pre-test as shown in the Table 4.5 in Chapter 4. While the order of increasing difficulty was LPK (-1.38) < CSA (-0.33) < WDT (0.07) < CTS (0.48) < REP (1.15) in the TSPCK pre-test, and a different order was observed in the post-test as: WDT (-

3.19) < REP (- 0.59) < LPK (-0.32) < CTS (0.65) < CSA (3.45), where the component CSA is experienced as most difficult. The difference in the order of difficulty of the components in either test illustrates the process of engaging with the components being of unequal ease of success and different degrees of improvement across individual components when comparing the pre and post tests. This illustrates the varying extent of shifts in the engagements with the components. All this shows the rigorous nature of the engagement needed to develop TSPCK even in the topic of intervention. This means there were reasoning processes going on as the pre-service teachers engaged with the components of TSPCK in transforming kinematics concepts. These could be associated with a cognitive pedagogical transformation process. Investigating the development of such competence using five knowledge components of TSPCK is the target and achievement of this study. Likewise, the order of item difficulty after the intervention further establishes topic specificity of PCK in kinematics as different from other topics like chemical equilibrium (Mavhunga & Rollnick, 2013) and particulate nature of matter (Judith, 2014) where the order of difficulty was observed different to each other and to the one now established in kinematics. In all, the pre-service teachers differently engaged with the TSPCK knowledge components which positively affected their quality of TSPCK in the topic of kinematics.

(ii) The learnt pedagogical competence is transferable and used to develop TSPCK in a new topic

The topic of transfer in this study was electricity, which was not discussed during the intervention. It was used as a new physics topic to examine the pre-service teachers' possible transferability of learnt pedagogical transformation competence. The difference between the pre and the post-TSPCK test in kinematics showed an improvement similar to that observed in the topic of transfer. For instance, in kinematics the pre-service teachers moved from a lower average group score of '2' to a higher average score of '3' as seen in the Table 4.1 as already discussed above. The newly acquired average score of '3' indicated that the pre-service teachers had "developing" TSPCK (Mavhunga, 2014) in the topic of the intervention (kinematics). This implies that the pre-service teachers demonstrated in most cases, understanding of interactive use of three knowledge components of TSPCK while formulating responses to teacher tasks prompted by the test items in the topic. Similarly, in the new physics topic (electricity), the pre-service teachers had an average group score of '3'. This could mean that the pre-service teachers

were able to transfer learnt knowledge and skills of interactive use of three knowledge components in pedagogically transforming CK in the topic electricity. The evidence of this is seen in the pre-service teachers' written responses analyzed in the previous chapter, chapter 5. This was also noticed in the record of TSPCK Episodes seen in the pre-service teachers' actual teaching summarized in the Table 5.2. For example, on the TSPCK component of Learner Prior Knowledge (LPK), pre-service teachers demonstrated understanding of interactively use of the knowledge components three content specific knowledge components in formulating responses to the kinematics tool in the post-test. This was indicated as in the statements (Figure 4.3) "*It is clear that the learner understands that you have to add the distance together but does not understand that the signs are not to be considered when the car is travelling at the opposite direction (**LPK**). It is thus important for the learners to know that the car is still covering a certain distance regardless of its direction (**CSA**). In simple terms we do not consider direction when we are dealing with distance (**LPK**) because it is a scalar quantity (**CSA**) and distance is not the same as displacement which includes direction (**WDT**)"*. Equally, pre-service teachers were able to engage three knowledge components while formulating responses to the TSPCK tool in electric circuits on the same TSPCK component LPK as in the statements (Figure 5.3) "*My reason is that, response C gives a detailed explanation about the influence of resistance in the brightness of the bulbs. It further connects the individual resistance to the total resistance of the series circuit (**CSA**), $R_{total} = R_1 + R_2$, which influence the total current flowing through the series circuit (**REP**). Meaning that an increase in R1 will increase total resistance of the circuit hence resisting more current from flowing through the circuit (series) (**CSA**). The learner had the misconception that 'resistance has no relationship with the brightness of the bulb (flow of current) (**LPK**). Hence, response C is now providing the correct conception to say that resistors/control current flowing through the circuit (decreasing brightness of the bulb) since current is inversely proportional to the resistance. Therefore, response C will not just provide what is correct but it will also teach the idea of resistance in series circuits and its influence to the appliances connected in series (**CSA**)*". The improvement observed in both the planned TSPCK in kinematics consistently seen in the planning and actual teaching of electricity, is encouraging. Meanwhile, this consistent improvement is linked to the development of pedagogical transformation competence in the intervention in a cautioned way, as it is only based on the known background context. This background context is that pre-service teachers have not been exposed to electricity from a teaching perspective particularly TSPCK. This study however, has no collected data on the level of TSPCK in electricity at the beginning of the

intervention on kinematics due to constraints and concerns to over-testing pre-service teachers in the formal methodology course. Nonetheless, the observed "developed" quality in the topic seen in both planned TSPCK and enacted TSPCK cannot be ignored given that the exposure to the pedagogy of TSPCK only came through the intervention. The findings showed that there seems to be a congruency between how the pre-service teachers' pedagogically transformed CK in the planning context and actual teaching. Thus, this finding stands to provide a substantial practical example of the argument that "*All these processes of transformation result in a plan……Pedagogical reasoning is as much a part of teaching as is the actual performance itself*" (Shulman, 1987, p. 17). This implies that developing pre-service teachers' pedagogical transformation competence in the planning context has an influence on their pedagogical actions in the actual classroom teaching. In relation to that from the psychological perspective, Vygotsky (1978) argued "*if someone learns to do any single thing well, he will also be able to do other entirely unrelated things well as a result of some secret connection*" (p. 82). Hence, it was of great significance developing pre-service teachers' knowledge and skills of using TSPCK components interactively in pedagogically transforming CK in a topic, the competence of which was transferable to another topic.

6.3.2 Methodological contribution

As already indicated, the TSPCK construct by Mavhunga (2012) served as the theoretical framework for this study. So, it sounds good to link the methodological findings in this study to those reported in other studies (e.g. Mavhunga, 2012; and Mavhunga & Rollnick, 2013). When used in the reported studies, the TSPCK construct was observed to be helpful in developing pre-service teachers' TSPCK in the chemistry topic of 'chemical equilibrium' with validity. Following that, Mavhunga and Rollnick (2013) suggested the use of the construct in some other core science topics. With respect to that, Mavhunga (2012) argued that the "*idea of exploring the concept piece by piece through the topics of school science has promise for understanding the nature of the whole (PCK) better*" (p. 205). Based on that suggestion, this current study additionally validated the construct of TSPCK with a developed tool that explores pre-service teachers' TSPCK in the physics topic of kinematics. There is an understanding that, construct validating of a newly developed research instrument (e.g. TSPCK kinematics tool used in this study) requires both interpretative and validity argument (Messick, 1989). The interpretative

argument entails description of the conceptual rationale, possible prospects and assumptions (Schilling *et al*., 2007; Kane, 2012) guiding the construct on which the tool is built. As discussed in the methodology chapter, chapter 3, the rationale that supports conceptualization of the developed TSPCK kinematics tool has its basis on the five content-specific knowledge components of TSPCK (Mavhunga, 2014) listed in the section 6.1 above. The understanding in developing the tool was that, as a teacher combines knowledge of the five components in transforming concepts within a topic, a new dimension of knowledge emerges which is specific to that topic as Mavhunga and Rollnick (2013) argued. This implies that the most important assumption that guided the development of tool is that the knowledge components, representing items in the tool, all work together to measure TSPCK as a single construct.

In addition to that, there are three features that contribute to the construct validity of this TSPCK kinematics tool. These include the hierarchy of the knowledge components; teachers' reflection-on and reflection-in-action activity; and multiple choices with open-ended questions. First, the hierarchy of the five knowledge components was critically looked at. The component 'learner prior knowledge' was put as the first with the assumption that it would be the least difficult and 'conceptual teaching strategy' as the last and most difficult as it draws on all other components. This was done in a similar way to the existing validated TSPCK tool in the topic of chemical equilibrium, the first topic used in examining TSPCK construct in pre-service teachers (Mavhunga, 2012; Mavhunga & Rollnick, 2013). For instance, Mavhunga (2012) found out that after pre-service teachers went through an intervention in the topic of chemical equilibrium, the hierarchy of knowledge was in the order 'learner prior knowledge' LPK, 'curricular saliency' CSA, 'what is difficult to teach' WDT, 'representations' REP, 'conceptual teaching strategies' CTS. However, the order has been realized to be strictly linked to the nature of each component in a particular topic. This as a result talks to the topic specificity of the construct which the items collectively work together to measure. With regards to that, Pitjeng (2014) found a slightly different order of item difficulty while studying the TSPCK of novice teachers in the topic of particular nature of matter. She found the knowledge components in the order: LPK, CSA, REP, WDT and CTS. On the second note, the inclusion of the 'reflection-on and reflection-in-action' (Cooner, 2010) in the TSPCK kinematics tool was such that each item represented a particular teacher task with explicit description of teaching and learning of kinematics. In support of that, when it comes to developing PCK, Magnusson *et al*. (1999) made mention of three things:

content a teacher is expected to teach; the context of teaching; and how reflection occurs as the teacher ponders on personal teaching experiences. Consequently, the pre-service teachers' ability to reflect on the concepts within the topic of kinematics was considered an essential component in their pedagogical transformation process. Thus in this study the items in the developed TSPCK tool targets pre-service teachers' understanding and pedagogical transformation competence for a specific topic (kinematics in this case). Thirdly, embedded in the tool are the multiple choice questions to which pre-service teachers were expected to pick specific options and then a number of open-ended questions which allow the participants to expand on their answers. Combining the two categories of questions in this way gives the opportunities to capture pre-service teachers' reflections on their responses. This made establishing the congruency and validity of their responses to the questions possible thereby facilitating both quantitative and qualitative analysis. This as well, in addition to other aforementioned features, contributed to establishing the validity of the TSPCK kinematics tool used in this study. The three features were the major things that the PCK researchers and experienced educators discussed in the course of developing this TSPCK tool. Likewise, there were two important points that emanated from the discussion of the assessors of TSPCK kinematics tool used in this study. The first emphasized the centrality and significance of content knowledge in developing PCK, implying that PCK in a particular topic could not be said to have been developed when the CK is incorrect (Rollnick & Mavhunga, 2014). Thus, the development of this TSPCK kinematics tool as well as the assessment indicated none of its contents (and items) portrayed incorrect content knowledge. This also recommended that the participant pre-service teachers with whom the tool was administered possessed sufficient CK of the kinematics to able to apply correctly their pedagogical transformation skill (Oh & Kim, 2013). That means for the pre-service teachers to be able to give right answers and explicitly discuss their responses they must have TSPCK and my judgment of the items as the researcher was based on that. Consequently, this understanding determined categories of the raters who marked the completed tool by the pre-service teachers. The raters were those who are familiar with and knowledgeable in developing pre-service teachers CK and PCK in the topic of kinematics. Doing this contributed to establishing content validity of the TSPCK kinematics tool used in this study.

With the validity argument, more information is made available regarding how coherent, plausible and reasonable the interpretative argument is (Kane, 2012). As a result, in this study, Rasch measurements have been employed as a channel of providing validity argument. Two important evidence of the TSPCK kinematics tool validity were gathered from the Rasch analysis. Firstly, as explained in the previous chapter, there were person measure and item measure generated from the Rasch analysis of pre-service teachers' responses to the TSPCK kinematics tool. These statistical indices for both measures in the pre-and-post test were all found to be within the conventional acceptable range of +2 and -2 (Boone *et al*. 2014). Having all indices in this range implies that the constituent tool items, representing the five TSPCK knowledge components, all work together measuring TSPCK as a single construct (Boone *et al*. 2014). This further speaks to support the establishment of the validity of TSPCK construct in this study. Secondly, the order of item difficulty in the post-test (after the intervention) indicated that the TSPCK component 'What is difficult to teach' emerged as the least difficult, followed by 'Representation', 'Learner Prior Knowledge', 'Conceptual teaching strategies' and 'Curricular saliency' as the most difficult. This order is different from that in the topic of chemical equilibrium (Mavhunga & Rollnick, 2013) and in the topic of particulate nature of matter (Pitjeng, 2014) already discussed above. This follows the theoretical assumption that TSPCK in one topic is different from that in another topic, further confirming topic specificity of PCK. Thus, the result empirically established construct validity of TSPCK kinematics tool in that, order of item difficultly did not follow the order in some other topics, yet the items work together to measure a single construct, TSPCK. The evidence from the interpretative argument and validity argument contribute to validating the TSPCK kinematics tool used in this study with TSPCK construct as the framework.

Having discussed the methodological and empirical contributions of this study to new knowledge, there is the need to critically reflect on the whole research design process from the findings emanated. These reflections are discussed below.

6.4 Critical Reflections on the Research Process

6.4.1 The Research Methodology used

This study used mixed methods (**MM**) as the research methodology such that the philosophical assumption connected with the use of this approach is situated within pragmatism. This combines detailed descriptions (qualitative) and numerical (quantitative) explanations of collected data in answering the research questions. Using MM in this study has assisted me in notable ways. It gave me a better understanding of the research problems and complex phenomena than individual method, either qualitative or quantitative would have done if used singly (Frels and Onwuegbuzie, 2013). Through that I had opportunities to access multiple perspectives of the development of a complex TSPCK construct (Loughran, Berry & Mulhall, 2012) in two different physics topics and particularly in pre-service teachers traditionally known to have poor PCK in general (Mavhunga & Rollnick, 2013). I also realized a qualitative method was more suitable in gathering evidence of developing TSPCK. This was evident in the pre-service teachers' demonstration of interactive use of knowledge components as they formulated responses to teacher tasks as seen in the Figure 4.5, 4.6 (in chapter 4), 5.6 and 5.7 (in chapter 5) to mention a few. This enabled explanations of the TSPCK episodes observed in the data, pointing at the pre-service teachers' quality of TSPCK in the two physics topics. Likewise, the quantitative method with Rasch techniques was most helpful in determining the extent to which pre-service teachers' engaged their pedagogical reasoning competence enhancing their TSPCK in the two physics topics. While the qualitative analysis showed that the pre-service teachers improved in their quality of TSPCK as they interactively used three or more knowledge components than one or two as they did in the pre-test, they quantitative analysis confirmed this by showing a significant difference between pre-TSPCK test versus post-TSPCK test.

Intervention – Explicit discussions of five TSPCK knowledge components

The intervention which served as the platform for explicit discussions of TSPCK components although was the not the main focus in this study, it notwithstanding helped in addressing problem statement and research questions guiding this study. So I considered it fitting starting my reflection with the intervention and all it entailed. As alluded to in the methodology chapter, chapter 3, the intervention exposed the pre-service teachers to the idea of transforming content knowledge (CK) within a specific topic, kinematics. Kinematics was chosen as the topic of

intervention because it is fundamental in understanding other topics especially in Mechanics (Lemmer, 2012). The key feature of the intervention was explicitness in discussing the TSPCK and how the constituent components, once understood could be used interactively to transform CK when thinking and planning to teach a topic. This happened over a period of six weeks organized into a total of 12 sessions of 15minutes. Each session commenced with three important things: reflecting on the purpose which was developing TSPCK by understanding transformation of content knowledge (Mavhunga, 2014); making ways of achieving the purpose known; and the amount of progress made so far. By so doing, there was a correlation between what was done during a particular session and another while a specific aspect of TSPCK construct was deliberated on in each session. I realized this supported Kind's (2009) opinion suggesting the need for arousing pre-service teachers' sensitivity to PCK and hence TSPCK in this study as the kind of knowledge they acquire in the course of being involved in such an explicit discussion (intervention). I also observed that in some instances, the participating pre-service teachers raised questions that had to do with what have been discussed in the preceding intervention sessions. This served as evidence of the interrelatedness of the TSPCK components discussed during the intervention.

With regards to the pedagogical approach employed in explaining knowledge components to the pre-service teachers during the intervention, I observed the whole session was more o interactive discussions among the pre-service teachers and their methodology lecturer. As a researcher who was there to observe, I could see understanding developing as the pre-service teachers were asking questions and giving explanations. However, I realized there were instances the pre-service teachers seemed to be unsatisfied about the approach that encouraged the painful of reasoning through owns understanding of content. These were instances where taking for instance a participating pre-service teacher had directed a question to the course lecturer and the course lecturer in response asked the pre-service teachers to reason in their groups and come up with an answer. In some of these cases, the pre-service teachers did shout and asked the course lecturer to answer such a question. Witnessing the quality of feedback that pre-service teachers gave after deliberating on such questions served as part of my own personal observed evidence of developing TSPCK in the pre-service teachers during the intervention. There were neither interruptions nor disturbances throughout the sessions, all went well as planned. Then, there is the need to reflect on the methodology used in this study. This is discussed below.

To sum it all, the use of MM in this study helped in providing correct and augmented levels of confidence in my research findings (Schram, 2014) thereby making contributions to new knowledge when all the findings were combined from different research strategies (Schram, 2014). With this, the validity and trustworthiness of findings were considered important in this study. These are discussed as follows.

6.4.2 Validity and Trustworthiness

In a mixed methods research study like this, examining the quality of data and findings is considered very important. Since such a research study combines both qualitative and quantitative methods, the quality of data dwells on the quality of standards of each (Ihantola & Kihn, 2011) strand involved. In support of that, Teddie and Tashakkori (2009) indicated if the data of the individual strands is valid and credible, then the mixed study will have a high overall data quality. Based on that, careful observations made of different standards in this study. This was done towards evaluating the quality of data collected through individual quantitative and qualitative methods combined to establish the entire obtained data quality.

With regards to the qualitative data, the trustworthiness was established in two ways. First, the accuracy of the data collected through the tools used was accounted for by involving two raters (myself as the researcher and the course methodology lecturer) in scoring pre-service teachers' responses to all the administered tools. We both individually marked pre-service teachers' using the same validated qualitative TSPCK rubric and thereafter discussed our scoring to ascertain consistencies in the marks. Where there were differences, we looked again at the pre-service teachers' responses in accordance with the rubric, discussed and reached an agreement on the final scores. The agreed final scores were used as the raw data all through in this study. The triangulation method of analyzing data from different sources - such as written responses to the TSPCK tools, submitted class activity group discussions and actual classroom teaching of selected pre-service teachers - was used so as to enhance the trustworthiness of this qualitative method. Ihantola and Kihn (2011) added that triangulation of methods in developing converging lines of inquiry helps in making case study findings and conclusions more convincing and accurate. Second, to account for the quantitative validity, we made efforts to verify if the TSPCK tools used measured what they have been designed to measure. In doing this, construct's quantitative validation was considered. This involves establishing evidence of

statistical inference validity (Bond & Fox, 2015). The Rasch Statistical Analysis applied helped in generating statistical indices within the acceptable range of -2 and +2 thereby establishing the validity of the tools (Boone *et al*. 2014). Apart from the validity, another important basic element of construct validation is reliability (Tavakol & Dennick, 2011). Reliability describes the consistency of a research tool in getting the same results when used to measure over and over again to the same person under similar conditions. Tavakol and Dennick (2011) indicated that a research tool cannot be valid unless it is reliable; nevertheless the reliability of an instrument does not depend on its validity. Based on that, Rasch Model Analysis was used in this study to provide statistical information on person and item reliability which tells on the validity of the instruments. There was a statistical record of the internal consistence of the test measures by the generated Cronbach's KR-20 Alpha indices (Linacre, 2015) in establishing reliability in this study.

Further evidence of care taken qualitative data, the underlying principles are based on the fact that validity is an issue of trustworthiness (Zohrabi, 2013). This concept of trustworthiness entails credibility, dependability, transferability and confirmability of the findings as the quality measurements in qualitative research (Ihantola & Kihn, 2011). As a result, the triangulation of data suggested by Zohrabi (2013) was followed in this study. This gave the privilege of obtaining data and information from different sources. Thus, this enhanced the trustworthiness of the data, the interpretations and conclusions drawn. This study was not without limitations. These are discussed as follows.

6.4.3 Implications to science education

- Luft *et al.* 2015 – pointed out that unlike mathematics education, science have not discussed agreeably on what constitute knowledge for teaching science – the study add to empirical data demonstrating TSPCK as valued construct and, a construct concerned with teachability of topics. Based on the various empirical studies reporting positive outcomes, TSPCK could be regarded as knowledge for teaching - this is a construct to be included as a goal for learning how to teach science.
- A demonstrated model for how to implement TSPCK in pre-service – resulting in improved quality of TSPCK in core topics of a science discipline long before pre-service

teachers become being qualified teachers – contradicting the understanding that PCK and by association TSPCK is developed over time in practice (Loughran *et al*. 2004).

- For the South African context and the problems in learning difficulties reported on physics topics, the findings from this study show it is promising addressing such difficulties at the grass root level, teacher preparation education programs. With the pedagogical transformation competence the pre-service teachers learnt in kinematics and which they were able to use in producing TSPCK in a new physics topic, there is possibility that developing their sound pedagogical reasoning this way will help them think about other topics in physics. This will hopefully prepare adequately them in addressing learning difficulties associated with physics teaching and learning.

6.4.4 Limitations of the study

The first an acknowledgeable limitation in this study has been that a small sample size of 19 pre-service teachers participated in this study. This small sample was realized to have been pre-determined by the total number of pre-service physical science teachers that registered for the methodology course in which this study was located. However, this was accounted for while estimating significance difference between pre and post-test in kinematics. For this purpose Wilcoxon paired signed rank test for non-parametric data (Whitley & Ball, 2002) was preferable to a paired-sample t-test in the study because of its appropriateness for non-parametric data of small sample size (N=19). Thus, the conclusion drawn from this study may not be generalized but it may be considered for the aforementioned reason. The second noticeable limitation was that observing pre-service teachers' TSPCK in kinematics was restricted to planning context. This basically encompassed pre-service teachers' pedagogical transformation reasoning of content knowledge in the topic with no actual classroom teaching observations. Park and Oliver (2008) argued that "*PCK can be expressed only when teachers deal with the transformation of subject matter for a specific group of students in a specific classroom, and in this regard it is closely linked to teachers' actual teaching performances and student learning*'' (p. 813). Following this argument, the actual classroom teaching has been regarded as where teachers develop PCK. As a result, I acknowledge actual classroom teaching exercises as necessary for developing PCK in the broad sense. Meanwhile, the thoughts and reasons that influence teachers' classroom instructions first happen in the transformation stage (Shulman, 1987), an

essential planning stage before the actual delivery of the lesson. It is at this stage that teachers prepare and think soundly about pedagogical transformation of their CK in order to make the concepts understandable to learners. Aydeniz and Kirbulut (2011, p. 2) referred to the PCK at the stage as the espoused PCK which guides teachers in making decisions about instructional strategies. Thus, while this study was limited in terms of actual TSPCK that is observable in the classroom teaching, I nevertheless indicate the significance of encouraging pre-service teachers to think and reason through the contents they intend to teach a specific topic. The third limitation worth pointing out has been that while a validated TSPCK rubric used in this study is majorly meant for responses in the planning context, another validated rubric was supposed to be used for classroom observation of evidence TSPCK. Examining pre-service teachers' possible transferability of pedagogical transformation competence in the actual classroom teaching using the same planning context criteria was done out of interest. For tight proof of transferability of learnt transformation competence - no comparison of before and after intervention in the quality of the TSPCK in the new topic could be made because of constraints of access and the number and frequency of tests permissible in the formal methodology course. These also prevent this study from exploring the boundary conditions and limitations to transfer.

6.4.5 Future Research

Based on the limitations in the above paragraph, I then point at the necessity of developing a validated rubric for analyzing pre-service teachers' TSPCK in the actual classroom teaching. Similarly, there is the need for further studies to go beyond mere transferability of TSPCK and look at the boundary conditions and limitations to transfer. This calls for exploring why pre-service teachers should understand each component of TSPCK drawing attentions to the reasons and conditions necessary for clearer context. Also, future studies should be carried out on the link extensively between the pre-service teachers' planned TSPCK and enacted TSPCK with respect to the understanding of the interactively use of TSPCK knowledge components. Likewise, I suggest the need for future research studies to explore developing pre-service teachers' TSPCK in more core physics topics.

6.4.6 Recommendations

There have been studies of this type that used TSPCK construct as the framework in chemistry topics with pre-service teachers in the South African context. Little is known about physics topics. In spite that the findings from this study cannot be generalized because of the small sample size, recommendations could be made majorly to the physics teacher educators and the university management. First, it was found out in the study that following an explicit discussion of TSPCK knowledge components in kinematics the pre-service developed pedagogical transformation of CK competence in the topic. Likewise, evidence of this competence was observed in a new physics that was not discussed during the intervention. Based on these findings, the pre-service teachers should first be made to understand the importance of transforming CK in each physics topic using TSPCK construct. Second, the pre-service teachers should be made to realize that while they are still learning to teach, they can develop TSPCK to an extent in every physics topic not until they become professional teachers. Third, the physics teacher educators should endeavor to engage pre-service teachers in core physics topics which serve as conceptual links to other topics with emphasis on learning pedagogical transformation competence. This has the possibility of enhancing the pre-service teachers' ability to reason soundly in transforming CK in other physics topics. To sum it all, the university management should see to using the construct of TSPCK in developing pre-service teachers' TSPCK in physics teaching and learning.

6.4.7 The end-piece

The ineffective teaching strategies, inadequate content knowledge and poor pedagogical content knowledge of high school physics teachers coupled with learners' unsatisfactory performances in physics examinations in South Africa motivated this study. The assumption is that teacher education programme which explicitly discuses knowledge components of TSPCK for transformation of CK in a topic may alleviate the aforementioned challenges with physics teaching and learning. The findings from this study are then suggesting that it will be helpful developing pre-service teachers' TSPCK in core physics topics in preparing them for effective classroom teaching and learning, as this also signals a possibility of learning pedagogical transformation competence that allows pre-service teachers to apply it in developing TSPCK in new topics by themselves.

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APPENDIX I – ETHICS CLEARANCE CERTIFICATE

Wits School of Education

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

27 St Andrews Road, Parktown, Johannesburg, 2193 Private Bag 3, Wits 2050, South Africa. Tel: +27 11 717-3064 Fax: +27 11 717-3100 E-mail: enquiries@educ.wits.ac.za Website: www.wits.ac.za

25 August 2015

Student Number: 882611

Protocol Number: 2015ECE036M

Dear Olutosin Akinyemi

Application for ethics clearance: Master of Science

Thank you very much for your ethics application. The Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate, has considered your application for ethics clearance for your proposal entitled:

Pre-service teachers' development of TopicSpecific Pedagogical Content Knowledge in Kinematics and transferability to a new Physics topic

The committee recently met and I am pleased to inform you that **clearance was granted**.

Please use the above protocol number in all correspondence to the relevant research parties (schools, parents, learners etc.) and include it in your research report or project on the title page.

The Protocol Number above should be submitted to the Graduate Studies in Education Committee upon submission of your final research report.

All the best with your research project.

Yours sincerely,

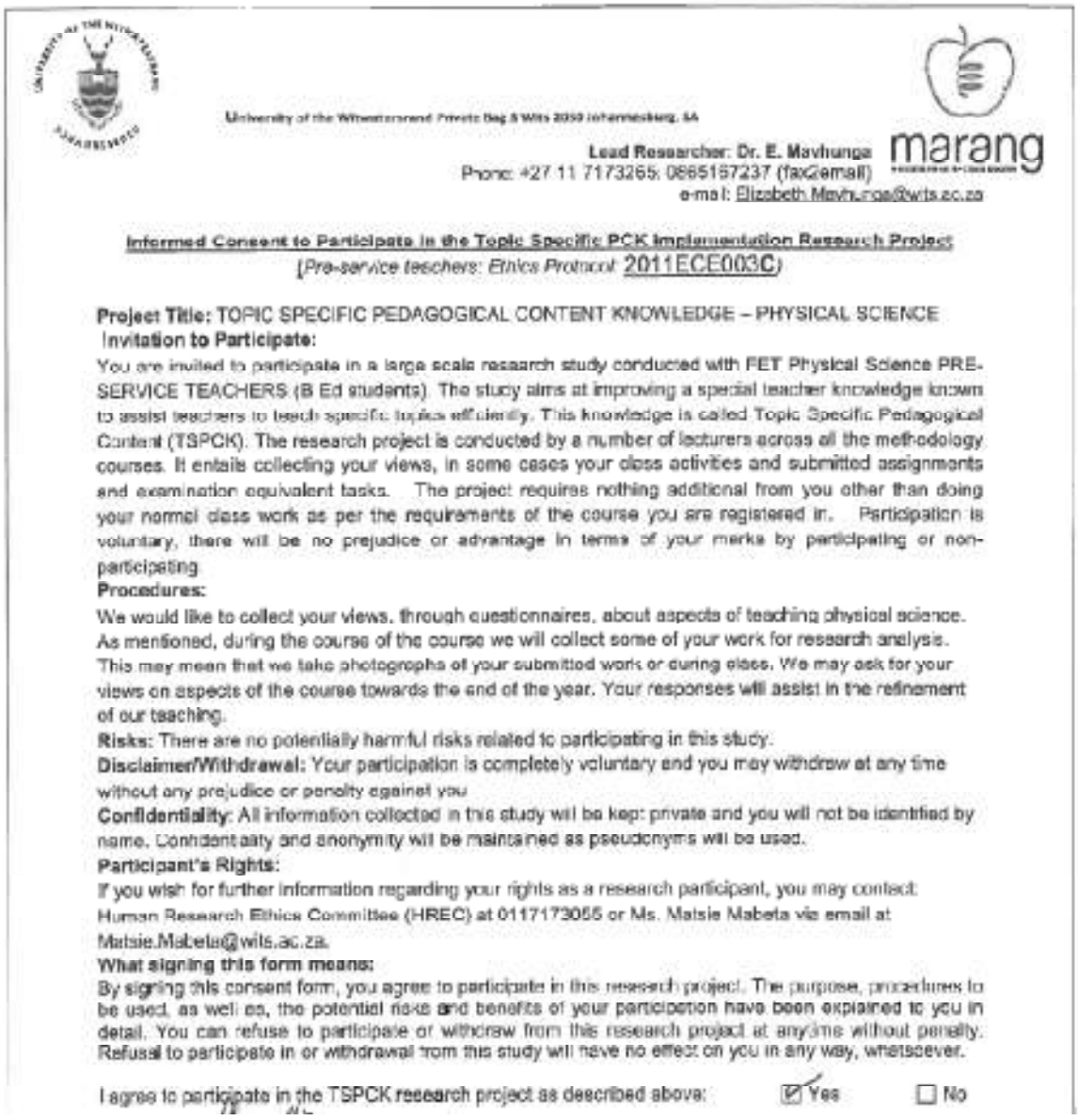
M Mosheta

Wits School of Education

011 717-3416

cc Supervisor -Dr Elizabeth Mavhunga

APPENDIX II – CONSENT LETTER



University of the Witwatersrand, Private Bag 3 Wits 2050 Johannesburg, SA

Lead Researcher: Dr. E. Mavhunga
Phone: +27 11 7173265; 0665157237 (fax2email)
e-mail: Elizabeth.Mavhunga@wits.ac.za

marang

Informed Consent to Participate in the Topic Specific PCK Implementation Research Project
(Pre-service teachers: Ethics Protocol 2011ECE003C*)*

Project Title: TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE – PHYSICAL SCIENCE

Invitation to Participate:
You are invited to participate in a large scale research study conducted with FET Physical Science PRE-SERVICE TEACHERS (B Ed students). The study aims at improving a special teacher knowledge known to assist teachers to teach specific topics efficiently. This knowledge is called Topic Specific Pedagogical Content (TSPCK). The research project is conducted by a number of lecturers across all the methodology courses. It entails collecting your views, in some cases your class activities and submitted assignments and examination equivalent tasks. The project requires nothing additional from you other than doing your normal class work as per the requirements of the course you are registered in. Participation is voluntary, there will be no prejudice or advantage in terms of your marks by participating or non-participating.

Procedures:
We would like to collect your views, through questionnaires, about aspects of teaching physical science. As mentioned, during the course of the course we will collect some of your work for research analysis. This may mean that we take photographs of your submitted work or during class. We may ask for your views on aspects of the course towards the end of the year. Your responses will assist in the refinement of our teaching.

Risks: There are no potentially harmful risks related to participating in this study.

Disclaimer/Withdrawal: Your participation is completely voluntary and you may withdraw at any time without any prejudice or penalty against you.

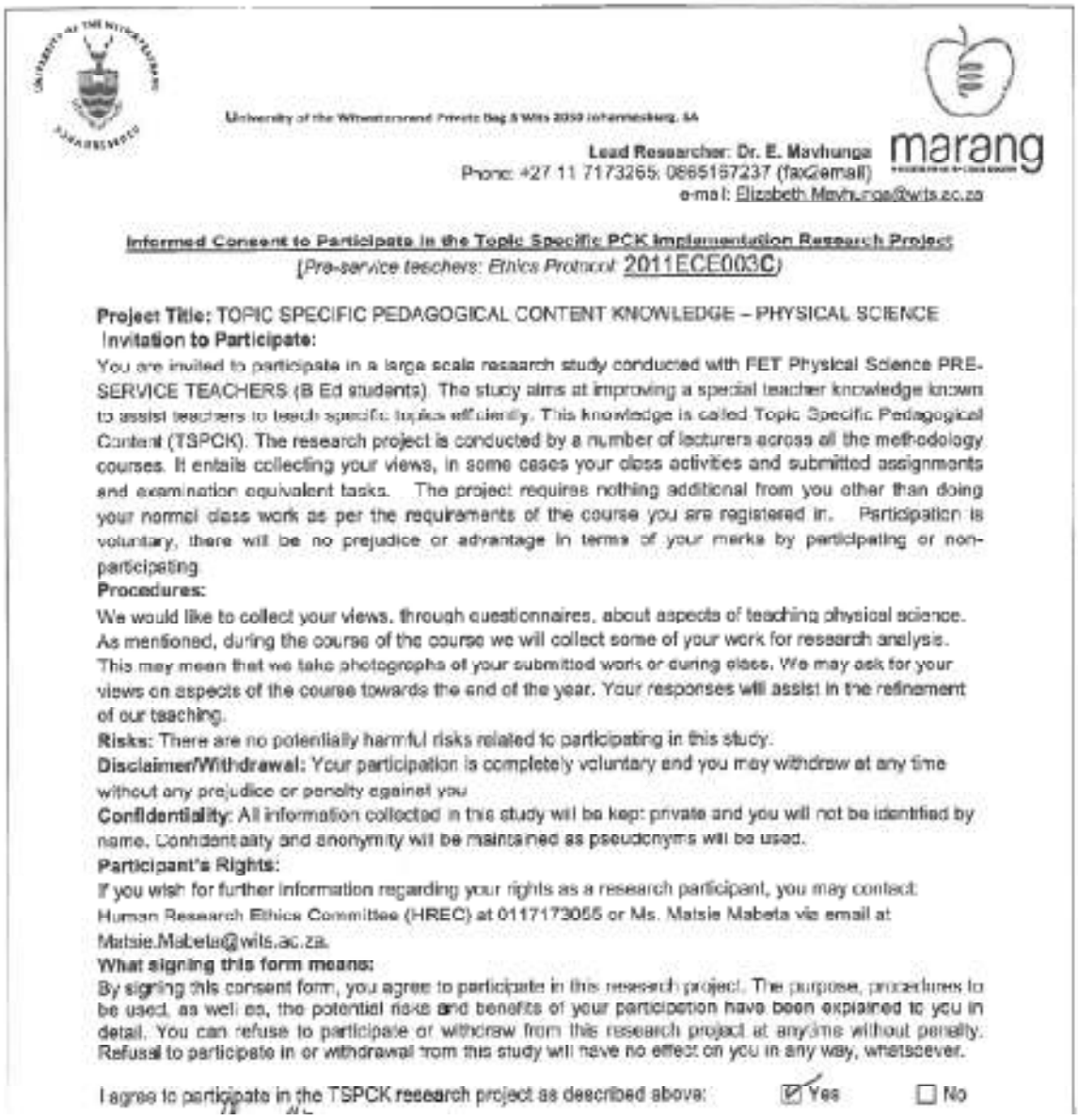
Confidentiality: All information collected in this study will be kept private and you will not be identified by name. Confidentiality and anonymity will be maintained as pseudonyms will be used.

Participant's Rights:
If you wish for further information regarding your rights as a research participant, you may contact: Human Research Ethics Committee (HREC) at 0117173055 or Ms. Matsie Mabeta via email at: Matsie.Mabeta@wits.ac.za.

What signing this form means:
By signing this consent form, you agree to participate in this research project. The purpose, procedures to be used, as well as, the potential risks and benefits of your participation have been explained to you in detail. You can refuse to participate or withdraw from this research project at anytime without penalty. Refusal to participate in or withdrawal from this study will have no effect on you in any way, whatsoever.

I agree to participate in the TSPCK research project as described above: ☑ Yes ☐ No

APPENDIX III – CONSENT LETTER FOR PRE-SERVICE TEACHERS



University of the Witwatersrand, Private Bag 3 Wits 2050 Johannesburg, SA

Lead Researcher: Dr. E. Mavhunga
Phone: +27 11 7173265; 0665157237 (fax/email)
e-mail: Elizabeth.Mavhunga@wits.ac.za

marang

Informed Consent to Participate in the Topic Specific PCK Implementation Research Project
(Pre-service teachers: Ethics Protocol 2011ECE003C*)*

Project Title: TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE – PHYSICAL SCIENCE

Invitation to Participate:
You are invited to participate in a large scale research study conducted with FET Physical Science PRE-SERVICE TEACHERS (B Ed students). The study aims at improving a special teacher knowledge known to assist teachers to teach specific topics efficiently. This knowledge is called Topic Specific Pedagogical Content (TSPCK). The research project is conducted by a number of lecturers across all the methodology courses. It entails collecting your views, in some cases your class activities and submitted assignments and examination equivalent tasks. The project requires nothing additional from you other than doing your normal class work as per the requirements of the course you are registered in. Participation is voluntary, there will be no prejudice or advantage in terms of your marks by participating or non-participating.

Procedures:
We would like to collect your views, through questionnaires, about aspects of teaching physical science. As mentioned, during the course of the course we will collect some of your work for research analysis. This may mean that we take photographs of your submitted work or during class. We may ask for your views on aspects of the course towards the end of the year. Your responses will assist in the refinement of our teaching.

Risks: There are no potentially harmful risks related to participating in this study.

Disclaimer/Withdrawal: Your participation is completely voluntary and you may withdraw at any time without any prejudice or penalty against you.

Confidentiality: All information collected in this study will be kept private and you will not be identified by name. Confidentiality and anonymity will be maintained as pseudonyms will be used.

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What signing this form means:
By signing this consent form, you agree to participate in this research project. The purpose, procedures to be used, as well as, the potential risks and benefits of your participation have been explained to you in detail. You can refuse to participate or withdraw from this research project at anytime without penalty. Refusal to participate in or withdrawal from this study will have no effect on you in any way, whatsoever.

I agree to participate in the TSPCK research project as described above: ☑ Yes ☐ No

APPENDIX IV – TSPCK KINEMATICS TOOL

University of the Witwatersrand Private Bag 3 Wits 2050 Johannesburg SA t+27 11 7173405 f+27867263424

Kinematics TSPCK Tool

The purpose of this research is to find the difficulties pre-service teachers experience and the strategies they use when teaching Kinematics at schools. The assessment instrument consists of two parts; (i) Kinematics content tool and (ii) Kinematics Topic Specific Pedagogical Content Knowledge tool

The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

NAME:					
GENDER	Male		Female		
SUBJECTS YOU HAVE TAUGHT BEFORE DURING TE					
Have you taught Kinematics during TE?	**YES**		**NO**		

There are 5 categories of questions in this tool

1. **CATEGORY A – it contains typical student responses. Please indicate how you would respond to learners in each case i.e. what feedback you would give learners. Provide as much detail as possible.**
2. **CATEGORY B – it relates to planning and sequencing of topics. Your responses will assist in developing a consensus on the main ideas. Main ideas are statements describing key understanding that must be learnt in a topic.**
3. **CATEGORY C – it asks you to reflect on which ideas about kinematics are difficult to teach and get across to learners. This will help in generating a list of difficult ideas that can be used for future research.**
4. **CATEGORY D – it provides different types of representations and analogies. Think about which ones you find more useful and then fill in the table relating to the effectiveness of these analogies in the classroom setting**

5. **CATEGORY E –it gives you a student's exercise and asks you to think about how you would assist this learner develop her/his conceptual understanding of kinematics**

Instructions

- Please write responses directly into the response boxes.
- Please be as detailed as possible as to how you respond in your teaching setting

Thank you for your valued input and assistance

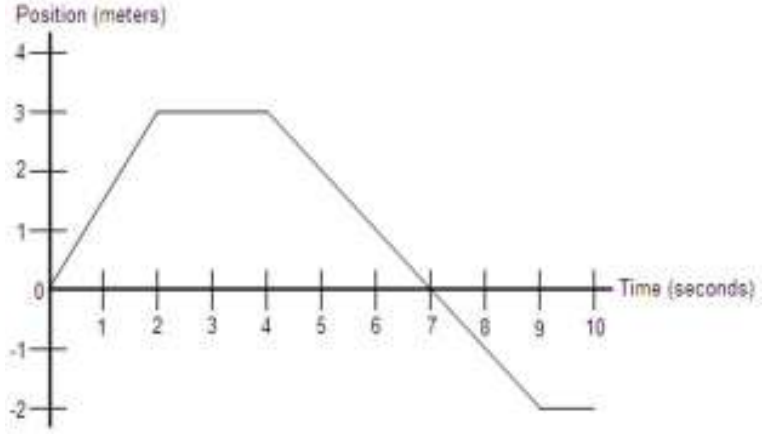
Kinematics TSPCK Instrument

Category A –Typical Student Responses

The two questions below are typical multiple choice items that students have answered incorrectly. A selection of possible teacher responses are provided, none of which are incorrect. Select the response you would most likely use in your practice and explain the reason for your response

A1. How would you comment in writing to the student who **selects C** as the answer to the question below?

Determine the total distance travelled by the car for the whole journey.



D. Distance = Area under the graph

= $\frac{1}{2}(2)(3) + (4-2)(3) + \frac{1}{2}(3)(3) + \frac{1}{2}(2)(-2) + 1(-2)$

= 9.5 m

E. Distance = Sum of all distances

= $3 + 0 + 3 + 2 + 0$

= 8 m

F. Distance = Sum of all distances

= $3 + 3 + (-3) + (-2) + (-2)$
= -1 m

Response A: There are three types of graphs in kinematics (i) position-time (ii) speed-time, and (iii) acceleration-time. When you are given a speed-time graph you calculate the distance travelled by getting the area under the curve. In this case, this is a position-time graph, position is distance, so just add the distances moved

Response B: When you have a position-time graph, the total distance travelled is the sum of the individual distances, so you add not taking signs into consideration

Response C: Distance is not a vector and it cannot have a negative sign

Response D: When you have a position-time graph, the total distance is the sum of the individual distances. However, when distance does not change but time does, it means the car has stopped. When he distance starts to decrease, it means it is moving in the opposite direction. This distance is still added as distance moved. From the graph at 7 seconds, the car has reached its initial starting position and is still moving in the opposite direction, so add the distance as well not including the sign

Response E: None of the above

Choose your response, and expand on the reason for your selection in the space provided

My choice is _____2 marks

My reason is …….

8 marks

A2. How would you respond to a student who answers B to the following question?
Determine the speed of the car at t = 1 second from the same graph of position-time.

A. $speed = average\ velocity = \frac{distance}{time} = \frac{\frac{1}{2}(2)(3)}{2} = 1.5$m/s. In this case average speed is equal to instantaneous speed, so speed = 1.5 m/s
B. At t = 1 sec, x = 1 m $\Rightarrow speed = instantaneous\ speed = \frac{1m}{1s} = 1$ m/s
C. Using concept of gradient: $speed = average\ speed = \frac{distance}{time} = \frac{\Delta x}{\Delta t} = \frac{3-0}{2-0} = 1.5$ m/s

Response A: Speed is determined as the slope of the graph but you calculate the slope using the lowest and the highest points

Response B: Instantaneous speed and average speed are the same if the gradient of a position-

time graph is constant, so calculate the average speed of the line segment and it will be equal to the instantaneous speed

Response C: You use the same concept as when determining the slope of a straight line graph so gradient is $\Delta y/\Delta x = (x_f - x_i)/(t_f - t_i)$. This gives you the average speed that is equal to the instantaneous speed

Response D: None of the above

Choose your response, and expand on the reason for your selection in the space provided

My choice is _____2 marks
My reason is _____
8 marks

Category B – Planning and Sequencing

A selection of content and concepts relating to kinematics is provided. The question below refers to how knowledge and concepts are ranked and how a teacher makes connections between content and concepts.

B1. Review the list of concepts relating to kinematics below.

Select and rank three foundational concepts that you regard, as both basic and central concepts in kinematics. Add you own if you feel your idea is not represented on the list.

1. Any object that is increasing in speed has acceleration
2. Distance is a scalar quantity while displacement is a vector quantity, speed is a scalar quantity while velocity is a vector quantity
3. $velocity = \frac{displacement}{time}$ and $acceleration = \frac{velocity}{time}$
4. Average quantity (speed, acceleration) is equal to final minus initial divided by change in time while instantaneous quantity (speed, acceleration) is rate of change at a particular point in time
5. In kinematics, a negative sign means something is slowing down for acceleration and

changing direction for velocity

6. Acceleration due to gravity does not change in vertical motion when an object is travelling up or down
7. Instantaneous quantity – at a particular instant in time; Average quantity – over an interval of time
8. Any object that has constant acceleration is not increasing in speed
9. Objects undergoing vertical and horizontal motion
10. Relationship between motion graphs for position, velocity and acceleration
11. Area under an acceleration-time graph gives speed/velocity. Area under a velocity-time graph gives distance/displacement
12. When an object is released from a certain distance from the ground, its speed keeps increasing
13. Equations of motion in one direction
14. The magnitude of velocity is speed

Write the number of the concepts you have selected, in order of importance.

Concepts

Concept 1.

1 mark

Concept 2.

B2. **Using the three selected concepts from B1, give the sequence you would teach them in a**

1 mark

Concept 3.

1 mark

B3. Using the above three concepts as your main ideas, **draw a concept map** of how they inter-relate. In your concept map include other subordinate ideas, from the concepts provided in B1 and from your own practice that you would bring into your teaching of kinematics.

Draw your concept map here

Concept	Reason for sequence
1 mark	1 mark
1 mark	1 mark
1 mark	1 mark

8 marks

B4: Why do you think it is important for students to learn about kinematics?

Write your response here:

Category C - What is difficult to teach?

C1. What **five** kinematics concepts, in your experience, are the most difficult to present effectively to students and what do you think the reason for this is? Some **examples** are provided, which you may use as a basis for your response if you rephrase them but rather **give your own ideas**. (**Only give reasons for 5 concepts)**

Fill in your response in the table below (1 mark for each concept and 1 mark for each reason)

Concept 1 – Instantaneous and average quantities **Reason…….**

Concept 2–Scalar and vector quantities **Reason…….**

Concept 3 – What is meant by deceleration? **Reason…….**

Concept 4 – **Reason…….**

Concept 5 – **Reason…….**

Concept 6 – **Reason…….**

Concept 7 – **Reason…….**

Concept 8 – **Reason…….**

C2. Physics terminology is quite precise and presents difficulties for students. Which five terms in kinematics pose the most difficulty for students and please give a reason for your selection

(1 mark for the term and 1 mark for the reason)

Term 1 Reason:

Term 2 Reason:

Term 3 Reason:

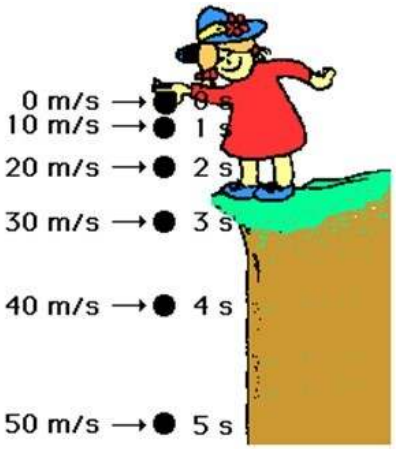
Term 4 Reason:

Term 5 Reason:

Category D – Representations

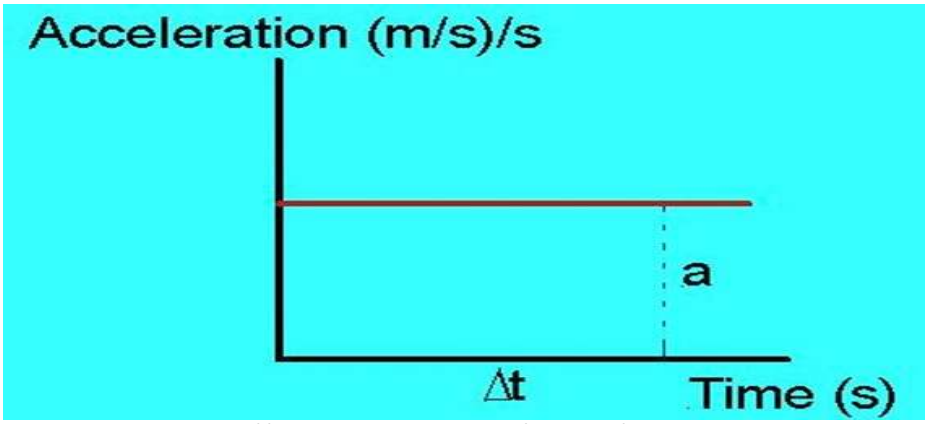
D1. Below are four possible representations for teaching the concept of constant acceleration. Complete the table below by describing what you like and dislike about each representation and why one representation is better than another.

Representation 1



Adapted from: http://www.mwit.ac.th/~physicslab/applet_04/physics_classroom/Class/1DKin/U1L5b.html

Representation 2



Adapted from: http://www.tutorvista.com/physics/acceleration-time-graph

Representation 3



Representation 4

Accelerating Objects are Changing Their Velocity ...

... by a constant amount each second ...

Time (s)	Velocity (m/s)
0	0
1	4
2	8
3	12
4	16

...in which case, it is referred to as a constant acceleration.

... or by a changing amount each second ...

Time (s)	Velocity (m/s)
0	0
1	1
2	4
3	5
4	7

...in which case, it is referred to as a non-constant acceleration.

Adapted from: http://www.physicsclassroom.com/class/1DKin/Lesson-1/Acceleration

What I like and why **What I dislike and why**

Representation 1

2marks

Representation 2

2 marks 2

Representation 3

2 marks 2

Representation 4

2 marks 2

D2. Which one of above three representations did you like the most and how would you use it in a lesson

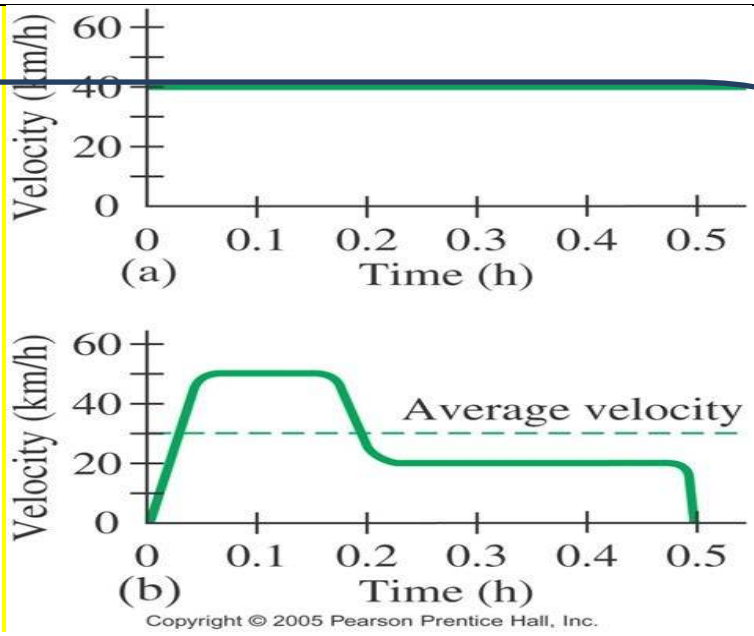
Category E - Conceptual Teaching strategies

E1. **Study the student's answers to a classroom activity below. Read through her answers and describe what strategies you would employ to assist the student. The student has given a mix of correct and incorrect responses.**

The student responses are given in *bold italic*

Activity

The following diagram represents change in velocity with time for Witsie's car, a fourth year student, on two different days {day 1 is represented by (a) and day 2 is represented by (b)} as she goes to her school for TE to teach her major (Physical science).Witsie is excited as she will teach kinematics to grade 11 learners. Answer the following questions with reference to the diagram.



Copyright © 2005 Pearson Prentice Hall, Inc.

(a) What is happening to the velocity of Witsie's car on the two days?

On day 1 (a), Witsie was moving at constant velocity of 40 km/hr

On day2 (b), Witsie was changing her velocity as follows:

0 – 0.1 hr –Witsie had higher acceleration

0.1 – 0.2 hr – Witsie moved at constant acceleration

0.2 – 0.2 hr – Witsie had a lower acceleration

0.2 – 0.5 hr – Witsie moved at constant acceleration

0.5 hr – Witsie decelerated until her car stopped

(b) What is happening to the acceleration of Witsie's car?

On day 1 (a), Witsie is moving at constant acceleration as velocity is constant

On day 2 (b), Witsie was changing her acceleration as follows:

0 – 0.1 hr – her car ha a higher acceleration

0.1 – 0.2 hr – Witsie moved with constant speed of 50 km/hr

0.2 – 0.2 hr – Witsie reduced her speed to 20 km/hr

0.2 – 0.5 hr – Witsie moved at constant velocity of 20 km/hr

0.5 hr – Witsie braked her car and stopped

(c) What does negative acceleration mean and where did it occur on the two days?

Negative acceleration means that the car has changed its direction and is moving in the opposite direction. It did not happen in this case as there was no negative velocity

(d) How else would you represent the concept of constant and changing velocity to learners?

I would use two different formats:

(i) I would use a table format side by side as shown below:

An object moving with a constant speed of 6 m/s

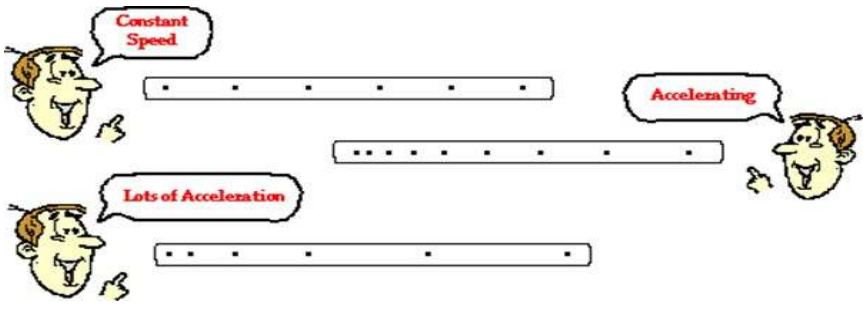
Time (s)	Position (m)
0	0
1	6
2	12
3	18
4	24

An object moving with a changing speed

Time (s)	Position (m)
0	0
1	1
2	4
3	9
4	16

The table makes it easier to compare the velocities for the learners and more so they are used to tables as they have been exposed to them since early grades.

(ii) I would use a ticker tape as they also have an idea from grade 10:



The ticker tape shows leaners when there is acceleration and when there is negative acceleration. This helps them learn the two concepts at the same time.

a. What conceptual ideas does this student have in place?

Write your response here

b. What are the key conceptual gaps, in your opinion, that this student demonstrates?

Write your response here

5 marks

c. What specific strategies would you employ to bridge these gaps?

Write your response here

THANK YOU

APPENDIX V – CLASS TASK DURING INTERVENTION

Class Task 1

A student gave this statement: "If I were driving a car in a circle at a constant speed of 40m/s, then the speed is neither decreasing nor increasing, therefore there must not be an acceleration". Discuss this statement in your individual groups and then provide answers to the questions below.

Group_____

Curricular saliency

What do you consider a big idea for the student to learn?
What do you intend the student to learn about this big idea?
Why do you consider the idea important for the student to know
What concepts need to be taught before teaching this idea?
What else do you know about this idea (that you do not intend the student to know yet)?

What is difficult to teach

What do you consider difficult in teaching this idea? Give reasons

Learner Prior Knowledge

What knowledge about student thinking influences your teaching of this idea? Indicate the student's typical misconception(s) on this idea.

Representations

What representations or analogies 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 VI – TSPCK TOOL IN ELECTRIC CIRCUITS







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Electric circuits TSPCK Tool

The purpose of this research is to find the difficulties pre-service teachers experience and the strategies they use when teaching Electric circuits at schools. The assessment instrument consists of two parts; (i) electric circuits content tool and (ii) Electric circuits Topic Specific Pedagogical Content Knowledge tool
The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

NAME:					
GENDER	Male		Female		
SUBJECTS YOU HAVE TAUGHT BEFORE DURING TE					
Have you taught Electric circuits during TE?	**YES**		**NO**		

There are 5 categories of questions in this tool

6. **CATEGORY A – it contains typical student responses. Please indicate how you would respond to learners in each case i.e. what feedback you would give learners. Provide as much detail as possible.**
7. **CATEGORY B – it relates to planning and sequencing of topics. Your responses will assist in developing a consensus on the main ideas. Main ideas are statements describing key understanding that must be learnt in a topic.**
8. **CATEGORY C – it asks you to reflect on which ideas about kinematics are difficult to teach and get across to learners. This will help in generating a list of difficult ideas that can be used for future research.**
9. **CATEGORY D – it provides different types of representations and analogies. Think about which ones you find more useful and then fill in the table relating to the effectiveness of these analogies in the classroom setting**

10. CATEGORY E –it gives you a student's exercise and asks you to think about how you would assist this learner develop her/his conceptual understanding of kinematics

Instructions

- Please write responses directly into the response boxes.
- Please be as detailed as possible as to how you respond in your teaching setting

Thank you for your valued input and assistance

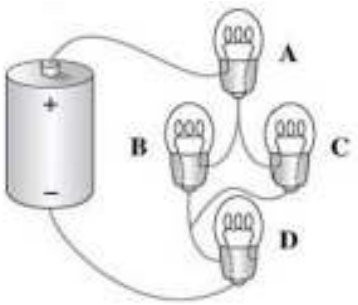
Electric circuits TSPCK Instrument

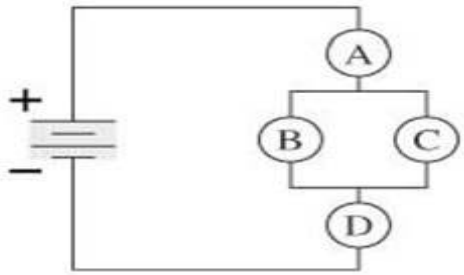
Category A – Typical Student Responses

The two questions below are typical multiple choice items that students have answered incorrectly. A selection of possible teacher responses are provided, none of which are incorrect. Select the response you would most likely use in your practice and explain the reason for your response

A1. How would you respond to a student who **selects A** as the answer to the question below?

Rank the bulbs in the following circuit according to their brightness, from brightest to dimmest. Assume that the bulbs are all identical.





G. A > B = C > D

H. A = B = C = D

I. A = D > B = C

J. B = C > A > D

Response A: Bulbs in series will always be brighter than those in parallel, so your answer is wrong.

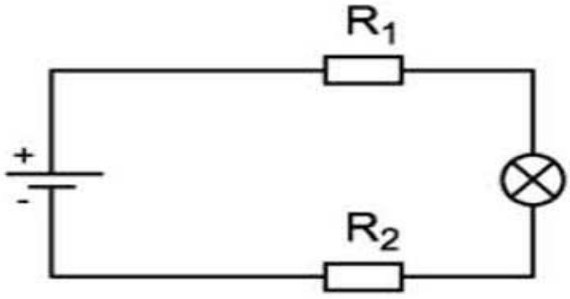
Response B: Current in a series circuit is the same and it divides in a parallel circuit, so A and D will be brighter than B and C.

Response C: Current does not change with position from the battery source but only with the arrangement in a circuit, so A and D should be brighter than B and C as they receive twice the current as in B and C.

Response D: None of the above
Choose your response, and expand on the reason for your selection in the space provided

My choice is _____
My reason is …….

A2. How would you respond to a student who **selects B** as the answer to the question below?
What will happen to the brightness of the bulb if R_1 is increased and R_2 remains constant?



D. The brightness of the bulb decreases.
E. The brightness of the bulb remains constant.
F. The brightness of the bulb increases.
G. None of the above

Response A: Even though it is the same battery, the current delivered is not the same since the resistance has changed from Ohms' Law. Therefore the brightness of the bulb should decrease.

Response B: Increasing R_1 results in a decrease in I_1 and therefore a decrease in the brightness of the bulb as the same current I_1 passes through the resistors R_1 and R_2 and the bulb.

Response C: Any change of the resistance influences the brightness of the bulb independently of itsposition in the circuit. Therefore, an increase in R_1 results in an increase in total resistance since $R_{total} = R_1 + R_2$ which results in a decrease in current flowing through and therefore a decrease in the brightness of the bulb.

Response D: None of the above

Choose your response, and expand on the reason for your selection in the space provided

My choice is _____
My reason is _____ 5 marks

Category B – Planning and Sequencing

A selection of content and concepts relating to electrical circuits is provided. The question below refers to how knowledge and concepts are ranked and how a teacher makes connections between content and concepts.

B1. Review the list of concepts relating to electrical circuits below.
Select three foundational statements that you regard, as Big Ideas to the topic of electrical circuits. Add your own if you feel your idea is not represented on the list.

15. Electric current flow from the positive terminal to the negative terminal as opposed to electrons which flow from the negative terminal to the positive terminal
16. A battery is the source of the electromotive force that makes the charges to flow in a circuit
17. Voltage in a series circuit is divided whilst in a parallel circuit it is constant
18. Ohms' law is written as: $R = \frac{V}{I}$
19. Resistance opposes the flow of current in a circuit
20. Resistance in a parallel circuit is calculated as $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ … while resistance in a series circuit is calculated as $R_s = R_1 + R_2 + R_3$ …
21. Current is the rate of flow of charges in a circuit
22. Power is the rate of energy dissipation by a circuit component.
23. Current is measured with an ammeter while voltage is measured by a voltmeter
24. Current is measured in series while voltage is measured in parallel
25. Current is measured in Amps while voltage is measured in volts
26. Current is the same in a series circuit and it divides itself in a parallel circuit
27. Power is calculated as the product of voltage and current

28. An electric circuit is a system in which changes in one part can affect other parts
29. Kirchhoff's laws can be used on basic and complex circuits to calculate current, voltage or resistance

B2.Write the number of the concepts you have selected, in order of sequence of teaching them

Concepts
Concept1.
Concept2.
Concept3.

B3. Using the three selected concepts from B1, give the sequence you would teach them and your reasons for doing so

Concept	Reason for sequence
	3 marks
	3 marks
	3 marks

3. Using the above three concepts as your Big Ideas, **draw a concept map** of how they inter-relate. In your concept map include subordinate concepts showing links and explanations of links with text next to the link demonstrated.

Draw your concept map here

8 marks

B4: Why do you think it is important for students to learn about electric circuits?

Write your response here:

3 marks

Category C - What is difficult to teach?

C1. What **five** electric circuits concepts, in your experience, are the most difficult to present effectively to students and what do you think the reason for this is? Some **examples** are provided, which you may use, or choose not to use, as a basis for your response if you rephrase them but rather **give your own ideas**. (**Only give reasons for five concepts).**

Fill in your response in the table below (1 mark for each concept and 2 mark for each reason)

Concept 1 – Ohms' law, the relationship between current and voltage	**Reason…….**
Concept 2 – What is meant by voltage or potential difference	**Reason…….**
Concept 3 – total resistance in a parallel circuit is less than the individual resistances	**Reason…….**
Concept 4 –	**Reason…….**

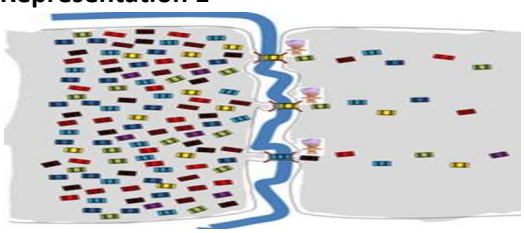
Concept 5 –	**Reason…….**	
Concept 6 –	**Reason…….**	
Concept 7 –	**Reason…….**	
Concept 8 –	**Reason…….**	

15 marks

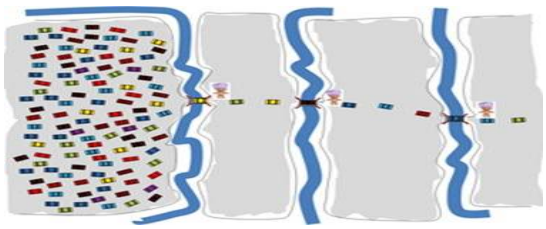
Category D – Representations

D1. Below are three possible representations for teaching the concept of series and parallel connections in a circuit. Complete the table below by describing what you like and dislike about each representation and why one representation is better than another.

Representation 1



Parallel connection

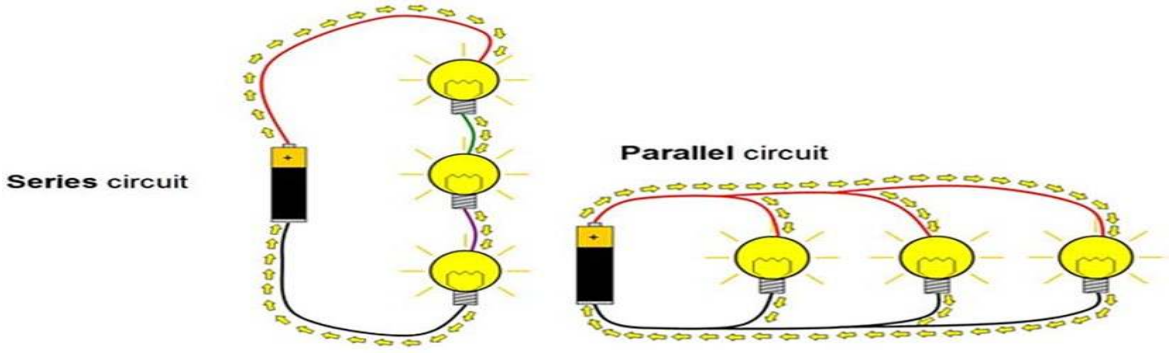


Series connection

Adapted from: https://learnelectricity.ausgrid.com.au/Common/For-Students-in-Years-9-and-

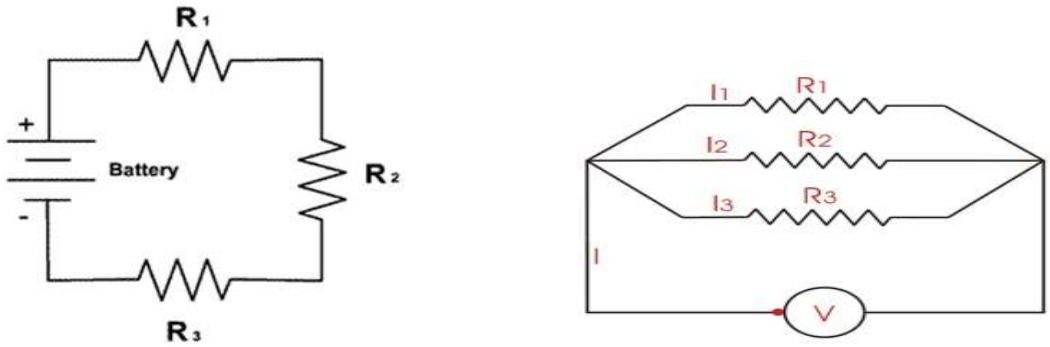
10/Series-and-parallel-circuits.aspx

Representation 2



Adapted from: http://www.cdn.sciencebuddies.org/Files/4803/6/fig2_parallel-series-circuit-battery-light-bulbs.jpg

Representation 3



Adapted from: http://www.electrical4u.com/images01/parallel-circuit.gif and http://www.school-for-champions.com/science/images/dc_circuits-series.gif

	What I like and why	What I dislike and why
Representation 1	2 marks	
Representation 2	2 marks	
Representation 3	2 marks	Total of 12 marks

D2. Which one of above three representations did you like the most and how would you use it in a lesson

Write your response here

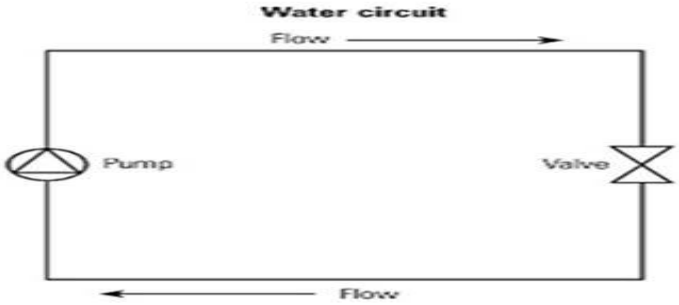
Category E - Conceptual Teaching strategies

E1. Study the student's answers to a classroom activity below. Read through his answers and describe what strategies you would employ to assist the student. The student has given a mix of correct and incorrect responses.

The student responses are given in *bold italic*

Activity

The following diagram shows a water circuit that is used to represent the flow of current in a series circuit. Answer the following questions with reference to the diagram.



Adapted from: http://www.spiraxsarco.com/Resources/Pages/Steam-Engineering-Tutorials/Images//3/16/Fig_3_16_2.gif

(e) What is represented by the pump?
Potential difference

(f) What is represented by the arrows?
They represent flow of electricity

(g) Where does the energy for the flow come from?
From the battery

(h) What is represented by the valve?
The valve represents a resistor

(i) Which one is the positive terminal and how do you know it is the positive terminal?
The positive terminal is the side where the electrons come out (tip of the triangle). I know this because they move from the positive terminal to the negative terminal

(j) What happens to the charges when they enter the battery after going around the circuit?

The charges will have been used up and more charges are produced by the battery which then go around the circuit

d. What conceptual ideas does this student have in place?

Write your response here 5 marks

e. What are the key conceptual gaps, in your opinion, that this student demonstrates?

Write your response here 5 marks

f. What specific strategies would you employ to bridge these gaps?

Write your response here 10 marks

APPENDIX VII – INTERVIEW SCHEDULE

Questions

1 (a) Considering you responses to the questions in category B (Planning and sequencing), what challenges did you experience:

(i) in selecting and ranking three fundamental concepts in the topic of kinmeatics?

(ii) while sequencing the concepts and giving reasons for how you would teach them?

(iii) in drawing a concept map of how the concepts inter-relate as you did?

1 (b) Is there anything you would do differently or in a better way when responding to such questions some other time?

(c) Would you find engaging 'planning and sequencing of big ideas' interesting in your planning and actual teaching some other time? Why?

2 (a) Looking at category E, what difficulties did you encounter in:

(i) describing strategies that you would employ to assist the student?

(ii) explaining how to represent the concept of constant and changing velocity to learners?

(iii) identifying conceptual ideas that the student have in place?

(b) Is there anything you would do differently or in a better way when responding to such questions some other time?

3. What assisted you in identifying and addressing student's misconceptions in category A?

4. What assisted you in identifying the most difficult concepts as you responded in category C?

5. What assisted in identifying appropriate representations as you responded in category D?

6. What aspects of the TSPCK model (components) did you find most helpful in teaching physics topics? Why?

7. Would you like engaging TSPCK components (model) in subsequent planning and teaching of physics topics? Why?

8. Have you ever taught kinematics before?

APPENDIX VIII – TSPCK RUBRIC

omponents		Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
y A Prior dge including eptions		**A1**: No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions No explanation of concepts	Teacher only acknowledges misconception/prior knowledge. Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Teacher acknowledges misconception and provides explanation to confront misconception that has logic Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Teacher acknowledges misconcepti provides a correct explanation to misconception Provide standardized knowledge as d and/or Expands and re-phrases explanation
		A2: No explanation of concepts	Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Provide standardized knowledge as d and/or Expands and re-phrases explanation
		B1: Only subordinate ideas identified Sequencing no value due to mixed concepts or no sequence provided at all	Identifies at least 1 Big Ideas Sequencing can be followed but has at least one illogical placing of key concepts (Big Ideas). Reasons given for sequence unclear or lacks logic	Identifies at least 2 Big Ideas Provides logical sequence of concepts of at least two Big Ideas, Reasons given are either clear or logical	Identifies at least 3 Big Ideas Provides logical sequence of all th Ideas with sound reasons
		B2: Identified subordinate ideas mixed with those Big Ideas of other topics Map lacks logic	Uses at least 1 Big Idea. Some subordinate ideas relate to big ideas, but not all.	Uses at least 2 Big Ideas. Identifies subordinate ideas and shows links to Big ideas Subordinate ideas relate to Big ideas on map	Uses all 3 Big ideas. Identifies subordinate ideas explains/shows links Subordinate ideas relate to Big id map Cross links shown where applicable
tegory B ılar Saliency		**B3**: Identified pre concepts lack coherence with current topics, do not relate to concept map	Identified pre concepts do not relate to concepts to be taught in map Not all Identified pre-concepts refer to concepts generally regarded as basic for the subject/ discipline	Most Identified pre concepts relate to concepts to be taught in map Most Identified pre-concepts refer to concepts generally regarded as basic for the subject/ discipline	All Identified pre-concepts refer to c generally regarded as basic for the discipline Identified pre concepts relate to con be taught in map
		B4: Reasons given for importance of topic limited to general benefit of education One reasons given or gives a general statement such as " has important applications)	Reasons given for importance of topic exclude conceptual considerations such as scaffolding/sequential development of understanding for other topics in the subject. But may include application to everyday life	Reasons given for importance of topic include reference to conceptual considerations such as scaffolding/sequential development of understanding of other topics in the subject (however topics not specified) and application to everyday life	Reasons given for importance o include conceptual considerations scaffolding/sequential developme understanding for specified subsequent topics in the subje application to everyday life and/or interest
tegory C standing of makes topic r difficult to derstand		Identifies broad topics without specifying the actual sub-concepts that are problematic Reasons not given to identified concepts	Identifies specific concepts but provides broad /generic reasons such as 'abstract'	Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions	Identifies specific concepts with related to prior knowledge of stud common misconceptions Provides reasons linking to specif keeping concepts that when n understood adds to the difficulty of a regarded as difficult
y D ntations/ s		No discussion on how the representation is going to be used or suggested use in appropriate, unworkable or	Discussion lacks logic or clarity List of concepts given with no explanation on how representation is going to be	Discussion on how the model shows logic and part of explanation shows conceptual orientation Gives clear or satisfactory	Explanation clear, logical and conceptual orientation Clearly, explained the procedure h chosen representation can be used

	unsafe	used Suggested procedure impractical	explanation on how the chosen representation is going to be used Suggested procedure is workable	Suggested procedure is workable an into consideration learners' context	
y E g Strategies	No evidence of acknowledgement of student prior knowledge and misconceptions Lacks aspects of curriculum saliency Use of representations limited to macroscopic or symbolic scientific symbolic representation Lack conceptual orientation	Acknowledges student misconceptions with no viable corresponding confrontation strategy Lacks aspects of curriculum saliency Use of macroscopic and symbolic and microscopic representations for different aspects of a concept not enforcing a singular aspect of the concept. Parts of the explanation show conceptual orientation	Considers confirmation/confrontation of student prior knowledge and/or common misconceptions Considers at least one aspect related to curriculum saliency: sequencing or emphasis of important conceptual aspects Uses at least two different levels of representations to enforce an aspect of a concept Conceptual orientation to approach	Considers app confirmation/confrontation of stude knowledge and/or common misconcep Considers at least two aspects rel curriculum saliency: sequencing, wha discuss yet, emphasis of important con aspects, etc. Uses either the macroscopic or s representation with sub-micr representation to enforce a singular a a concept. Conceptual approach to topic clear	

APPENDIX IX – PERSON MEASURES (PRE-TEST KINEMATICS)

pre-person

TABLE 17.1 Pre-test ZOU589WS.TXT Dec 9 2015 6:30
INPUT: 19 Person 5 Item REPORTED: 19 Person 5 Item 4 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.55 REL.: .71 ... Item: REAL SEP.: 1.47 REL.: .68

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
8	13	5	.46	.73	.86	.0	.81	-.1	.80	.47	60.0	56.5	TMAM
13	13	5	.46	.73	1.00	.2	1.05	.3	-.12	.47	20.0	56.5	TANA
6	12	5	-.09	.75	.90	.1	.78	-.1	.82	.46	80.0	61.5	TEMA
14	12	5	-.09	.75	.57	-.6	.59	-.5	.43	.46	80.0	61.5	TISI
15	12	5	-.09	.75	.24	-1.5	.24	-1.5	.82	.46	80.0	61.5	TOSM
2	10	5	-1.31	.81	1.83	1.2	1.89	1.3	-.30	.42	60.0	65.3	TNAH
3	10	5	-1.31	.81	1.07	.3	1.07	.3	.39	.42	60.0	65.3	TAKA
5	10	5	-1.31	.81	1.22	.5	1.25	.6	.30	.42	60.0	65.3	TCMM
12	10	5	-1.31	.81	.96	.2	.98	.2	.55	.42	60.0	65.3	TUMA
16	10	5	-1.31	.81	1.22	.5	1.25	.6	.30	.42	60.0	65.3	TMAT
18	10	5	-1.31	.81	.96	.2	.98	.2	.55	.42	60.0	65.3	TSZO
19	10	5	-1.31	.81	.51	-.7	.49	-.7	.95	.42	60.0	65.3	TAZU
11	9	5	-1.98	.83	1.35	.7	1.33	.7	.61	.41	20.0	63.6	TUMO
17	8	5	-2.68	.86	1.21	.5	1.17	.5	-.11	.41	60.0	62.6	TIFA
1	7	5	-3.47	.93	.67	-.5	.63	-.5	.63	.40	80.0	68.7	TIGO
7	6	5	-4.53	1.16	1.33	.6	1.29	.6	-.04	.33	80.0	80.1	TLMO
10	6	5	-4.53	1.16	1.16	.5	.92	.3	.19	.33	80.0	80.1	TLEM
4	5	5	-5.98	1.91	MINIMUM MEASURE				.00	.00	100.0	100.0	TSIU
9	5	5	-5.98	1.91	MINIMUM MEASURE				.00	.00	100.0	100.0	TSMO

pre-person

MEAN	9.4	5.0	-1.98	.95	1.00	.1	.98	.1			62.4	65.3	
P.SD	2.5	.0	1.97	.35	.36	.6	.37	.6			18.0	6.2	

APPENDIX X – PERSON MEASURES (POST-TEST KINEMATICS)

po-person

TABLE 17.1 Post-test scores ZOU530WS.TXT Dec 9 2015 6:35
INPUT: 19 Person 5 Item REPORTED: 19 Person 5 Item 4 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.23 REL.: .60 ... Item: REAL SEP.: 3.84 REL.: .94

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
11	19	5	6.67	1.49	.19	-.8	.11	-.6	.80	.60	100.0	89.3	TUMO
5	18	5	5.02	1.11	1.46	.8	1.22	.6	.80	.64	80.0	77.6	TCMM
8	18	5	5.02	1.11	1.14	.4	1.04	.5	.55	.64	80.0	77.6	TMAM
6	17	5	3.96	.98	.57	-.9	.48	-.4	.72	.67	80.0	68.2	TEMA
12	17	5	3.96	.98	.57	-.9	.48	-.4	.72	.67	80.0	68.2	TUMA
14	17	5	3.96	.98	.57	-.9	.48	-.4	.72	.67	80.0	68.2	TISI
2	15	5	2.05	.99	.13	-1.7	.13	-1.6	.98	.74	100.0	77.1	TNAH
9	15	5	2.05	.99	.13	-1.7	.13	-1.6	.98	.74	100.0	77.1	TSMO
13	15	5	2.05	.99	.13	-1.7	.13	-1.6	.98	.74	100.0	77.1	TANA
17	15	5	2.05	.99	1.22	.5	1.11	.4	.00	.74	60.0	77.1	TIFA
18	15	5	2.05	.99	.13	-1.7	.13	-1.6	.98	.74	100.0	77.1	TSZO
3	14	5	1.11	.94	.34	-1.1	.30	-1.1	.80	.73	80.0	71.1	TAKA
10	14	5	1.11	.94	.34	-1.1	.30	-1.1	.80	.73	80.0	71.1	TLEM
15	14	5	1.11	.94	2.51	1.8	2.83	2.0	.67	.73	40.0	71.1	TOSM
16	14	5	1.11	.94	2.49	1.8	2.42	1.7	.31	.73	40.0	71.1	TMAT
19	14	5	1.11	.94	1.73	1.1	1.85	1.2	.55	.73	40.0	71.1	TAZU
1	13	5	.28	.89	1.06	.3	1.07	.3	.81	.71	60.0	65.4	TIGO
4	13	5	.28	.89	.83	-.1	.79	-.2	.80	.71	60.0	65.4	TSIU
7	13	5	.28	.89	2.22	1.9	2.65	1.7	.73	.71	60.0	65.4	TLMO

po-person

MEAN	15.3	5.0	2.38	1.00	.93	-.2	.90	-.1			74.7	73.0	
P.SD	1.8	.0	1.80	.13	.79	1.2	.82	1.2			20.4	5.9	

APPENDIX XI – SUMMARY STATISTICS (PRE-TEST KINEMATICS)

pre-test sum

TABLE 3.1 Pre-test ZOU975WS.TXT Jan 17 2016 14:14
INPUT: 19 Person 5 Item REPORTED: 19 Person 5 Item 4 CATS MINISTEP 3.90.2

SUMMARY OF 17 MEASURED (NON-EXTREME) Person

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	9.9	5.0	-1.51	.84	1.00	.1	.98	.1
P.SD	2.1	.0	1.49	.13	.36	.6	.37	.6
S.SD	2.2	.0	1.54	.13	.37	.7	.39	.7
MAX.	13.0	5.0	.46	1.16	1.83	1.2	1.89	1.3
MIN.	6.0	5.0	-4.53	.73	.24	-1.5	.24	-1.5
REAL RMSE	.92	TRUE SD	1.18	SEPARATION	1.28	Person RELIABILITY		.62
MODEL RMSE	.85	TRUE SD	1.22	SEPARATION	1.44	Person RELIABILITY		.67
S.E. OF Person MEAN = .37								

MINIMUM EXTREME SCORE: 2 Person 10.5%

SUMMARY OF 19 MEASURED (EXTREME AND NON-EXTREME) Person

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	9.4	5.0	-1.98	.95				
P.SD	2.5	.0	1.97	.35				
S.SD	2.6	.0	2.02	.36				
MAX.	13.0	5.0	.46	1.91				
MIN.	5.0	5.0	-5.98	.73				
REAL RMSE	1.06	TRUE SD	1.65	SEPARATION	1.55	Person RELIABILITY		.71
MODEL RMSE	1.02	TRUE SD	1.68	SEPARATION	1.66	Person RELIABILITY		.73
S.E. OF Person MEAN = .46								

Person RAW SCORE-TO-MEASURE CORRELATION = .99
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .73 SEM = 1.30

SUMMARY OF 5 MEASURED (NON-EXTREME) Item

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	35.6	19.0	.00	.45	.97	-.1	.98	.0
P.SD	4.4	.0	.85	.03	.37	1.0	.38	.9
S.SD	4.9	.0	.94	.03	.41	1.1	.42	1.0
MAX.	43.0	19.0	1.15	.48	1.61	1.6	1.68	1.7
MIN.	30.0	19.0	-1.38	.41	.57	-1.3	.59	-.9
REAL RMSE	.48	TRUE SD	.70	SEPARATION	1.47	Item RELIABILITY		.68
MODEL RMSE	.45	TRUE SD	.72	SEPARATION	1.60	Item RELIABILITY		.72
S.E. OF Item MEAN = .42								

Page 1

APPENDIX XII – SUMMARY STATISTICS (POST-TEST KINEMATICS)

Post-test TSPCK sum statist

TABLE 3.1 Post-test TSPCK ZOU591WS.TXT Jan 16 2016 21: 6
INPUT: 19 Person 5 Item REPORTED: 19 Person 5 Item 4 CATS MINISTEP 3.90.2

SUMMARY OF 19 MEASURED Person

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	15.3	5.0	2.38	1.00	.93	-.2	.90	-.1
P.SD	1.8	.0	1.80	.13	.79	1.2	.82	1.2
S.SD	1.9	.0	1.85	.13	.81	1.3	.84	1.2
MAX.	19.0	5.0	6.67	1.49	2.51	1.9	2.83	2.0
MIN.	13.0	5.0	.28	.89	.13	-1.7	.11	-1.6

REAL RMSE 1.14 TRUE SD 1.40 SEPARATION 1.23 Person RELIABILITY .60
MODEL RMSE 1.01 TRUE SD 1.49 SEPARATION 1.48 Person RELIABILITY .69
S.E. OF Person MEAN = .42

Person RAW SCORE-TO-MEASURE CORRELATION = 1.00
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .59 SEM = 1.15

SUMMARY OF 5 MEASURED Item

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	58.0	19.0	.00	.51	.98	.0	.90	-.1
P.SD	8.8	.0	2.14	.03	.33	1.0	.28	.8
S.SD	9.8	.0	2.40	.04	.37	1.1	.32	.8
MAX.	70.0	19.0	3.45	.56	1.41	1.3	1.25	.8
MIN.	45.0	19.0	-3.19	.46	.58	-1.3	.62	-1.1

REAL RMSE .54 TRUE SD 2.07 SEPARATION 3.84 Item RELIABILITY .94
MODEL RMSE .51 TRUE SD 2.08 SEPARATION 4.10 Item RELIABILITY .94
S.E. OF Item MEAN = 1.07

Item RAW SCORE-TO-MEASURE CORRELATION = -1.00
Global statistics: please see Table 44.
UMEAN=.0000 USCALE=1.0000

APPENDIX XIII – ANCHORING PRE-TEST KINEMATICS)

pre-test sum

TABLE 3.1 Pre-test ZOU975WS.TXT Jan 17 2016 14:14
INPUT: 19 Person 5 Item REPORTED: 19 Person 5 Item 4 CATS MINISTEP 3.90.2

SUMMARY OF 17 MEASURED (NON-EXTREME) Person

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	9.9	5.0	-1.51	.84	1.00	.1	.98	.1
P.SD	2.1	.0	1.49	.13	.36	.6	.37	.6
S.SD	2.2	.0	1.54	.13	.37	.7	.39	.7
MAX.	13.0	5.0	.46	1.16	1.83	1.2	1.89	1.3
MIN.	6.0	5.0	-4.53	.73	.24	-1.5	.24	-1.5

REAL RMSE .92 TRUE SD 1.18 SEPARATION 1.28 Person RELIABILITY .62
MODEL RMSE .85 TRUE SD 1.22 SEPARATION 1.44 Person RELIABILITY .67
S.E. OF Person MEAN = .37

MINIMUM EXTREME SCORE: 2 Person 10.5%

SUMMARY OF 19 MEASURED (EXTREME AND NON-EXTREME) Person

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	9.4	5.0	-1.98	.95				
P.SD	2.5	.0	1.97	.35				
S.SD	2.6	.0	2.02	.36				
MAX.	13.0	5.0	.46	1.91				
MIN.	5.0	5.0	-5.98	.73				

REAL RMSE 1.06 TRUE SD 1.65 SEPARATION 1.55 Person RELIABILITY .71
MODEL RMSE 1.02 TRUE SD 1.68 SEPARATION 1.66 Person RELIABILITY .73
S.E. OF Person MEAN = .46

Person RAW SCORE-TO-MEASURE CORRELATION = .99
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .73 SEM = 1.30

SUMMARY OF 5 MEASURED (NON-EXTREME) Item

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	35.6	19.0	.00	.45	.97	-.1	.98	.0
P.SD	4.4	.0	.85	.03	.37	1.0	.38	.9
S.SD	4.9	.0	.94	.03	.41	1.1	.42	1.0
MAX.	43.0	19.0	1.15	.46	1.61	1.6	1.60	1.7
MIN.	30.0	19.0	-1.38	.41	.57	-1.3	.59	-.9

REAL RMSE .48 TRUE SD .70 SEPARATION 1.47 Item RELIABILITY .68
MODEL RMSE .45 TRUE SD .72 SEPARATION 1.60 Item RELIABILITY .72
S.E. OF Item MEAN = .42

Page 1

APPENDIX XIV – ANCHORED POST-TEST KINEMATICS

Person Stat - Anchored

TABLE 17.1 Post-test scores ZOU390WS.TXT Sep 19 2015 7:26
INPUT: 19 Person 5 Item REPORTED: 19 Person 5 Item 4 CATS MINISTEP 3.90.2

Person: REAL SEP.: .49 REL.: .19 ... Item: REAL SEP.: 1.30 REL.: .63

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
11	19	5	4.11	1.13	1.32	.6	1.60	.8	-.19	.28	80.0	80.3	TUMO
5	18	5	3.11	.90	3.15	2.6	3.29	2.3	-.19	.37	40.0	65.3	TCMM
8	18	5	3.11	.90	.82	-.1	.82	.0	.40	.37	60.0	65.3	TMAM
6	17	5	2.38	.82	1.51	.9	1.64	1.1	-.59	.41	20.0	62.0	TEMA
12	17	5	2.38	.82	1.51	.9	1.64	1.1	-.59	.41	20.0	62.0	TUMA
14	17	5	2.38	.82	1.51	.9	1.64	1.1	-.59	.41	20.0	62.0	TISI
2	15	5	1.17	.74	1.51	.9	1.56	1.0	-.15	.45	60.0	58.7	TNAH
9	15	5	1.17	.74	1.51	.9	1.56	1.0	-.15	.45	60.0	58.7	TSMO
13	15	5	1.17	.74	1.51	.9	1.56	1.0	-.15	.45	60.0	58.7	TANA
17	15	5	1.17	.74	.25	-1.5	.26	-1.5	.00	.45	100.0	58.7	TIFA
18	15	5	1.17	.74	1.51	.9	1.56	1.0	-.15	.45	60.0	58.7	TSZO
3	14	5	.64	.72	.82	-.1	.83	-.1	-.19	.46	60.0	58.1	TAKA
10	14	5	.64	.72	.82	-.1	.83	-.1	-.19	.46	60.0	58.1	TLEM
15	14	5	.64	.72	1.72	1.2	1.78	1.2	.63	.46	20.0	58.1	TOSM
16	14	5	.64	.72	2.55	2.0	2.64	2.1	-.69	.46	20.0	58.1	TMAT
19	14	5	.64	.72	1.16	.5	1.19	.5	.40	.46	20.0	58.1	TAZU
1	13	5	.14	.70	2.34	1.8	2.41	1.9	-.38	.47	20.0	56.2	TIGO
4	13	5	.14	.70	2.14	1.6	2.17	1.6	-.19	.47	40.0	56.2	TSIU
7	13	5	.14	.70	2.62	2.1	2.51	2.0	.13	.47	20.0	56.2	TLMO

Person Stat - Anchored

MEAN	15.3	5.0	1.42	.78	1.59	.9	1.66	.9			44.2	60.5	
P.SD	1.8	.0	1.12	.10	.69	.9	.71	.9			23.9	5.4	

APPENDIX XV – ITEM RANK ORDER (PRE-TEST KINEMATICS)

```
                                        item masure
TABLE 13.1 Pre-test                                ZOU975WS.TXT  Jan 17 2016 14:14
INPUT: 19 Person  5 Item  REPORTED: 19 Person  5 Item  4 CATS    MINISTEP 3.90.2
-------------------------------------------------------------------------------
Person: REAL SEP.: 1.55  REL.: .71 ... Item: REAL SEP.: 1.47  REL.: .68

         Item STATISTICS:  MEASURE ORDER

-------------------------------------------------------------------------------------------------
-------------------------
|ENTRY   TOTAL  TOTAL           MODEL|   INFIT  |  OUTFIT  |PTMEASUR-AL|EXACT MATCH|
                    |
|NUMBER  SCORE  COUNT  MEASURE  S.E. |MNSQ  ZSTD|MNSQ  ZSTD|CORR.  EXP.| OBS%  EXP%| Item
                    |
|------------------------------------+----------+----------+-----------+-----------+-------
------------------------|
|     4     30     19     1.15     .48| .67   -.9| .59   -.9|  .71   .61| 70.6  68.5|
Representations                 |
|     5     33     19      .48     .46|1.05    .3| .99    .1|  .68   .66| 58.8  68.6|
Conceptual Teaching Strategies|
|     3     35     19      .07     .45| .57  -1.3| .72   -.7|  .71   .69| 76.5  66.4| What
is difficult to teach     |
|     2     37     19     -.33     .44|1.61   1.6|1.68   1.7|  .54   .71| 41.2  64.7|
Curricular saliency             |
|     1     43     19    -1.38     .41| .92   -.1| .95   -.1|  .83   .75| 64.7  58.1|
Learner Prior Knowledge         |
|------------------------------------+----------+----------+-----------+-----------+-------
------------------------|
| MEAN    35.6   19.0      .00     .45| .97   -.1| .98    .0|           | 62.4  65.3|
                    |
| P.SD     4.4     .0      .85     .03| .37   1.0| .38    .9|           | 12.1   3.9|
                    |
-------------------------------------------------------------------------------------------------
```

APPENDIX XVI – ITEM RANK ORDER (POST-TEST KINEMATICS)

```
                                        po-item
TABLE 13.1 Post-test scores                      ZOU530WS.TXT  Dec  9 2015  6:35
INPUT: 19 Person  5 Item  REPORTED: 19 Person  5 Item  4 CATS    MINISTEP 3.90.2
-------------------------------------------------------------------------------
Person: REAL SEP.: 1.23  REL.: .60 ... Item: REAL SEP.: 3.84  REL.: .94

         Item STATISTICS:  MEASURE ORDER

-------------------------------------------------------------------------------------
-------------------------
|ENTRY   TOTAL  TOTAL           MODEL|   INFIT  |  OUTFIT  |PTMEASUR-AL|EXACT MATCH|
                       |
|NUMBER  SCORE  COUNT  MEASURE  S.E. |MNSQ  ZSTD|MNSQ  ZSTD|CORR.  EXP.| OBS%  EXP%| Item
                       |
|-----------------------------------+----------+----------+-----------+-----------+-------
-----------------------|
|     2     43     19    3.45     .46| .58  -1.3| .62  -1.1|  .72   .67| 84.2  72.0|
Curricular saliency           |
|     5     56     19     .65     .48|1.41   1.3|1.24    .8|  .66   .63| 73.7  67.8|
Conceptual Teaching Strategies|
|     1     60     19    -.32     .51|1.27    .8|1.25    .7|  .52   .64| 63.2  74.3|
Learner Prior Knowledge       |
|     4     61     19    -.59     .52| .64   -.9| .66   -.7|  .72   .64| 89.5  76.6|
Representations               |
|     3     70     19   -3.19     .56|1.00    .1| .72    .1|  .47   .47| 63.2  74.1| What
is difficult to teach    |
|-----------------------------------+----------+----------+-----------+-----------+-------
-----------------------|
| MEAN    58.0   19.0     .00     .51| .98    .0| .90   -.1|           | 74.7  73.0|
                       |
| P.SD     8.8     .0    2.14     .03| .33   1.0| .28    .8|           | 10.7   3.0|
                       |
-------------------------------------------------------------------------------------
```