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Teaching graphs of motion: translating pedagogical content knowledge into practice

by

Ernest Nkosingiphile Mazibe

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Student: Ernest Nkosingiphile Mazibe Signature: ……………………………

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Supervisor: Mrs. Corene Coetzee Signature: ……………………………..

Co-supervisor: Prof Estelle Gaigher Signature: ……………………………..

31 March 2017

Dedication

I dedicate this piece of work to:

- My father, I may have not known or seen you even in a picture, but wherever you are, I am sure you are proud of what your son has accomplished.

Acknowledgements

First and foremost, Almighty God, it is because of You that this study became a success. I thank You for giving me strength and carrying me through the journey of this research.

I also appreciate the financial support that I received from the University of Pretoria, it is because of the support that this study materialised.

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I would also like to thank all the people who supported me throughout the study; my former colleagues who helped with the editorial, my friends and family members who encouraged me not to give up.

Abstract

This study investigated the comparison between captured and revealed Pedagogical Content Knowledge (PCK) about graphs of motion. The aim of the study was to explore PCK when captured in a written format and discussions (captured PCK) and compare it to the PCK that the same teachers revealed in practice (revealed PCK) when teaching the topic. Four Grade 10 Physical sciences teachers were purposively and conveniently selected as participants of the study. Their PCK was captured through Content Representations (CoRes) and interviews. The revealed PCK on the other hand was gathered through lesson observations. The Topic Specific Pedagogical Content Knowledge (TSPCK) model was used as the framework that guided the analysis of the two manifestations of PCK. The focus was on teachers' competences in the TSPCK components namely; learners' prior knowledge including misconceptions, curricular saliency, what is difficult to teach, representations including analogies, and conceptual teaching strategies.

The results of this study indicated that teachers' competences in the TSPCK components varied. This was evident in both the captured and the revealed PCK. Thus it suggested that a teacher's level of competence in one component is not necessarily an indication of his or her competence in the other components that define PCK, and subsequently in his/her overall captured or revealed PCK. Furthermore, the study suggested that the level of competence in a component in the captured PCK is not necessarily an indication of the level of competence within that component that the teacher would reveal during lesson presentation. The level may be the same, slightly different (higher or lower) or even be drastically different in the lesson than suggested by the captured PCK. A concluding remark was then made that teachers' captured PCK is not necessarily a true reflection of the PCK they reveal during lesson presentation and that different instruments must be used to reflect on and assess teachers' PCK in a topic.

Key words:

Topic Specific Pedagogical Content Knowledge, Content Representations, Graphs of motion, lesson preparation, teaching strategies.

Language editor

Member South African Translators' Institute

28 18th Street

Menlo Park

Pretoria 0081

29 March 2017

Anethadewet0@gmail.com

TO WHOM IT MAY CONCERN

This is to confirm that the dissertation titled *Teaching Graphs of motion: translating Pedagogical Content Knowledge into practice* by *Ernest Nkosingiphile Mazibe,* was proof read and edited by me in respect of language and style.

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List of abbreviations

CAPS	Curriculum and Assessment Policy Statement
CCK	Common Content Knowledge
CK	Content Knowledge
CoRes	Content Representations
DoBE	Department of Basic Education
FET	Further Education and Training
PCK	Pedagogical Content Knowledge
PK	Pedagogical Knowledge
SCK	Specialised Content Knowledge
SMK	Subject Matter Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge

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1. CHAPTER ONE: INTRODUCTION AND STUDY BACKGROUND

1.1 INTRODUCTION

This chapter introduces the concept of Pedagogical Content Knowledge (PCK), what it is and its importance for this study. The chapter also outlines the reasons as to why the researcher would like to research PCK by discussing the problem to be addressed and stating the objective of the study. The research questions to be answered by this study to address the stated problems are also included in this chapter.

1.2 BACKGROUND OF THE STUDY

Pedagogical Content Knowledge

Teaching a topic in a way that enhances learners' understanding has no specific procedure (Park and Oliver, 2008). It is not surprising that teachers have different ideas about teaching (Ndlovu, 2014) and also different teaching approaches even if they are teaching the same topic (Kind, 2009). However, there are teacher traits that are commonly accepted as agents of effective teaching (see Table 2.1, p. 10). Shulman (1986) commented that in the 1870s, people regarded teachers' content knowledge as an important trait to effective teaching, whereas teachers' teaching approaches were considered to be less important. However, in the 1980s people's perceptions changed in a sense that they regarded teaching approaches as more important compared to content knowledge as Shulman (1986) put it. As mentioned by Mishra and Koehler (2006), teachers' knowledge of the content and their pedagogical skills (teaching skills) were treated as mutually exclusive domains. They further added that this belief resulted in teacher education programs focusing more on either of the two, content and pedagogy, without considering the idea that they go together.

Shulman (1986) viewed effective teaching from a different perspective. His point of view was that effective teaching is an amalgam of teachers' understanding of the content, their teaching skills and their knowledge of the curriculum. The idea was that a teacher uses his or her teaching skills to transform what he or she knows, with reference to the curriculum, to something his or her learners can understand. The knowledge for transforming what a teacher knows (the content knowledge) to what can be known by his or her learners was termed Pedagogical Content Knowledge

(PCK) by Shulman (1986). Mishra and Koehler (2006) described PCK as the intersection between pedagogy and content.

Successful teachers are believed to have a special type of knowledge, embedded in their PCK, which informs their practice (Loughran, Berry & Mulhall, 2006). According to Lee and Luft (2008), this type of knowledge influences teachers' decisions with regard to the presentation of a topic, for example, modifying the curriculum where necessary, by conducting activities that are not required by the curriculum. The teacher may also present topics in a sequence that is different from the one suggested by the curriculum. Thus not only does PCK inform lesson presentation, it also informs the planning of the lesson. An effective teacher is believed by Magnusson, Krajcik, and Borko (1999) to be one that "knows how to best design and guide learning experiences, under particular conditions and constraints, to help diverse groups of students develop scientific knowledge and an understanding of these scientific enterprise" (p. 95). This point is in line with the claim made by Käpylä, Heikkinen, and Asunta (2009) that teachers' thinking is based on their planning and their implementations of the plans, together with the theories that influenced the planning and the implementation. This means an effective teacher is one that plans for his or her lessons well, keeping in mind that learners have different learning abilities.

Graphs of motion in the South African education curriculum

In the physical sciences Curriculum and Assessment Policy Statement (CAPS) document by the Department of Basic Education (DoBE) (2011) in South Africa, the topic mechanics involves the greatest amount of work in the Further Education and Training (FET) phase, which is from Grade 10 level to Grade 12 level. Furthermore, a lot of emphasis is put on assessing mechanics concepts in the physics paper of the physical sciences examinations in the FET phase. Learners in the FET phase write two examinations in each grade, the first paper assesses physics concepts and the second paper assesses chemistry concepts. In Grade 10, mechanics concepts make up 50% of the concepts assessed in the physics exam, in Grade 11 the concepts make up 45.3% and in Grade 12 they make up 42%. Mechanics is defined as the branch of physics that deals with the action of forces on objects and the motion (movement) associated with the forces (Concise Oxford English Dictionary, 2011). Graphs of motion form part of the themes under mechanics that are regarded as important by scholars (Shemwell, 2011). McDermott, Rosenquist, and Van Zee (1987) believe that being able to construct and interpret graphs is an essential skill that enhances learners' understanding of physics concepts.

In South Africa, graphs are taught from as early as Grade 4 in the Natural Sciences curriculum (DoBE, 2011). Under skills that should be acquired by learners at Grade 4 level, it is stated that learners must be able to:

- Record information – recording data from an investigation in a systematic way, including drawings, descriptions, tables and graphs.
- Communicate – using written, oral, visual, graphic and other forms of communication to make information available to other people.

Examples of graphs constructed by Grade 4 learners include a graph showing how far inflated balloons with different amounts of air travel up a fishing line, and also a graph showing how far vehicles run down a ramp. However, at Grade 4 level, learners are only expected to draw bar graphs (DoBE, 2011). By the time learners get to Grade 10, they should have an understanding of basic graphing concepts like the types of graphs, variables (dependent, independent and constant), the horizontal and the vertical axes as well as the interpretation of a variety of graphs. This study investigated teachers' PCK about graphs of motion at Grade 10 level because the topic is covered extensively in this grade (DoBE, 2011). According to the physical sciences curriculum as described in the CAPS document, a Grade 10 learner must be able to:

- Describe the motion of an object from position-time, velocity-time and acceleration-time graphs.
- Determine the velocity of an object from the gradient of a position-time graph.
- Determine acceleration of an object from the gradient of a velocity-time graph.
- Determine the displacement/distance covered by an object from the area under a velocity-time graph.
- Understand that the gradient of a tangent to a position time graph gives the instantaneous velocity of an object.

This knowledge of graphs of motion at Grade 10 level scaffolds to, and is applied in other topics in the subject that include forces at Grade 11 level, and projectile motion at Grade 12 level.

Learners' difficulties in graphs of motion

It is well known that learners have misconceptions across science concepts in general. Thompson and Logue (2006) defined a misconception as an incorrect understanding of ideas, objects or events that are based on a persons' experience. In literature, many scholars (Yang, Noh, Scharmann & Kang, 2014; Lane, 2015) referred to alternative conceptions, a term that was introduced by Hewson and Hewson (1983), because misconceptions are often regarded as being wrong ideas. In this study, the researcher refers to misconceptions because the focus was on alternative conceptions as well as wrong ideas. Learners' misconceptions about motion in general include:

- Learners believe that velocity and acceleration are always in the same direction.
- They believe that a fast moving object is believed to have a high acceleration and a slow moving object is believed to have a low acceleration (Lemmer, 2013).
- They believe that heavy objects fall faster than lighter objects (Halloun & Hestenes, 1985).

Although the above mentioned are not graphing misconceptions, the researcher believes they have a negative impact on the learners' conceptualisation of graphs of motion. Learners' misconceptions about graphs of motion have been investigated by scholars. Clement (1985) reported that learners view graphs as pictures. In his study, when learners were asked to draw a velocity time graph showing a cyclist riding up a hill at a constant velocity, they literally drew a hill. This misconception has been explored by other scholars (Barclay, 1985; Lapp & Cyrus, 2000) and the results were similar. Barclay (1985), in his study, commented that learners failed to understand that when an object returns to its starting point, the graph of the motion does not return to where it started. Lapp and Cyrus (2000) presented a position-time graph to learners for them to "walk" according to it. The learners walked in a path that resembled the shape of the graph given to them. Learners who possess this misconception believe a graph should literally look like the actual trajectory of the object under observation (Lapp & Cyrus, 2000). Brasell (1987) and Nemirovsky and Rubin (1992) found that learners interpret different types of graphs of motion using the same principles, especially position and velocity-time graphs. After the analysis of Grade 12 learners' answers in the final examination, the DoBE (2014) reported that this confusion also existed between velocity-time and acceleration-time graphs. Furthermore, learners find it difficult to infer data from one graph and use it to construct corresponding graphs (McDermott et al., 1987). For example, they do not know whether to infer data from the gradient or the height of a position-time graph to determine velocity. Nemirovsky and Rubin (1992) further mentioned that these difficulties might be perpetuated by the fact that the different graphs of motion are usually presented with regard to the motion of the same object over the same time interval. This makes learners think that since the object and the motion are the same, the graphs that represent the motion should also be identical.

Teaching graphs of motion

Many scholars in literature believe that learners' understanding of concepts is a reflection of the quality of teaching they receive (Bukova-Güzel, 2010; Khosa, 2014). Thus the DoBE usually presents courses aimed at improving teachers' practice, especially after a new curriculum is implemented, to enhance the quality of teaching and learning. As mentioned by Darling-Hammond, Wei, Andree, Richardson, and Orphanos (2009), teacher development interventions should include deepening teachers' content knowledge, helping teachers understand how learners learn specific content and how to present the content to learners. The DoBE (2014) suggested the following strategy for teachers – learners must be given more exercises to practise the translation of diagrams into graphs and graphs into diagrams. Learners must also be given exercises to practise the translation of narratives into graphs and graphs into narratives. In the CAPS document, the DoBe (2011) recommended a practical method (ticker-time experiment) that teachers can incorporate in their lesson to help learners conceptualise the topic of graphs of motion. The DoBe (2011) suggests that teachers should have objects moving at a constant velocity (even spaces between the dots), or accelerate (different spaces between the dots). The teachers can then use the data from the ticker tape to construct a position-time graph, and subsequently velocity-time and acceleration-time graphs. To interpret graphs of motion a teacher can simulate the motion depicted by the graph by walking according to it, or even let learners reveal their understanding of graphs by walking according to the graphs.

1.3 STATEMENT OF PURPOSE

The purpose of this study was to explore physical sciences teachers' PCK about graphs of motion. The PCK was accessed in two ways; the PCK manifested by teachers in a written format and discussions, which was conceptualised as "captured PCK", and the PCK manifested by the same teachers during their lesson presentations, which was conceptualised as "revealed PCK". The study then qualitatively compared the two manifestations of PCK to establish whether the enacted PCK is a reflection of the captured PCK or not.

1.4 RATIONALE

Being a physical sciences teacher made me realise that learners' misconceptions and misunderstandings are inevitable across topics and that helping learners understand scientific concepts is a challenging task. For the researcher, graphs of motion at grade 10 level are amongst the topics that learners find difficult to understand. Some of the misconceptions and difficulties that the researcher has picked up in his previous teaching experiences included those that have been reported in literature – viewing graphs as pictures (Barclay, 1985; Clement, 1985; Lapp & Cyrus, 2000), the slope-height misconception (McDermott et al., 1987) and the difficulty in interpreting different graphs of motion (Brasell,1987; Nemirovsky and Rubin, 1992). In terms of the interpretation of the graphs, the researcher has observed that once learners have mastered the interpretation of a position-time graph, they apply the same principles when interpreting velocity-time and acceleration-time graphs respectively. Below are some of the examples of the difficulties regarding the interpretation of graphs that the researcher has observed:

- Learners believe that a horizontal non-zero line in any graph shows a state of rest. This is only true in a position-time graph. Such a line in a velocity-time graph indicates that the object is moving with constant velocity, and in an acceleration-time graph this line indicates that the velocity of the object is changing at a constant rate.
- Learners believe that the sign of the gradient of a position-time and a velocity-time graph indicate the direction in which the object is moving. This is true in a position-time graph because the gradient represents the velocity – the direction of velocity is the direction in which the object is moving. The gradient of a

velocity-time graph represents acceleration – the sign of acceleration does not indicate the direction of motion, it indicates whether the velocity is increasing or decreasing.

- Learners fail to understand that a line that cuts the horizontal axis indicates that an object has returned to its starting point only on a position time graph. They fail to understand that on a velocity-time graph this means an object slowed down to a stop, not necessarily at the object's starting point.

It is important for the researcher to find out how other physical sciences teachers teach graphs of motion. In literature consulted, there was a paucity of information about teachers' PCK about graphs of motion.

It has been just over 10 years since one of the instruments, a Content Representation (CoRe), which capture teachers' PCK about specific topics (Maryati & Susilowati, 2015) was developed by Loughran, Mulhall and Berry (2004). This instrument has been administered to teachers to capture their PCK about several science topics namely; chemistry (Davidowitz, Potgieter, & Vokwana, 2014; Mavhunga & Rollnick, 2013), biology (Jüttner, Boone, Park, & Nehaus, 2013; Chordnork & Yuenyong, 2014) and physics (Chantaranima & Yuenyong, 2014). Nevertheless, there is a paucity of information regarding teachers' captured PCK about graphs of motion, and how it compares to the PCK revealed during lesson presentation. The paucity of information regarding the comparison of the two manifestations of PCK is also evident in other topics including the ones outlined above.

1.5 CONCEPT CLARIFICATION

- **Captured PCK**: This term refers to the PCK portrayed by teachers in a written and discussion format. This information was gathered through CoRes (for PCK in a written format) and interviews (for PCK in a discussed format).
- **Revealed PCK**: This term refers to the PCK that teachers enacted during their actual lesson presentations. This information was gathered by means of classroom observations.

1.6 RESEARCH QUESTIONS

1.6.1 Primary question

- How does teachers' captured PCK compare to the PCK they reveal when teaching graphs of motion?

1.6.2 Secondary questions

- How do teachers reveal their PCK about graphs of motion when captured by means of CoRes and interviews?
- How do teachers reveal their PCK about graphs of motion during their lesson presentations?

1.7 ASSUMPTIONS

This study was conducted under the following assumptions:

- PCK is tacit knowledge, hence written CoRes outline the PCK in the mind of a teacher, which may not necessarily be translated into practice.
- As Baxter and Lederman (1999) put it, PCK is both an observable and internal construct, thus written CoRes (internal) do not give the true PCK of teachers until it is revealed (observed) in a lesson.
- Teachers' PCK is embedded in their minds and can only be communicated by the teachers themselves to, for example a researcher, to make valuable conclusions about the PCK. Hence observing teachers teaching will only provide limited insight to their PCK.

2. CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

A literature review is a report of information found in literature related to one's topic of interest (Concise Oxford English Dictionary, 2011). In this chapter, the literature that sheds light to the concept of PCK is outlined. The chapter also outlines key findings in PCK studies and by so doing, it brings awareness about the ways in which scholars have captured and measured PCK. This chapter also outlines the development of one of the instruments that capture participants' PCK and how it has been used. Furthermore, the TSPCK model is introduced and discussed as it is the framework of that guided this study.

2.2 THE CONSTRUCT: PEDAGOGICAL CONTENT KNOWLEDGE

PCK is a construct which is considered by many scholars (Cochran, King & DeRuiter, 1991; Eames, Williams, Hume and Lockley, 2011) as one of the factors enhancing teacher effectiveness. Shulman (1987) believed the "minimum", as he put it, amount of knowledge needed for adequate teaching includes: (a) *Content knowledge*, which in this paper is referred to as Subject Matter Knowledge (SMK) and is defined as "the amount and organization of knowledge per se in the mind of the teacher" (p. 9). This is the raw, untransformed knowledge of a teacher in a topic or subject (Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008). (b) *General pedagogical knowledge*; this is teachers' general teaching approaches to any topic. (c) *Curriculum knowledge*; this is teachers' knowledge about what to teach and when as stipulated by the curriculum, together with the materials that enhance the teaching of topics (Shulman, 1987). (d) *Pedagogical content knowledge*; the knowledge about transforming SMK into teachable forms. (e) *Knowledge of learners and their characteristics*; this knowledge includes knowing learners' difficulties and strengths in different topics. (f) *Knowledge of educational contexts*; this knowledge includes knowing learners' background, the community surrounding the learning environment, the governance of the school and cultures (Shulman, 1987). (g) *Knowledge of educational ends*; these are teachers' aims or objectives rooted to their teaching. After Shulman (1986) introduced the concept of PCK, scholars have, since then, refined and developed models that define PCK. They believed that some of the knowledge domains that Shulman (1987) grouped with PCK as agents of effective teaching were components of PCK (see Table 2.1 below). Table 2.1, adapted from Van Driel, De Jong and Verloop (1998) and Ndlovu (2014), shows how scholars have conceptualised PCK.

Table 2. 1: Scholars' conceptualisation of PCK

	Subject Matter	Representations and strategies	Student learning and conceptions	General Pedagogy	Curriculum and media	Context	Purposes
Shulman (1987)	X	PCK	PCK	X	X	X	X
Grossman (1990)	X	PCK	PCK	X	PCK	X	PCK
Veal & MaKinster (1999)	PCK	PCK	PCK	PCK	PCK	PCK	PCK
Magnusson et al. (1999)	Y	PCK	PCK	PCK	PCK	Y	PCK
Rollnick et al. (2008)	PCK	M	Y	PCK	PCK	PCK	M

Key: X – Not part of PCK. PCK – Part of PCK. Y – Not discussed thoroughly. M – Manifestation of teacher knowledge

The conceptualisation of PCK by the scholars is indeed different, although there are similarities. Most scholars hold the conception that teachers' knowledge of representations and strategies is part of PCK. This means that if a teacher knows a variety of teaching strategies and representations, namely experiments, drawings and analogies (Loughran et al., 2006) then he or she is most likely to unpack and present content in ways that benefit learners. Furthermore, the scholars believe that teachers' knowledge of how learners learn and their possible misconceptions is an important feature of PCK. However, these conceptualisations of PCK do not outline how the components fit together to define PCK within a specific topic.

2.3 TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE (TSPCK)

Veal and MaKinster (1999) presented taxonomies of PCK to help ease the categorisation of this construct in teacher education. Their belief was that PCK was divided into levels, just like Bloom's taxonomy levels of questioning. These scholars used researchers' conceptions of the characteristics or components of PCK, including those in Table 2.1, to determine the most prevalent attributes of PCK which were then used to develop a taxonomy about the levels of PCK. The identified levels were general PCK, domain-specific PCK and topic-specific PCK. General PCK is said to be subject or discipline based, that is, the PCK possessed by teachers about teaching, for example, physical sciences. Rollnick and Mavhunga (2014) refer to this level of PCK as subject specific PCK. Veal and Makinster (1999) believe the orientation of this level of PCK may be used in other disciplines, however, processes employed, purposes and the SMK will differ. For example, teaching physical sciences is linked with inquiry, discovery, critical thinking, problem solving amongst other approaches, whereas teaching art is linked with creativity and visualisations amongst other strategies and teaching history is linked with storytelling. However, a physical sciences teacher, may, for example, also teach learners to use drawings, like an art teacher, but the approaches will differ altogether.

The next level of PCK, domain-specific PCK, is said to be rooted in a particular discipline within a subject (Veal & Makinster, 1999; Rollnick & Mavhunga, 2014), for example physics being a domain in physical sciences. A physical sciences teacher will demonstrate physics and chemistry concepts differently to learners, depending on the suitable “domain-specific PCK” for the lesson, although the domains are within the same subject. In physics, the teacher may, for example, connect circuit components to demonstrate that parallel resistors are current dividers, and in chemistry, boil water to demonstrate that temperature stays constant when a phase changes. These two approaches are similar, as both are based on practical work, but the apparatus, the processes, and the purposes of the practical activities are specific to a domain.

Veal and MaKinster (1999) believe that a teacher that possesses the third level of PCK, topic-specific PCK, is most probably well-equipped in the preceding levels of PCK. This level of PCK is rooted in the specificity of the topic within a domain, for example, graphs of motion being the specific topic in the physics domain within physical sciences. Veal and MaKinster (1999) assert that though domains may contain similar topics or ideas, the deliverance of the lessons will depend on the purpose of the lesson with reference to the topic itself. Suppose two teachers are teaching learners how to carry out calculations involving quadratic equations, one in mathematics (parabolic functions) and the other one in physics (newton’s equations of motion). The mathematics teacher, for example calculating the roots of a parabolic function can accept a negative answer depending on the nature of the question. The physics teacher on the other hand, for example calculating the time taken by a vertically thrown object to hit the ground should, however, cannot accept a negative answer because time is a scalar quantity and can never be negative. The topic specific nature of the two concepts explained by the two teachers determines the PCK used to carry out calculations during lesson presentations.

Many scholars in literature (Geddis & Wood, 1997; Loewenberg Ball, Thames, & Phelps, 2008) agreed with Veal and MaKinster (1999) that PCK is a construct embedded in specific topics. The PCK about specific topics means that content knowledge about specific topics needs to be transformed into teachable forms. Geddis and Wood (1997) developed a model that describes this transformation. They believed that teachers knowledge about learners' prior concepts, subject matter representations, instructional strategies, curriculum materials and curricular saliency were the agents of the transformation. In the field of mathematics education, different terminologies are often used to describe the different levels of PCK. Loewenberg Ball et al. (2008) identified two mathematical knowledge domains which are Specialised Content Knowledge (SCK) and Common Content Knowledge (CCK). SCK is said to be the knowledge needed for teaching purposes only, whereas CCK is knowledge used in settings other than teaching. For example, CCK is said to be general teaching knowledge including; pronouncing mathematics terms correctly, and recognising incorrect answers as given by their learners or textbooks. Loewenberg Ball et al. (2008) mentioned that this type of knowledge, CCK, is not special as it is not unique to teaching. SCK, on the other hand includes: presenting mathematical ideas, responding to students' "why" questions and finding an example to make a specific mathematical point.

These scholars (Geddis & Wood, 1997; Veal & MaKinster, 1999; Loewenberg Ball et al., 2008) provided a starting point in the development of the TSPCK model by Mavhunga (2012). The development of the model, as asserted by Mavhunga (2012), was to fill a gap in literature. Although scholars mention the topic specific nature of PCK (Veal & Makinster, 1999; Veal, Tippins & Bell, 1999), a construct that describes the topic specific nature of PCK had not been developed in teacher education at that stage. Mavhunga and Rollnick (2013) mentioned that scholars in the field of PCK have agreed upon the TSPCK model and that it was different from general PCK. In support of the model they asserted that:

> *The topic-specific nature [of PCK] suggests the need for a PCK construct that is defined more sharply to reflect the specificity of the topic rather than reference to a subject or discipline. (p. 113)*

It is mentioned by Loewenberg Ball et al. (2008) that although the notion of PCK is commonly accepted, it has however, been thinly developed. They further asserted that what is meant by PCK is underspecified, hence it limits the usefulness of the construct. The researcher believes that it is important to have a model that defines the features of PCK about specific topics, as different topics require a repertoire of content knowledge transformation specific to them.

2.4 CONCEPTUAL FRAMEWORK

A study conducted by Rollnick et al. (2008) developed a model that connects teachers' classroom observable practices with their knowledge domains. They believed that knowledge of subject matter, knowledge of students, general pedagogical knowledge, and knowledge of context are fundamental domains of knowledge for teaching. Furthermore, they believed that PCK is a combination of all these domains to produce observable events in the classroom which they referred to as "manifestations". These "manifestations" included for the purpose of their study are subject matter representations, topic-specific instructional strategies, curricular saliency and assessment in their model. This model contributed to the development of the theoretical framework that guided this study.

The theoretical framework (Figure 2.1) for this study, developed by Mavhunga (2012), elicits the distinction between PCK and TSPCK. In the model, PCK is defined by; knowledge of context, knowledge about learners, SMK and pedagogical knowledge (Rollnick et al., 2008). TSPCK on the other hand is defined by teachers' knowledge about; learners' prior knowledge including their misconceptions, curricular saliency, what is difficult to teach, representations including analogies and conceptual teaching strategies (Mavhunga, 2012). It is through reasoning about specific content in relation to these components that the specific content is transformed into teachable forms. In the framework itself, TSPCK is said to be a component of PCK (Malcom & Mavhunga, 2015), that is, a teacher develops an adequate PCK of, for example, physical sciences after having developed the TSPCK of all the specific topics in physical sciences. The TSPCK model by Mavhunga (2012) does not vary significantly for the model by Magnusson et al. (1999) that many scholars in PCK research referred to in support of their studies. In the model by Magnusson et al. (1999), PCK includes orientations to science teaching which shapes teachers knowledge of science curricular (curricular saliency), knowledge of learners' understanding of science (learners' prior knowledge and what is difficult to teach), knowledge of instructional strategies (representations and conceptual teaching strategies) and knowledge of assessment of scientific literacy.

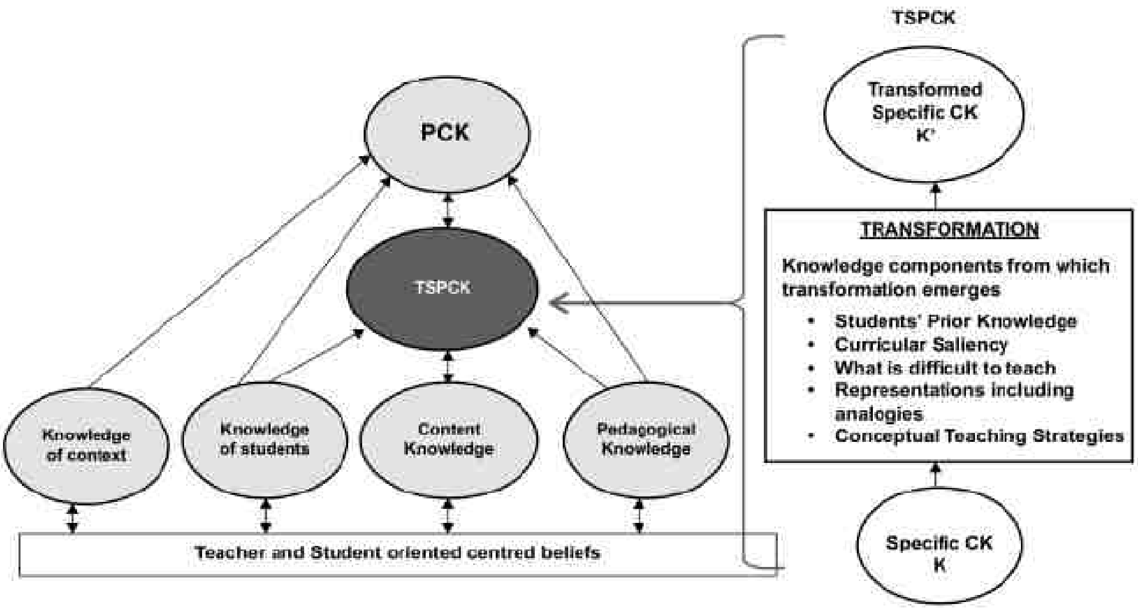


Figure 2.1: the TSPCK model

Components of knowledge transformation

Discussion of the TSPCK components

The discussion of the components is aimed at outlining what each of the components entails, which reflects the PCK of the teachers about specific topics.

- *Learners' prior knowledge*

This component describes teachers' awareness of learners' misconceptions arising from their prior knowledge or previous experience. This also includes understanding of the necessary knowledge that ought to be in place as a result of prior teaching before new concepts can be explained.

- *Curricular saliency*

This component describes teachers' understanding of how concepts within a topic fit together as key ideas. This component also includes the understanding of the importance of concepts, as well as the ways in which the concepts should be sequenced – that is, what should be taught now and what should be taught later.

Furthermore, the interrelatedness between concepts, showing how new knowledge develops from prior knowledge, is included in this component.

- *What is difficult to teach?*

This component is not to be confused with learners' prior knowledge. This component describes teachers' awareness of the concepts within a specific topic that are difficult to teach. This includes the reasons as to why teachers regard these concepts as difficult and/or their awareness of the gate keeping concepts that are making it difficult for learners to understand new concepts.

- *Representations including analogies*

Representations refer to how some physical reality which is the object of learning, is presented symbolically to carry meaning about the reality. This includes analogies, demonstrations, experiments, simulations, et cetera, that a teacher considers to be aiding the teaching of specific content.

- *Conceptual teaching strategies*

This component is conceptualised by scholars as a strategic combination of the preceding four components of TSPCK (Mavhunga, 2012). In this study, it will be the integration of the TSPCK components. As a result, this component includes:

- The involvement of learners through activities, discussions and questions to expose their misconceptions and difficulties, and to confirm understanding.
- The strategies aimed at addressing misconceptions and difficulties. This could be through addressing gate-keeping concepts first before addressing difficulties.
- The use of representations, especially to explain the concepts identified as difficult to teach and misconceptions.

2.5 SMK AND PCK

Shulman (1986) coined the term PCK eliciting the importance of both content knowledge and pedagogy in effective teaching. However, some teacher education institutions teach content and pedagogy to prospective teachers separately and at times, by different lecturers (Nilsson, 2008). This implies that, although it is widely accepted that both content and pedagogy are important, there is still a gap between them in teacher education programs. Studies have however been conducted to investigate the relationship between SMK and PCK. A large number of studies reported a positive relationship, that is, adequate SMK yields high PCK levels (Davidowitz et al., 2014; Rollnick & Mavhunga, 2014; Mdolo & Mundalamo, 2015) and inadequate SMK yields low PCK levels (Rollick & Mavhunga, 2014). Jüttner et al. (2013) indicated that there are inconsistencies in literature regarding this relationship. There have been cases where teachers with adequate SMK displayed a poor PCK knowledge base (Davidowitz et al., 2014; Rollnick and Mavhunga, 2014; Pitjeng, 2014). These teachers are said to be well equipped with the knowledge to be taught, whereas they lack strategies of unpacking and presenting the knowledge (Rollnick & Mavhunga, 2014). As a result, it cannot be concluded that adequate SMK necessarily translates into a sound PCK (Buschang, Chung, Delacruz & Baker, 2012; Bukova-Güzel, Kula, Ugurel & Özgür, 2010).

In literature there is evidence of cases where teachers who portrayed poor SMK portrayed sound PCK in organic chemistry (Davidowitz et al., 2014) and particulate nature of matter (Pitjeng, 2014). In such cases, participants demonstrated rich strategies to unpack and present concepts but not a thorough understanding of the concepts. Pitjeng (2014) asserted that their participant struggled with remembering concepts, which negatively impacted his SMK, however, he thoroughly understood how to unpack concepts for instruction. Nevertheless, the scholars (Davidowitz et al., 2014 & Pitjeng, 2014) have mentioned that this was a very rare finding in their studies.

To investigate the effects of inadequate SMK on PCK, scholars investigated the PCK of under qualified teachers (Rollnick et al., 2008; Mdolo & Mundalamo, 2015) and that of teachers teaching outside their subject specialisation (Henze, Van Driel & Verloop, 2008; Childs & McNicholl, 2007; Mizzi, 2013). Childs and McNicholl (2007) and Mizzi (2013) reported similar findings, that is, some of the teachers teaching outside their area of specialisation presented content as it is from the textbooks due to insufficient strategies of unpacking and modifying it. As reported by Mizzi (2013), teachers' lack of knowledge about the structure and the nature of a topic makes it difficult for them to unpack it for instruction. Similar to findings by Rollnick et al. (2008) and Mdolo and Mundalamo (2015) these teachers prepare learners to pass examinations through memorisation of concepts and algorithms rather than through understanding the content. It was also indicated by Childs and McNicholl (2007) that their participants asked fewer open ended questions, facilitated fewer discussions and hardly used illustrations and analogies. The reason why the teachers asked less open ended questions could be that the teachers did not have the answers to the questions themselves, and/or that they asked questions that they could easily assess. Childs and McNicholl (2007) also asserted that their participants viewed the idea of teaching a topic that they did not understand as an advantage. The teachers (participants) believed that this lack of content knowledge put them at their learners' level and as a result they understood the problems and challenges that learners are most likely to face in understanding a particular concept.

The findings outlined revealed the importance of SMK in the level of the PCK of a teacher. Although this study is not necessarily interested in exploring the SMK of the teachers, it considers the possibility that the teachers' captured and revealed PCK may be influenced by their SMK.

2.6 TEACHING EXPERIENCE AND PCK

Van Driel et al. (1998) conducted a literature review about the influence of experience on one's PCK. They found that experience was regarded as a major source of PCK whereas SMK was regarded as a prerequisite. The literature that they consulted reported that experienced teachers, as opposed to novice teachers, "appear to have developed a conceptual framework in which knowledge and beliefs about science, subject matter, teaching and learning, and students are interrelated in a coherent manner" (p. 679). In a more recent study, Mavhunga (2014) reported similar findings, that is, inexperienced teachers portrayed low levels of PCK. The major factor towards the low levels of PCK, as reported by Cochran et al. (1991) is that inexperienced teachers rely on unmodified subject matter, which comes mostly from textbooks, as they have limited strategies of unpacking it for instruction. Van Driel et al. (1998) further reported that experienced teachers teaching outside their area of specialisation rely mostly on general pedagogical skills developed through experience to make concepts comprehensible for learners. Furthermore, they learn new content as well as the representations of that content easily through the use of their general pedagogical skills. This outcome was also evident in a study by Henze et al. (2008) where experienced teachers' PCK on a topic outside their subject specialisation developed over time as their SMK also developed in the process.

This study is not necessarily interested in exploring teachers' PCK based on their teaching experiences, but it considers the idea that the teachers' captured and revealed PCK may be influenced by their teaching experience.

2.7 CAPTURING PCK

Capturing PCK is regarded, by Rollnick and Mavhunga (2014), as capturing teachers' thinking about ways of unpacking and presenting content. As PCK is an internal tacit construct, it cannot be observed directly (Kagan, 1990), hence capturing the construct is rather challenging (Rollnick & Mavhunga, 2014).

Capturing PCK is described for the purpose of this study as "drawing" PCK from the minds of the teachers, giving them the opportunity to make it explicit so that it can be assessed. This is done by administering instruments to teachers in which they can effectively portray their own PCK. After the theorisation of PCK scholars have investigated the components that define it in order to be able to measure it. In the previous decade, the different instruments that have been developed and implemented to capture teachers' PCK were mostly qualitative in nature (Baxter & Lederman, 1999). More recently, Rohaan, Taconis and Jochems (2009) investigated the feasibility of capturing teachers' PCK using a quantitative approach. The instrument that they used was a multiple choice test where they presented teachers with different teaching approaches and then teachers had to choose the most effective approach. The teachers were not given a platform to come up with their own strategies, which the researcher believes would have deepened the understanding of the PCK of the teachers. The scholars have however asserted that their method of capturing PCK was rather complicated and limiting. Jüttner and Neuhaus (2012) designed an instrument that captured teachers' PCK about learners' errors. The instrument was designed in such a manner that it presented a specific scenario with related questions. The common errors in the learners' answers were assessed and used to design a PCK test for biology teachers.

Teachers' PCK can also be determined from their lesson plans (Van Der Valk & Broekman, 1999) by exploring the concepts to be presented, the outcomes that the teacher aims to achieve as well as the strategies that the teacher intends to utilise to achieve the outcomes (Khosa, 2014).

2.7.1 Content Representations (CoRes)

Loughran et al. (2004) developed an instrument to access the PCK of teachers about specific topics. The instrument is known as a Content Representation (CoRe). According to the developers, a CoRe is a tool that captures and portrays teachers' PCK by helping them articulate it (see Figure 2.2). CoRes outline teachers' ideas about their methods of unpacking specific content to make it suitable for instruction (Padilla, Ponce-de-León, Rembado and Garritz, 2008). The questions that teachers answer when completing their CoRes are based on "big ideas" that are the concepts within a particular content area (Loughran et al., 2006; Bertram & Loughran, 2012) where the conceptualisation of that content is based (Padilla et al., 2008).

The CoRe template in Figure 2.2 does not restrict participants to only three key ideas as shown. A teacher can have more or even less, depending on the topic (Loughran et al., 2006). When completing CoRes, a teacher has to identify key ideas and answer the eight prompts or questions based on those ideas. There is no specific amount of information that must be written in the CoRe, some spaces may be left blank if a teacher prefers not to complete it (Loughran et al. 2006).

Content Area:……………….	Key idea A	Key idea B	Key idea C
What do you intend the learners to learn about this idea?			
Why is it important for learners to know this?			
What else do you know about this idea (that you do not intend learners to know yet)?			
What are the difficulties/limitations connected with teaching this idea?			
What is your knowledge about learners' thinking that influences your teaching of these ideas?			
Are there any other factors that influence your teaching of these ideas?			
What are your teaching procedures (and particular reasons for using these to engage with this idea)?			
Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).			

Figure 2. 2: A Content Representation (CoRe) template

The significance of responses to the prompts in the CoRe

The following discussion is aimed at outlining the significance of the responses to the prompts in relation to the PCK portrayed in the process. This also includes evidence from literature which indicates the features of PCK in relation to the prompts.

- *What do you intend learners to learn about this idea?*

This prompt is regarded as the starting point for unpacking the key ideas. Teachers' answers to this prompt reveal their understanding of the important concepts within an idea. Loughran et al. (2006), further added that a teacher with an adequate PCK would know what was important in an idea, whereas teachers with poor PCK would be unsure and as a result they did not know what to teach.

- *Why is it important for learners to know this?*

This prompt is linked to the previous prompt. It is a build-up question where a teacher should not just realise what is important for learners to know, but also the reasons why they should know it. For example, Rollnick et al. (2008) mentioned that when their participants were asked this question, they mentioned that the concepts were examined in the final examinations, hence it was important for learners to memorise them. This revealed a poor PCK base. As stated by Loughran et al. (2006), other reasons as to why learners should know a concept may be linked with other curriculum aims, for example subsequent topics within the subject of interest.

- *What else do you know about this idea (that you do not intend learners to know yet)?*

Answers to this prompt will reveal teachers' decision making attributes, where a teacher gets to select what is important from a multitude of knowledge. Loughran et al. (2006) asserted that successful teachers do not believe in oversimplifying concepts by leaving out other necessary concepts, or keeping it as complex as it is from the beginning by including irrelevant concepts, they rather try and find a balance in between. This prompt also explores teachers' knowledge about the sequencing of concepts, how the concepts that should be taught currently scaffold to those that will be taught at a later stage.

- *What are the difficulties and limitations associated with learning this idea?*

Clearly this prompt can best be answered by someone who has taught before, as a new teacher would not know what learners find difficult to grasp. Loughran et al. (2006) asserted that successful teachers plan their lessons according to learners' difficulties in a sense that they try to prevent a misunderstanding before it arises. It is important to know what makes the learning of a concept difficult so you can build on it through the utilisation of adequate teaching strategies to induce a conceptual change (Van Driel, De Jong & Verloop, 2002).

- *What is your knowledge about learners' thinking that influences your teaching of these ideas?*

This prompt explores teachers' awareness of the ways in which learners think about phenomena, as it is evident in literature that learners have misconceptions about phenomena in general (Periago, Pejuan, Jaen & Bohigas, 2009). This knowledge then informs lesson preparation as the teacher will focus on strategies to rectify misconceptions before imparting new knowledge. It was reported by Käpylä et al. (2009) that their participants, who revealed a limited understanding about the ways in which learners perceive photosynthesis and plant growth, struggled to prepare sound lessons. Lederman, Gess-Newsome and Latz (1994) asserted that when teachers become acquainted with the way learners perceive phenomena, they can restructure subject matter in ways that allow productive communication with them.

- *Are there any other factors that influence your teaching of these ideas?*

This prompt is interested in exploring factors, apart from the topic itself, that influence the way teachers teach a certain topic. These may be contextual factors (Loughran et al., 2006), which could include; "availability of resources, class size, students' socio-economic background, curriculum, the situation in the country, classroom conditions, and time available for teaching and learning" (Rollnick et al., 2008, p. 1381).

- *What are your teaching procedures (and particular reasons for using these to engage with this idea)?*

This prompt builds upon the preceding prompts, especially the ones that explore teachers' awareness of learners' thinking and their possible misconceptions and difficulties. Familiarity with a variety of teaching procedures and activities is seen as an important aspect of PCK (Loughran et al., 2006; Childs & McNicholl, 2007) as it enables teachers to unpack and present concepts in ways that addresses misconceptions and difficulties. As mentioned by Lee, Brown, Luft and Roehrig (2007), teachers who portray low PCK levels find it difficult to tailor learning materials and activities to suit their learners. As a result they find it difficult to identify representations that would aid the explanation of concepts and thus effectively deal with learners' difficulties (Van Driel et al., 1998). Teachers who portray high levels of PCK, on the other hand, demonstrate a greater repertoire of representations and strategies that benefit learners (Clermont, Krajcik & Borko, 1993; Clement, Borko & Krajcik, 1994).

- *Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).*

This prompt brings awareness about how teachers examine the effectiveness of their teaching and their learners' understanding. Cochran et al. (1991) asserted that merely asking simple recall questions to learners was proof that the PCK of the teacher was low. Childs and McNicholl (2007) reported that their participants, who were teaching outside their subject specialisation, portrayed low levels of PCK as they facilitated fewer discussions, asked closed ended questions and used fewer illustrations and analogies. They further asserted that the teachers' lack of SMK may have influenced the questions they asked as closed ended questions are easier to assess. This then implies that teachers who possess limited PCK find it difficult to assess the progress of their learners (Lee et al., 2007).

Administration of CoRes

The ways in which researchers administered CoRes in their studies are not the same, but the purpose is quite similar, that is, to gain an insight of individuals' PCK about specific topics (Maryati & Susilowati, 2015). Mavhunga and Rollnick (2013) administered CoRes to their participants, before and after an intervention to explore the degree to which an intervention developed their PCK. CoRes are difficult to understand, especially how to recognise key ideas, hence the tool must be explained to the participants before they complete it, so that they can know what is expected of them (Chapoo, Thatong and Halim 2014; Garritz, Porro, Rembado, & Trinidad, 2007).

In some studies (Eames et al., 2011; Williams and Lockley, 2012; Chordnork & Yuenyong, 2014; Garritz, Alvarado, Canada & Mellado, 2013) CoRes were written down by participants whereas in other studies (Loughran, Mulhall & Berry, 2008;

Padilla et al., 2008) they were used in other ways. Padilla et al., (2008) and Chordnork and Yuenyong (2014) developed interview questions from the CoRe prompts, whereas Rollnick et al. (2008), collected data using interviews and observations and grouped the data in the CoRe prompts to which they belong.

Advantages of CoRes

The most prevalent advantage of using CoRes is that they simplify the difficulty associated with exploring teachers' PCK. Although PCK is unique to individuals (Shulman, 1986; Kind, 2009) and cannot be generalised, capturing successful teachers' PCK through CoRes makes the PCK accessible to other teachers who can improve their practice (Loughran et al., 2004).

Scholars who have involved CoRes in their studies have reported that:

- CoRes, shape teachers' thinking about their own practices (Bertram & Loughran, 2012) as they turn their attention from "just teaching" to teaching with a purpose in mind.
- CoRes help pre-service teachers link content with pedagogy (Loughran et al., 2008) as they make them reason about content in teaching situations (Mavhunga & Rollnick, 2013).
- CoRes help novice teachers understand PCK and portray it on the tool. This enables the teachers to reflect on their own PCK and make changes where necessary. This develops their PCK (Kaya, 2009)

Van Driel et al. (2002) mentioned that pre-service teachers' PCK develops through a constant use of content in teaching situations and Kaya (2009) asserted that writing CoRes repeatedly allows an individual to reflect on his or her practice and as a result, his or her PCK develops.

These developments are observed over time. Introducing CoRes to novice teachers is believed to accelerate the process of development. For example, Cooper, Loughran and Berry (2015) asserted that:

> *"Working with CoRes appears to be a catalyst for teachers to see the value of pursuing their understanding of science teaching through the notion of PCK" (p. 64)*

Maryati and Susilowati (2015) investigated the relationship between CoRes and lesson preparation in Indonesia by comparing their formats and the outcomes each document aims to achieve. They found many differences between the instruments and explicitly pointed out that CoRes are well developed in a sense that they require a teacher to understand learners' conditions and plan his/her lessons according to those conditions. As a result, a teacher prepares for a lesson better when using CoRes than a lesson planning form.

2.8 ASSESSMENT OF PCK

Assessing PCK is described for the purpose of this study as exploring the quality of the PCK by determining the extent to which it is developed. The complexity of PCK suggests that PCK should be captured by a variety of instruments (Kagan, 1990) before it can be assessed. As PCK is tacit and internal, Kagan (1990) argued that only using observations limited insight in the assessment of PCK as the examples that the teacher decided not to use in the lesson wouldn't be known. As a result, Baxter and Lederman (1999) suggested that interviews should also be used as an instrument that captures PCK as they provide a platform for teachers to verbally articulate the PCK.

In studies described in literature, rubrics are commonly used to assess the quality of teacher's PCK (Park, Jang, Chen & Jung, 2011; Mavhunga, 2012). Park et al. (2011) used interviews and observations to explore teachers' competence on two components of PCK, namely; knowledge of learners' understanding and knowledge of instructional strategies and representations. Mavhunga (2012) used qualitative questionnaires to explore teachers' competences in the five components of TSPCK. To assess the competences, the scholars (Park et al., 2011; Mavhunga, 2012) set standards that classified teachers' levels of competences based on the information they shared in the instruments capturing PCK. The levels of competences were set on a scale of one to four, where one is limited, two is basic, three is developing and four is exemplary. The validity and the credibility of the rubric (Mavhunga, 2012) were then determined quantitatively to explore the degree to which the rubric scores teachers' levels of PCK. After the development of the TSPCK model by Mavhunga (2012), scholars began investigating ways of designing and validating instruments that measure the TSPCK of science topics namely, organic chemistry (Vokwana, 2013), electrochemistry (Davidowitz et al., 2014), particulate nature of matter (Pitjeng, 2014) and electric circuits (Zimmerman, 2015).

3. CHAPTER THREE: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the procedures that were followed to investigate the research questions that guided this study. This includes the discussion of the paradigm from which this study was approached, the research design and the research methodology. As such, the chapter outlines the sampling procedure, the profile of the participants, and the instruments that were used to collect and analyse data.

3.2 EPISTEMOLOGICAL PARADIGM

Epistemological paradigm refers to the theory of knowledge, how we get to know what we know (Concise Oxford English Dictionary, 2011). The study was approached from an interpretivist point of view, because the researcher believes that people do not behave according to fixed rules and that people's actions need to be interpreted in the context they appear. For example, there is no "right" teaching approach and teachers adopt strategies that they believe are effective for teaching. Interpretivism is a knowledge gathering theory that interprets a situation or phenomenon in order to adequately understand it and thus be able to explain it (Maree, 2010). The epistemology of this paradigm is described by Hesse-Biber and Leavy (2011), where they stated that:

> *"The interpretive position assumes the social world is constantly being constructed through group interactions, and thus, social reality can be understood via the perspective of social actors enmeshed in meaning-making activities." (p. 5)*

One of the characteristics, indicated in the quote above, which was evident in this study, was that social reality was understood from the perspective of social actors. The social reality was the PCK of the teachers, the social actor was the researcher and the meaning-making activity was the research itself – comparing the PCK that teachers portray in written and spoken format to the PCK they enact during lesson presentation. The understanding of the social reality from the interpretive point of view is subjective, that is, the knowledge generated in this study was influenced by the personal views and opinions of the researcher. This is because in this paradigm, there are multiple understandings of social reality and each and every one of them depends on the person interpreting the reality (Tsang, 2014).

3.3 RESEARCH METHODOLOGY

This study followed a qualitative research methodology inferring from the aims and objectives that were to be achieved. As the researcher has indicated earlier, he believes teachers teach according to what they regard as effective. It was important to approach this study from a methodology that effectively enabled the teachers to share their practice. According to Hancock (2002) qualitative research is "conducted if a researcher is interested in studying human behaviour and the social world inhabited by human beings" (p. 1). He further added that it is "…concerned with developing explanations of social phenomena" (p. 2), the social phenomenon being the PCK of the teachers. The qualitative research methodology was also employed because it conformed to the nature and beliefs of the interpretive paradigm. The link between qualitative research and interpretivism is indicated by Muhl (2014) where it is claimed, "by its nature, interpretivism promotes the value of qualitative data in pursuit of knowledge" (p. 77).

3.4 RESEARCH DESIGN

This study adopted a case study research design, which also conformed to the nature and beliefs of the interpretive paradigm. The link between case study research and the paradigm is explicitly revealed by Maree (2010) where he says:

> *"From an interpretivist perspective, the typical characteristic of case studies is that they strive towards a comprehensive (holistic) understanding of how participants…make meaning out of a phenomenon under study." (p. 75)*

A case study, by definition, is an in-depth inquiry of a single unit to extensively explore phenomena (Thomas, 1998; Ary, Jacobs, Razavieh, & Sorensen, 2006). In this study, the unit (of analysis) was Grade 10 level physical sciences teachers and the phenomenon was their PCK about graphs of motion. With reference to Yin (2003), a case study research design was adopted because the behaviours of the participants were not manipulated in any way, but rather explored. As suggested by Maree (2010), the unit of analysis and the behaviour that describes the explored phenomenon were explicitly defined beforehand to keep the researcher focused on the important and relevant behaviour.

Like any other research design, case studies have advantages and disadvantages. According to Thomas (1998):

"The greatest advantage of a case study is that it permits a researcher to reveal the way a multiplicity of factors have interacted to produce unique characteristics of the entity that is the subject of the study." (p. 82)

In relation to what Thomas (1998) stated, the interacting factors in this study were the five components of TSPCK and the unique characteristics produced were the captured and revealed PCK. Another advantage of using a case study research design was that there were no restrictions regarding the techniques that were used to collect and analyse data (Maree, 2010). One of the disadvantages of results obtained from case study research designs is that the findings from such a study cannot be generalised to a larger population, although they can be used to generalise towards a theory (Maree, 2010).

3.5 SELECTION OF PARTICIPANTS AND SAMPLING PROCEDURES

As Maree (2010) puts it, it requires money, time and energy to include the entire population in a study. As a result, only a part of the population (sample) was involved in this study. From the population of this study, which was grade 10 physical sciences teachers, a sample of four teachers was selected.

For convenience, teachers teaching in the proximity of the institution, where the researcher was situated, were requested to participate in this study. Convenience sampling is used to select people who are easily accessible (Maree, 2010). Purposive sampling was used to select teachers who met the requirements that were set out before the study was conducted. Maree (2010) asserted that purposive sampling is used with a specific purpose in mind, which is to select individuals that meet a certain criterion. In this study, participants were selected because they were teaching physical sciences at Grade 10 level, as the topic of graphs of motion is covered extensively in the grade (CAPS, 2011). This study acknowledges the evidence outlined in Chapter Two that SMK and teaching experience are amongst the major sources affecting teachers' PCK. However, the study explored teachers' captured and revealed PCK without necessarily focusing on the teachers' levels of SMK and their teaching experience, and these factors did not determine whether a teacher participated in this study or not. The most important requirement was that the teachers had to be teaching graphs of motion at Grade 10 level. The biographical information of the participants is presented in Table 3.1 below.

Table 3. 1: Participants' biographical information

Teachers' name	Highest qualification	Grade 10 level teaching experience in years.	Type of school in terms of resources
Mrs. VM	B.Ed Degree in Science Education	Six	Adequately resourced
Mrs. SC	PGCE in Science Education	Three	Adequately resourced
Miss. MH	Higher Diploma in Science Education	Five	Poorly resourced
Mr. KZ	B.Ed Degree in Science Education	Three	Adequately resourced

3.6 DATA COLLECTION INSTRUMENTS

In this study, CoRes, interviews and classroom observations were used to collect data, similar to Chapoo et al. (2014).

Content representations (CoRes)

As mentioned in Chapter Two, a CoRe is a tool that captures and portrays teachers' PCK within a specific topic by helping them articulate it (Loughran et al., 2004). This tool is designed in a way that requires teachers to identify "big ideas" which are the major concepts in which the conceptualisation of the content is based (Padilla et al., 2008). In this study, the term "big idea" is replaced with "key idea". The reason for this is that the lesson planning form for pre-service teachers at the University of Pretoria describe "big idea" as a theme in a subject. In this case a big idea would be "graphs of motion". The researcher assumed that since the participants in this study were within the vicinity of the university, they might have mentored pre-service teachers from the institution and they might have come across the term "big idea" in the past. Thus the tool was different in that regard, but the prompts remained unchanged. The tool then sets out eight prompts that teachers have to answer based on the key ideas that they identified. The instrument was validated by examining its usefulness in the way concepts were organised and expressed in it, as stated by Loughran et al. (2006). In this study the instrument was used to capture the PCK of the teachers about graphs of motion and assess it to infer answers to the first sub-question: How do teachers portray their PCK about graphs of motion as captured by means of CoRes?

In Figure 3.1 below, the link between CoRes and the framework that guided this study is indicated. This link shows the CoRe prompts in which information about teachers' knowledge of the TSPCK components is expected. However, teachers' knowledge about the TSPCK components can be inferred in any of their responses to the prompts.

CoRe prompts	TSPCK components
What do you intend the learners to learn about this idea?	Curricular saliency
Why is it important for learners to know this?	Curricular saliency
What else do you know about this idea (that you do not intend learners to know yet)?	Curricular saliency
What are the difficulties/limitations connected with teaching this idea?	What is difficult to teach
What is your knowledge about learners' thinking that influences your teaching of these ideas?	Learners' prior knowledge (misconceptions)
Are there any other factors that influence your teaching of these ideas?	
What are your teaching procedures (and particular reasons for using these to engage with this idea)?	Conceptual teaching strategies/representations
Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).	Conceptual teaching strategies/ representations

Figure 3.1: The link between CoRes and the TSPCK components

Observations

An observation is an act of recording behavioural patterns of participants without influencing them (Maree, 2010). In this study, classroom observations were conducted to explore the ways in which teachers reveal their PCK so as to assess it and thus infer answers to the second sub-question of the study: How do teachers' reveal their PCK about graphs of motion during lesson presentations?

Interviews

Interviews are considered to be amongst the instruments that capture teachers' PCK because the interviews provide teachers with a platform to verbally articulate the PCK

(Baxter and Lederman, 1999). In this study interviews were used to supplement the information teachers shared in the CoRes, because teachers left some prompts unanswered or their responses were unclear in their CoRes.

3.7 DATA GATHERING PROCESS

The results from the pilot study revealed that CoRes take time to complete, hence they were administered to teachers well in advance. Furthermore, key ideas and prompts had to be explained to teachers, especially Prompt Three (what else do you know about this idea that you do not intend learners to know yet).

Content Representations (CoRes)

CoRes were given to teachers before they were observed teaching graphs of motion. The teachers were not assisted in writing up their CoRes, but the meaning of the term “key idea” and the prompts were explained and clarified. The teachers completed the CoRes in their own time and place. The teachers were also provided with the researchers’ contact details should they need clarity while completing the CoRe tool. Due to unforeseen circumstances, the teachers took longer than was expected to return their CoRes. As a result, teachers CoRes were only assessed after they had presented their lesson, which was not the way the researcher had intended to approach the study. The aim was to observe teachers after having read their CoRes.

Observations

The participants were observed and video recorded while they were teaching graphs of motion. The lessons were recorded in a way that did not interfere with the normal teaching of the teachers, that is, the researcher was just filming the lesson without taking part in it. The lessons of the teachers were observed until the teachers felt that they had presented everything that they had to present for the purpose of this study in the topic of graphs of motion. As a result some teachers were observed teaching two lessons whereas others were observed teaching only one lesson. The data collection from lesson observations was guided by the rubric that the researcher developed to suit captured PCK about graphs of motion. Thus the researcher used the rubric to look for episodes that reflected the teacher’s revealed PCK based on the TSPCK components in Mavhunga’s (2012) model.

Interviews

The interviews were conducted a few days after the teachers had presented their lessons and returned their CoRes. It was unfortunate that the teachers returned their CoRes with unanswered and unclear answers to the prompts. As a result, interviews were then conducted to supplement the information that was missing and clarify the information that was unclear. In the interview the researcher did not prompt the teachers about decisions made during the presentation of the lesson, because the focus of the second part of the study was on the PCK revealed while teaching. During the lessons the teacher had the opportunity to impact on the leaners and any clarification or additional information about the teacher's PCK during an interview would not benefit the learners.

Interview questions were then taken and adapted from the CoRe prompts and the researcher, who did the interviews, attempted to clarify the prompts as the interview progressed. Teachers were reminded of the key ideas that they had selected in the written CoRes and given a platform to add key ideas if they had any in mind so they could answer the questions based on them. The interviews were then transcribed and aligned with the information that the teachers had shared in the CoRes and together they constituted the captured PCK of the teachers.

3.8 DATA ANALYSIS

The data that were collected throughout this study were analysed through the use of two rubrics, one for captured PCK and one revealed PCK. These rubrics were modified TSPCK rubrics (see Appendix II and III) adapted from Mavhunga (2012). The original rubric by Mavhunga was aimed at assessing teachers' PCK from a test that was set to explore teachers' PCK about chemical equilibrium. Thus the original rubric had to be modified because in this study, teachers' PCK was explored by means of CoRes instead of a TSPCK test. However, the levels of competence were still kept the same; limited, basic, developing and exemplary. The modifications were on the information that described those four levels of competence.

In this study, the topic whose PCK was assessed, was graphs of motion instead of chemical equilibrium. As a result, a few items had to be changed or adapted, for example in the assessment of teachers' use of representations, because representations used in chemistry are usually different from those used in physics.

Figure 3.2 indicates the original rubric that was set out by Mavhunga (2012) in terms of representations.

Limited	Basic	Developing	Exemplary
Limited to use of only macroscopic (analogies, demos, etc.) representation with no explanation of specific links to the concepts represented.	Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to establish the links to the aspects of the concepts being explained.	Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation with explanatory notes linking the two representations to the aspect(s) of the concepts being explained.	Use of macroscopic representation (analogies, demos, etc.) or symbolic representation and, use of sub-microscopic representation to enforce a specific aspect (s) of the concept explained

Figure 3. 2: Mavhunga's (2012) rubric about representations

Mavhunga's (2012) rubric explored, in terms of representations, teachers' use of micro and macroscopic representations to support their explanations of concepts. In graphs of motion, one cannot refer to microscopic representations, as a result, this part of the rubric was then modified (see Figure 3.3 below).

Limited	Basic	Developing	Exemplary
Representations not identified	Identified a relevant representation. No information about how the representation works and which concepts it supports.	Identified a relevant representation. Outlined how the representation supports the explanations of concepts.	Identified a variety of relevant representations. Outlined how the representations support the confrontation of misconceptions and difficult concepts.

Figure 3. 3: Modified TSPCK rubric about representations

Furthermore, the original rubric by Mavhunga (2012) was suitable for captured PCK only. In this study, the revealed PCK was also explored, hence a rubric that assesses this form of PCK had to be developed. In terms of the component "what is difficult to teach?" the modified rubric for captured PCK focused on teachers' awareness of specific concepts that were difficult to teach in graphs of motion. This included teachers' awareness of the gatekeeping concepts and/or reasons as to what makes the concepts difficult to teach. The revealed PCK rubric was then designed to assess how teachers then address the concepts that they had presented as difficult in their captured PCK (see Figure 3.4). To analyse the revealed PCK of the teachers the researcher watched the videos repeatedly and looked for significant pedagogical episodes that reflected the TSPCK components. Furthermore, those episodes were transcribed and given to the experts to examine them to ensure that the researcher analysed them adequately.

Limited	Basic	Developing	Exemplary
No facilitation of discussions that expose difficulties. Identified difficult concepts are not confronted/confronted incorrectly	Facilitation of discussions that reveal difficulties. No expansion of explanations of the difficult concepts.	Facilitation of discussions that reveal difficulties. Teacher expands on the explanation of difficult concepts.	Facilitation of discussions that reveal difficulties. Confrontation starts from gate-keeping concepts and concepts are expanded. Teacher then confirms learners' understanding

Figure 3. 4: Developed revealed TSPCK rubric about "what is difficult to teach"

The researcher then designed an expert CoRe (see Appendix I) in collaboration with experts in science education research to guide the assessment of the teachers' CoRes and interviews. The expert CoRe was considered to be exemplary in all the TSPCK components and was used as a point of reference when assessing the teachers' captured PCK. The way content is presented in the expert CoRe is not necessarily the only way in which it could be presented, but it's an example of good practice. As indicated earlier, according to Park and Oliver (2008), PCK is not fixed and there is no "right" PCK for teaching a topic. Other experts could present key ideas that differ from those presented in the expert CoRe and yet present content adequately. The key ideas that were presented by the experts who compiled the expert CoRes were:

Key idea	Sub-ordinate idea
Understand these graphs: • Position-time graph • Velocity-time graph • Acceleration-time graph	Understand the graphs under these conditions: • Stationery object in the origin, positive and negative direction • Constant velocity in the positive and negative direction. • Constant acceleration in the positive or negative direction.
Gradient of a position-time graph (including tangents and secants)	Represents velocity (instantaneous velocity and average velocity)
Gradient of a velocity-time graph	Represents acceleration.
Area under a velocity-time graph	Represents displacement, a change in position.

Figure 3. 5: An extract of the Expert CoRe

3.9 TRUSTWORTHINESS

Data collection

Trustworthiness of qualitative research designs refers to the degree to which the interpretation of the concepts used in the study has mutual meaning for the participants and the researcher (Maree, 2010). As previously indicated, the instruments that were used to collect data have been validated and used with success in the past. Furthermore, they were piloted by the researcher to determine their feasibility (Maree, 2010). The trustworthiness of the data was also ensured through triangulation, which refers to the act of incorporating multiple strategies to collect and analyse data so as to develop a comprehensive understanding of phenomena (Maree, 2010). In this study, different techniques were used to access the PCK of the teachers. CoRes and interviews reflected the captured PCK of the teachers, whereas classroom observations reflected the revealed PCK of the teachers.

Data analysis

The fact that the data were collected using different instruments enabled the researcher to cross check the data for consistency or deviations. The original rubric that was adopted to suit this study has also been validated as reported by Mavhunga (2012). However, experts reviewed the modified rubric to ensure that it adequately described the information that classified teachers within the four levels of competence.

As it was indicated earlier, case study designs have their disadvantages. Analysing cases provides opportunities for subjectivity or even prejudice (Ary et al., 2006). This could also lead to biased interpretations, where the observation by the researcher could be selective and the interpretation could be based on the personal opinions of the researcher. To eliminate bias, thus ensuring the credibility of the interpretations, the analysis of the data was continuously reviewed by the same experts to ensure inter-rater reliability. This refers to having at least two independent researchers assessing the same data.

3.10 ETHICAL CONSIDERATIONS

To ensure that this study is conducted in an ethical manner, the researcher applied for ethical clearance and only approached nearby schools after the clearance was granted. Consent and assent forms were given to teachers, parents and learners to complete before data was collected. This was to ensure that permission was granted by every party involved and that they understood the procedure of the study. The forms explicitly stated that participation was voluntary, discontinuation is allowed, and that the names of people and schools involved would be kept confidential. Furthermore, the researcher and supervisors are the only people that have access to the data and it will be kept in a safe place and will only be destroyed 15 years after the study.

4. CHAPTER FOUR: CAPTURED PCK

This chapter presents and analyses the data reflecting the captured PCK of the four teachers. The data were collected using CoRes and interviews. The data were then analysed using a rubric for captured PCK (Appendix II), focusing on the five TSPCK components, to find answers to the first sub-question of the study: How do teachers reveal their PCK of graphs of motion as captured by means of CoRes and interviews?

The chapter is organised as four cases to present and analyse the data from the CoRes and the interviews of each of the four participating teachers. The data is presented in terms of the TSPCK components discussed previously in Chapter Two. To guide the analysis of the teachers' captured PCK, an expert CoRe (Appendix I) was developed as discussed in the previous chapter. The PCK about this topic as articulated in the expert CoRe was regarded as exemplary in all the components, thus teachers competences were assessed with reference to the expert CoRe.

The information explored by the TSPCK components

The following information is aimed at clarifying what each of the five TSPCK components entail as described in the discussion of the framework of this study (Chapter Two, Page 14). This is to help readers to be aware of the type of information to expect when reading the interpretation of the data. These components are knowledge components through which the teacher transforms her/his own comprehension of a topic to forms that are comprehensible to learners.

Learners' prior knowledge: This component described teachers' knowledge about learners' prior knowledge – the knowledge that ought to have been in place before teaching learners new concepts, as well as the misconceptions that learners might have had in their prior knowledge.

Curricular saliency: This component describes teachers' understanding of how the concepts within the topic of graphs of motion fit together as key ideas. This also includes teachers' indication of the sequence in which the key ideas should be taught – that is, what should be taught now and what should be taught later. Furthermore, the component describes teachers' explanations of the interrelatedness between those key ideas.

What is difficult to teach: This component is not to be confused with misconceptions. Instead, it describes teachers' awareness of the new concepts within graphs of motion that learners find difficult to understand. This includes the reasons why teachers regard these concepts as difficult and the possible gate keeping concepts for the difficulties. A gate keeping concept refers to an essential concept that should be in place for learners to understand subsequent concepts. These concepts are often difficult for learners to grasp and frequently obstruct further conceptual development.

Representations including analogies: Representations refer to how some physical reality, the object of study, is presented to carry meaning about the reality. For example, a graph of motion is a representation that represents or describes a physical situation, of how an object is moving. However, in the current study the situation is reversed. Graphs of motion are regarded as the object of study while examples of physical reality (models, experiments, drawings, simulations) are regarded as representations that teachers may use to explain graphs of motion. Hence this component is focused on the relevance and feasibility of the indicated representations.

Conceptual teaching strategies: This component is conceptualised by other scholars as a strategic combination of the preceding four components of TSPCK (Mavhunga, 2012). For the current study such a strategic combination of the components is captured in the following criteria:

- Indication of how key ideas, and their sub-ordinate ideas, in graphs of motion should be discussed; how they should be sequenced, as well as the indication of the interrelatedness between them.
- The instructional strategies that should be used to present concepts, as well as confrontational strategies to address misconceptions and difficult concepts.
- The use of representations, especially to explain the concepts identified as difficult to teach or to address the misconceptions.

4.1 CASE STUDY 1 – MRS. VM

Mrs. VM is a physical sciences teacher who holds a B.Ed degree in Science Education and has been teaching the subject at Grade 10 level for six years. At the time of this study she was teaching graphs of motion for the seventh consecutive year.

4.1.1 Data from the CoRes and interview

Mrs. VM indicated only three key ideas when writing the CoRes as shown in Figure 4.1. The focus of her responses to the CoRe prompts was mostly on the last two key ideas that she indicated, this accounts for the large number of blank spaces in the CoRe tool. During the interview, Mrs. VM was not entirely confident in responding to the questions that were asked. At times she asked the researcher whether she correctly understood the question asked. The information she revealed in the interview was mostly similar to the information she had shared in the CoRes. Her full interview transcript is available in Appendix IV.

Section A

Think carefully about the way you teach Graphs of motion in Grade 10. List all the key ideas that you consider important in the teaching/learning of Graphs of motion.

Key idea A: why do we use graphs in science

Key idea B: motion with a constant velocity

Key idea C: motion with a constant acceleration

Key idea D: ___

Key idea E: ___

Key idea F: ___

Key Idea G: ___

Key Idea H: ___

Key Idea I: ___

Key Idea J: ___

Key Idea K: ___

Key Idea L ___

2

Section B

Answer the following questions based on the Key ideas listed in Section A above.

1. What do you intend learners to learn about each of the ideas below?

Key Idea A	Key Idea B	Key Idea C
Usefull information can be derived from graphs. 30% Textbooks	movement with constant velocity - object at rest. - object moving at a constant velocity to the negative direction - object moving to the positive direction. Remind learners about the vector nature of position + velocity	movement with constant acceleration - object moving at a constant velocity + constant acceleration. - object moving constant acceleration - object moving constant acceleration Remind learners about the vector nature of velocity + acceleration.
Key Idea D	**Key Idea E**	**Key Idea F**

3

2. Why is it important for learners to know this?

Key Idea A	Key Idea B	Key Idea C
- Identify - conclusions. - calculations	They need to be able to read interpret draw position/time and corresponding velocity/time graphs need to be able to describe the motion in words	need to be able to read interpret, draw velocity/time and corresponding acceleration time graphs need to be able to describe in words.
Key Idea D	**Key Idea E**	**Key Idea F**

4

3. What else do you know about this idea (that you do not intend learners to know yet)?

Key Idea A	Key Idea B	Key Idea C
	The gradient of a position time graph represents the velocity of the motion Area below a velocity-time graph represents the magnitude of the displacement → } * steeper the gradient - the greater the velocity	* The steeper the gradient the greater the acceleration velocity / time
Key Idea D	**Key Idea E**	**Key Idea F**

5

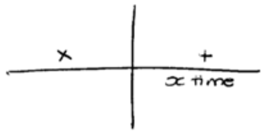
4. What are the difficulties/limitations connected with teaching this idea?

Key Idea A	Key Idea B	Key Idea C
	To construct an understanding of these graphs and to get to [learners] see how these graphs are related. is quite challenging. I think it is important to allow [learners] enough time to develop their own "mental model" Encourage them to actively participate. I found that if teacher / learner do the actual motion it brings the graphs to life! [learners] understand better. . . Hopefully	
Key Idea D	**Key Idea E**	**Key Idea F**

5. What is your knowledge about learners' thinking that influences your teaching of these ideas?

Key Idea A	Key Idea B	Key Idea C
	♀ find it hard to learn about Don't understand how / why Try to make the lesson fun make it real !!!!	things they can not see it is relevant to their lives. – actively involve ♀
Key Idea D	**Key Idea E**	**Key Idea F**

6. Are there any other factors that influence your teaching of these ideas?

Key Idea A	Key Idea B	Key Idea C
	* need to make ♀ aware that  Drawing graphs ≠ time	time can never be – –
Key Idea D	**Key Idea E**	**Key Idea F**

7. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key Idea A	Key Idea B	Key Idea C
	Tell them that graphs the best way to test understanding + ability to apply knowledge.	
Key Idea D	**Key Idea E**	**Key Idea F**

8. Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).

Key Idea A	Key Idea B	Key Idea C
	* Direction of motion " " Direction of velocity & acceleration not to be confused. * Repition.	
Key Idea D	**Key Idea E**	**Key Idea F**

Figure 4.1: Mrs VM's Content Representations

4.1.2 Analysis of the CoRes and the interview

Below follows the analysis of Mrs. VM's CoRe and her interview. The data are compared to the expert CoRe and graded in terms of the levels described in the TSPCK rubric.

Learners' prior knowledge

Mrs. VM revealed awareness of learners' misconceptions in their prior knowledge in both the CoRes and the interview. The misconceptions she identified were:

- Learners believed that time could be negative (Prompt Six, key idea B; Interview Question Three).
- Learners confused the direction of velocity and acceleration (prompt eight, key idea B).
- Learners did not distinguish between the direction of position and that of velocity. In the interview, she mentioned that "they [learners] find it difficult to indicate direction in terms of motion as they confuse it with position. When is it going east, what is going west?" (Interview Question Five). Fundamentally, this difficulty indicated poor distinction between displacement and velocity.

In comparison to the expert CoRe, the first difficulty is regarded as basic because it requires a simple basic agreement about when the clock starts, that is, where time equals zero and can therefore be easily dealt with. The last two difficulties that she indicated were of a conceptual nature, thus they were regarded as major misconceptions. These were also referred to in the expert CoRe (Prompt Five, key idea A and C). Although she explained the third misconception during the interview, she did not elaborate on the second misconception in the CoRe or the interview. This suggested that she did not regard it as important as the third misconception. In fact, it was not clear whether she was aware what the confusion between the direction of velocity and acceleration entails.

When comparing Mrs. VM's knowledge about learners' prior knowledge to the TSPCK rubric, it can be seen that the second level describes her knowledge about learners' misconceptions. Hence her competence in this TSPCK component was classified as basic.

Curricular saliency

The key ideas that Mrs. VM chose were: why do we use graphs, motion with a constant velocity and motion with a constant acceleration. The first key idea was also repeated in the interview when she said "firstly let them [learners] know why we are using graphs". She also indicated that "useful information can be deduced from graphs of motion" in her CoRe (Prompt One, key idea A). This information is deduced by learners when they identify [different graphs of motion], conclude and calculate [applicable variables] as she further indicated in her CoRe (Prompt Two, key idea A). Subsequently, this will enable them to read, interpret and construct graphs of motion (Prompt Two, key idea B and C). This information was also repeated and elaborated on in the interview (Interview Question One):

> *"A key concept especially for graphs of motion, they need to be able to draw, identify and use a graph to determine velocity speed acceleration and displacement…they must be able to draw velocity-time, position-time and acceleration-time and interpret. They must be able to draw and interpret."*

While elaborating on this information, she specified other key ideas referred to in the expert CoRe, namely; position-time, velocity-time and acceleration-time graphs. The sub-ordinate ideas (constant velocity and constant acceleration) for these key ideas (the graphs) were indicated as key ideas in her CoRe (key idea B and C). It cannot be concluded that the teacher understood that constant velocity and constant acceleration are special cases of motion, subordinate to the key ideas of graphs of motion.

Mrs. VM regarded gradient (of position-time and velocity-time graphs) and the area (under a velocity-time graph) as concepts that learners did not have to learn at this stage (Prompt Three, key idea B and C). The fact that she mentioned those concepts suggests that she was aware of their importance in the topic. She also specified that "the gradient of a position-time graph represents the velocity of the motion", "the area below a velocity-time graph represents the magnitude of the displacement" (Prompt Three, key idea B). It is however, not clear at which stage of the lesson learners should learn about gradient and area, because it seems that she considered teaching the different types of graphs of motion separately without involving them at this stage. Hence her knowledge about the interrelatedness between position-time, velocity-time and acceleration-time graphs was considered to be insufficient.

Mrs. VM's revealed knowledge about the importance of learning graphs of motion did not show understanding of the progression towards subsequent topics. In the interview, when asked about the importance of learning concepts (Interview Question Two), she said:

> *"For me more than a key idea it's about a skill. We're teaching them a skill…because graphs is part of science"*

The skill(s) that she was referring to, were that learners must be able to identify graphs, calculate necessary variables, construct graphs and interpret them. Inferring from the extract above, she was aware that graphs are applicable in other science topics, however, she did not specify those topics.

It was noticed that Mrs. VM was aware of the majority of concepts that should be presented in the topic, despite not mentioning instantaneous velocity. However, in her CoRe and interview not much was evident about her knowledge about organising and sequencing the concepts. When comparing her knowledge about the curricular saliency of this topic to the TSPCK rubric, it can be seen that the second level of competence, "basic", describes the knowledge.

What is difficult to teach?

Mrs. VM identified concepts or ideas that were difficult to teach in both the CoRes and the interview. In the CoRe, she mentioned that learners found it challenging to understand how graphs of motion were related to one another (Prompt Four, key idea B and C). The interrelatedness between graphs of motion was through gradient and area, the concepts that she regarded as those that learners should not learn yet. This suggests that her teaching approach, teaching graphs of motion separately, could be the reason why this difficulty prevailed. During the interview (Question Three), she specified another difficulty (which relates to the one mentioned in the CoRe; Prompt Four, key idea B and C) when she said:

> *"They [learners] find it difficult to know when is it a position-time when is it a velocity-time when is it an acceleration-time…they think that all the graphs show position-time… they find it difficult to see that the person is moving away from the point of origin, in what direction, is it with a constant velocity, is it with increasing or decreasing velocity?"*

This difficulty is also referred to in the expert CoRe (Prompt Four, key idea B), that is, learners find it difficult to interpret graphs of motion to correctly infer information because they regard them as position-time graphs.

It is noticed that Mrs. VM specified concepts that were problematic for learners without specifying the gate keeping concepts. When comparing Mrs. VM's knowledge about the concepts that learners find difficult in the topic to the TSPCK rubric, her competence was regarded as basic.

Representations including analogies

In her CoRe, Prompt Five, key idea B and C, Mrs. VM indicated that learners find it difficult to learn about phenomena they cannot see. Accordingly, she mentioned in the interview (Question Six) and the CoRe (Prompt Four, key idea B and C), that it is important to simulate motion by walking and to also let the learners walk according to the motion described by the graphs. As a confrontational strategy to learners' confusion of the direction of motion with the location (position) of an object (Question Five), Mrs. VM said:

> *"What I try and do is show them by walking that this is my point of origin, so even though I'm in the east side, I turn around and move direction west."*

This was aimed at showing learners that position and velocity did not necessarily have to be in the same direction; an object could, for example, be located to the east of a reference point and move either to the east or the west.

Mrs. VM mentioned "walking the graph" more than once and it is clear that she knew that this representation was useful to clarify learners' confusion between the directions of position and velocity. However, she did not mention any representations to clarify the related confusion between the directions of velocity and acceleration. With reference to the rubric and the expert CoRe, it was clear that the third level described Mrs. VM's competence about representations, therefore her knowledge about representations was classified as "developing".

Conceptual teaching strategies

It was apparent from Mrs. VM's CoRe that she considered gradient of a position-time graph and area under a velocity-time graph as concepts that should not have been discussed while teaching motion at constant velocity. This approach has potential to limit learners' understanding of the ways in which different graphs of motion are related to one another, which is one of the ideas that she identified as difficult for learners (Prompt Four, key idea B and C). Having indicated that learners had to develop a skill of calculating applicable variables in this topic, one might have concluded that Mrs.

VM taught learners how to use definitions (in terms of formulae) of displacement, velocity and acceleration to perform the calculations. Although the calculations, and the subsequent graphs will be correct, they will be based on pre-concepts rather than the new concepts that learners should learn. As a result, learners' conceptual understanding of the graphs of motion through gradient and area would be limited.

The teaching strategies that Mrs. VM specified in the CoRe and interview with regard to time (including a strategy to address the negative time misconception) were in agreement with one another. The teaching strategies that Mrs. VM suggested in the CoRe and her interview indicated that she sometimes relied on rote teaching. During the interview, she mentioned that "learners must be told that time will be measured on the x-axis [horizontal axis]" (Question Six). As a confrontational strategy to the negative time misconception, Mrs. VM said "[you] need to make learners aware that time cannot be negative" (Prompt Six, key idea B and C). She also indicated the necessary gate-keeping concepts (vectors and scalars) that could help her confront the negative time misconception, however she did not link those pre-concepts with time. She said "remind learners about the vector nature of position, velocity and acceleration". This information also suggested that she considered direct instruction, without a conceptual underpinning, as a strategy to explain some of the concepts in the topic because learners had to be reminded instead of being conceptually guided.

Mrs. VM indicated a strategy that she used to confront the confusion that learners had about the direction of position and velocity. This strategy entailed using a representation, which was to simulate by walking the motion of an object located to the east of the reference point and moving in the westerly direction. She also mentioned that she involved learners by requesting them to also simulate motion represented on the graphs by walking. This suggested that she knew a conceptual teaching strategy that incorporated representations and learner participation to support the teaching of some concepts.

The other difficulties and misconceptions were not accompanied by confrontational strategies. When she pointed out that learners conceptualised all graphs of motion as position-time graphs and thus interpreted them incorrectly, she mentioned that learners needed to read headings to be able to interpret graphs correctly. This strategy is rather a starting point towards addressing this difficulty and would not necessarily guarantee a conceptual development in the learners.

Mrs. VM's knowledge of conceptual teaching strategies, as compared to those indicated in the expert CoRe, was affected by the fact that she overlooked crucial ideas when specifying key ideas. Thus there was no clear indication of the development of learners' conceptual understanding of the topic through the ideas. Nevertheless, she mentioned one conceptual strategy that involved the representation of walking a graph. According to the TSPCK rubric, the second level of competence, "basic", best described her knowledge about the conceptual teaching strategies of this topic.

4.2 CASE STUDY 2 – MRS. SC

Mrs. SC is a physical sciences teacher who firstly studied BSc in Human Genetics and later studied a Post Graduate Certificate in science education (PGCE). She has been teaching physical sciences at Grade 10 level for three years, and at the time of the study she was teaching graphs of motion for the fourth consecutive year.

4.2.1 Data from the CoRe and the interview

Mrs. SC wrote her CoRes about general teaching strategies rather than the representation of the content specific to graphs of motion (see Figure 4.2 below). She also did not respond to Prompt Three and six, hence they are excluded in the Figure. During the interview, she shared information that was significantly different and much more detailed than the information that she had shared in her CoRe. Her full interview transcript is available in Appendix IV.

Section A

Think carefully about the way you teach Graphs of motion in Grade 10. List all the key ideas that you consider important in the teaching/learning of Graphs of motion.

Key idea A: Explain Graphs as a Math teacher

Key idea B: link x & y gradient to science concepts $\vec{v}, \vec{\Delta x}; t$

Key idea C: Give Summary

Key idea D: Practice, Practice, Practice

Key idea E: __________

Key idea F: __________

Key Idea G: __________

Key Idea H: __________

Key Idea I: __________

Key Idea J: __________

Key Idea K: __________

Key Idea L __________

Section B

Answer the following questions based on the Key ideas listed in Section A above.

1. What do you intend learners to learn about each of the ideas below?

Key Idea A	Key Idea B	Key Idea C
Revise on Previous knowledge. Link knowledge areas	Similarities between areas	Learn summary
Key Idea D	**Key Idea E**	**Key Idea F**
Practice to imprint a veriaty of questions		

2. Why is it important for learners to know this?

Key Idea A	Key Idea B	Key Idea C
· Basics are important	* Integration of subjects this is not new just different	* Revision to pick up links easy

Key Idea D	Key Idea E	Key Idea F
* Set the concept. Practice diff examples		

4. What are the difficulties/limitations connected with teaching this idea?

Key Idea A	Key Idea B	Key Idea C
Previous knowledge not always there	* Math not up to standard	* learners don't comprehend summaries

Key Idea D	Key Idea E	Key Idea F
* Learners lazy to practice		

5. What is your knowledge about learners' thinking that influences your teaching of these ideas?

Key Idea A	Key Idea B	Key Idea C
they can't remember previous work	Lazy ———	———
Key Idea D	**Key Idea E**	**Key Idea F**
———		

7. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key Idea A	Key Idea B	Key Idea C
A basic understanding of graphs will help more detailed explanation	• Show similarities of previous knowledge	• Show underding
Key Idea D	**Key Idea E**	**Key Idea F**
Understanding		

8. Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).

Key Idea A	Key Idea B	Key Idea C
Verbal assesment	Verbal assesment	Informal Class test

Key Idea D	Key Idea E	Key Idea F
Informal Class test Formal assesment		

Figure 4. 2: Mrs. SC's Content Representations

4.2.2 Analysis of the CoRe and the interview

Learners' prior knowledge

According to the information Mrs. SC shared in her CoRes (key idea B; Prompt One, key idea A; Prompt Two, key idea A, B and C; Prompt Four, key idea A and B; Prompt Five, key idea A; Prompt Seven, key idea A), she believed that learners' understanding of graphs from a mathematical point of view was the starting point to a successful understanding of this topic. However, in the responses to these prompts she did not reveal knowledge of how the prior knowledge affected their understanding of new concepts. It was only in the interview where she indicated difficulties in learners' prior knowledge (Question One), stating that:

> *"The moment I start teaching graphs, they [learners] don't know the difference between the x and the y-axis, how to read a value off the y-axis, how to read a value off the x-axis."*

She also added that:

> *"…the second thing I do is look at the gradient, explain to them what is the change in gradient, why is a straight line constant? Why is a parabola a change? Because I found that those as well confuse them…"*

The first difficulty that she identified was considered to be a basic mathematical skill and could be easily corrected. Learners could easily be convinced about axes and how to read values from them. The second difficulty possibly led to misconceptions and required adequate explanations to help learners understand the magnitudes and signs of gradients.

When comparing the difficulties that Mrs. SC identified to the TSPCK rubric, it was evident that she revealed a basic knowledge base about learners' prior knowledge. This was inferred from the fact that she mentioned learners' prior knowledge in mathematics only, without relating it to the key ideas in graphs of motion.

Curricular saliency

Section A of Mrs. SC's CoRes described only one key idea (B) from which information about her knowledge about curricular saliency can be deduced. The idea was "link x and y gradient to science concepts, change in position, velocity and time". The other ideas were teaching approaches: "explain graphs as a math teacher, give summaries, and practise". During the interview, she indicated other key ideas presented in the expert CoRe where she was responding to questions that were not necessarily exploring her understanding of key ideas of the topic. As a result, it cannot be concluded that she regarded them as key ideas. The ideas were; the three graphs of motion (Question Five), the area and gradients of the graphs of motion (Question Six). Mrs. SC repeated key idea B (link x and y gradient to science concepts, change in position, velocity and time) during the interview (question six) where she said:

> *"In math you say gradient equals $y_2 - y_1$ over $x_2 - x_1$. Then if you substitute that into your formula for gradient, they can immediately recognise the formulas that we used before we started graphs of motion."*

Although she did not directly specify the link between the gradient as a mathematical concept and the motion variables, the idea she was referring to is that velocity and acceleration are represented by the gradients of position-time and velocity-time graphs respectively. There were a number of other fundamental ideas that she did not mention, such as instantaneous and average velocity and the idea that they are represented by the gradient of a tangent and a secant to a curved position-time graph. She also did not indicate the idea that displacement is represented by the area under a velocity-time graph.

In the interview she indicated the sequence in which concepts should be taught, starting from a position-time graph, then velocity-time graph and subsequently acceleration-time graph. This sequence of teaching the graphs was indicated as she mentioned that learners found it difficult to understand how data was inferred from one graph and used to construct the corresponding graphs representing other variables (question four):

> *"If you jump from one part of the graph to the other, like for example your position-time to your velocity, or velocity-time to acceleration. Those linkages confuse them a lot. Because now you jump from a constant like to a horizontal line."*

She also indicated that she presented a summary that helped learners remember whether to infer data by calculating either gradient or area of the graphs. Although the sequence included reference to area and gradient, the absence of sub-ordinate ideas limited the researcher's insight in understanding how she explained the relevance of gradient and area in this topic.

Mrs. SC revealed a limited understanding of the importance of graphs of motion in relation to other topics. She mentioned that understanding graphs [of motion] would help learners communicate with the diversity of people in the world. She however did not specify the ideas that would be communicated and how those ideas would be communicated.

> *"It is very diverse, you don't have to understand the language to be able to understand the graph. So I think the basics of setting up graphs and understanding how a graph works, can in any job line enhance communication between any kinds of people, especially in the world we live in today" (Question Three)*

Although Mrs. SC mentioned the importance of graphs of motion in real life, she did not show progression towards understanding other concepts in line with this topic.

Mrs. SC's knowledge base about curricular saliency, when compared to the TSPCK rubric, was regarded as basic. Although she indicated a majority of the key ideas of this topic, she did not explicitly present them as key ideas. Furthermore, sub-ordinate ideas were absent, thus, although she indicated a logical sequence of teaching the key ideas, she did not indicate the interrelatedness between them.

What is difficult to teach?

Although Mrs. SC did not identify concepts or ideas in the CoRes that were difficult for learners to understand, she indicated such concepts in the interview (Question Four). She mentioned that:

> *"They [learners] don't understand how to calculate the gradient. If I show them this is point x, y that is point x, y then they can do it, but linking that to the science part they struggle with it."*

The point she was trying to get across was that learners found it difficult to calculate gradients of graphs of motion and to recognise the physical quantities that were represented by the gradients. She was not specific about the variables substituted in the formula for gradient and the variables represented by the subsequent formulae that emerged. She specified another difficulty (Question Four), stating that:

> *"I found that when your graph doesn't start at zero, they get completely confused on what values to use when calculating the area. They can't see that it's a square, rectangle or a triangle, they can't fit those shapes together."*

Although Mrs. SC did not specifically link this difficulty with displacement, as the area and a velocity-time graph, it was well known that learners find it difficult to calculate displacement through the area of complex shapes under a velocity-time graph. This difficulty is referred to in the expert CoRe (Prompt Four, key idea F). Mrs. SC also specified a difficulty that appeared to be perpetuated by the previous difficulties that she identified, although she did not explicitly state it herself (Question Four). She said:

> *"If you jump from one part of the graph to the other, like for example your position-time to your velocity, or velocity-time to acceleration. Those linkages confuse them a lot. Because now you jump from a constant like to a horizontal line."*

If learners find it difficult to calculate gradient and area, they will ultimately find it difficult to infer data and use it to construct corresponding graphs.

Her knowledge about concepts that are difficult, compared to the TSPCK rubric, suggested that her competence about this component was basic. She identified difficulties without clarifying them because the corresponding sub-ordinate ideas were absent.

Representations including analogies

Although Mrs. SC did not specify representations that she incorporated to support the explanation of graphs of motion concepts when she wrote her CoRes, she discussed them in the interview. Having said that learners found it difficult to calculate the area of complex shapes under a velocity-time graph, she also specified a strategy that she would use to confront the difficulty (Question Four). She said:

> *"…start with the shapes say "ok, in this shape what is the area. How do you measure the area, how do you measure certain things in this shape"…"*

Although her response is still vague and does not explicitly indicate how those shapes will help learners calculate the area, it seems that her intention is to help learners divide complex shapes (for example a trapezium) into simpler shapes (square, rectangle and a triangle), when calculating displacement. This strategy is suggested in the expert CoRe (Prompt Five, key idea F). The other representation identified is the ticker-timer experiment (Question Five):

> *"At this stage we do the ticker timer experiment, to indicate the change in the graph. But the problem is still that linkage from data to a graph, they struggle with that immensely. At this stage I haven't figured out a visual representation on how to show a pattern and how the pattern works."*

Notice that she also mentioned that she had not identified a representation that supported the teaching of this topic. This could suggest that she considered the representations that she specified as insufficient. In fact there was not enough evidence about how she used ticker-timers to help learners understand graphs of motion.

The use of two representations that Mrs. SC discussed in the interview were inadequately described and as a result, her understanding of representations and how they support concepts in graphs of motion was regarded as basic.

Conceptual teaching strategies

The way Mrs. SC teaches this topic, as explained in the interview, is to begin by teaching the necessary pre-concepts of mathematics, aiming at filling the gaps and confronting the difficulties in the prior knowledge that she identified. In her response to question one, Mrs. SC said:

> *"…I immediately go to the maths part before I even start looking at the physical quantities of velocity and acceleration".*

She later revealed the same strategy and elaborated on it when she responded to Question Six:

> *"I basically start from the math part, the basic maths graphs. I always tell them "remember, science is just math that makes sense", so basically your maths gives you an unknown. It gives you x and y values whereas in science we give meaning to x and y"*

Paying attention to mathematics concepts could have enable her to explain to learners that a straight line graph has a constant gradient and a curved graph has a changing gradient. As indicated previously, she mentioned that substituting variables in the formula for gradient leads to formulae (velocity and acceleration) that learners know from their prior knowledge of kinematics. She also mentioned that:

> *"I think because you can clearly show the change in a graph, they more easily understand the definitions because they can see the time changing and they can see the velocity changing, so there must be acceleration (Question One)."*

This extract suggests that she explains the link between acceleration and a velocity-time graph. She however, did not make any reference to the fact that the acceleration was represented by the gradient of the velocity-time graph. As it was indicated earlier that, although Mrs. SC mentioned important key ideas, she omitted a large number of sub-ordinate ideas, hence there was not enough information about how she conceptually developed learners' understanding of the topic. There was however evidence of her awareness about the sequence in which ideas should be presented: position-time graph, velocity-time graph and acceleration-time graph, including area and gradient when shifting from one graph to the next. There was just not enough information about how she explained the interrelatedness between these ideas. Having indicated that learners find it difficult to infer data from one graph and use it to construct another, as a strategy to address this difficulty, she said (Question Five):

> *"There are two things that I teach them, that's basically writing "p", then underneath it a "v" and underneath it an "a" and show them if you go one direction you use the gradient and if you go the other direction you use the area. But that is just the basic summary to help them to know when to use a gradient on a graph and when to use the area of a graph"*

This description suggests the development of a diagram that will help learners to remember whether gradient or area should be calculated to determine a required value. She however did not mention how she helped them understand how gradient and area were calculated, but rather the cases in which they should use them to infer data. It would be rather unfortunate if learners were shown when to calculate gradient and area, but not how to, especially if the significance of the calculations was also not explained.

There was information about how Mrs. SC thought she could conceptually develop learners' ability to calculate displacement, the area under a velocity-time graph, through a representation (shapes). Although she was aware of another representation (ticker timer experiment), she did not elaborate on how she developed learners' understanding of concepts through this representation.

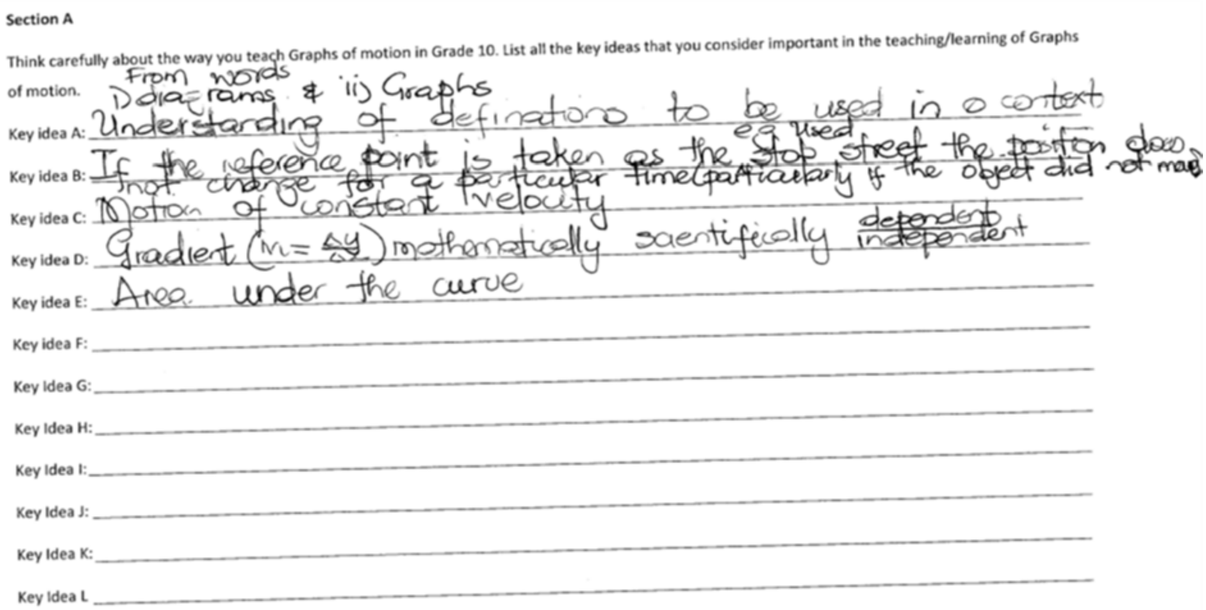
Mrs. SC's knowledge base about the strategies of teaching this topic was regarded as "basic". This was because she indicated a number of key ideas in the topic without specifying how she conceptually developed learners' understanding of the ideas, especially how they were interrelated.

4.3 CASE STUDY 3 – MISS. MH

Miss. MH is a physical sciences teacher who holds a higher diploma in science education. She has been teaching physical sciences at Grade 10 level for five years. At the time of this study she was teaching graphs of motion for the six consecutive year.

4.3.1 Data from the CoRe and the interview

It was noticed that Miss. MH wrote her CoRes referring mostly to concepts related to motion at constant velocity. The CoRes are shown in Figure 4.3. Prompt Six was excluded from Figure 4.3 because Miss. MH did not complete that section of the CoRe. During the interview, she responded to questions without limiting herself to motion at constant velocity. Her full interview transcripts are available in Appendix IV.


Section A

Think carefully about the way you teach Graphs of motion in Grade 10. List all the key ideas that you consider important in the teaching/learning of Graphs of motion.

Key idea A: Understanding of definations to be used in a context (From words i) Diagrams & ii) Graphs)

Key idea B: If the reference point is taken as the stop street (eg used) the position does not change for a particular time (particularly if the object did not move)

Key idea C: Motion of constant velocity

Key idea D: Gradient ($m = \frac{\Delta y}{\Delta x}$) mathematically scientifically dependent independent

Key idea E: Area under the curve

Key idea F:

Key Idea G:

Key Idea H:

Key Idea I:

Key Idea J:

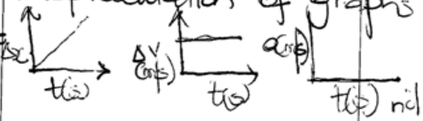
Key Idea K:

Key Idea L

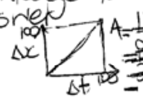
Section B

Answer the following questions based on the Key ideas listed in Section A above.

1. What do you intend learners to learn about each of the ideas below?

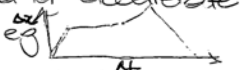
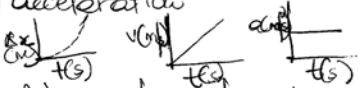
Key Idea A	Key Idea B	Key Idea C
What does a stationary object represent Graphically * The graphs indicate ~~that~~ the object is not moving for a particular time ∴ The velocity is nil & also acceleration is nil	* Importance of identifying the reference point to be able to represent the information graphically eg Assume Vivian takes 100s to walk 100m to the taxi stop every morning	* What does constant velocity mean * Representation of graphs 
Key Idea D	**Key Idea E**	**Key Idea F**
* linking of Mathematics to Physical Science moving from Known to unknown Gradient $m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{x_2 - x_1 \text{(dependent)}}{t_2 - t_1 \text{(independent)}}$ * To be able to link their Knowledge of info in other subjects with their Science successfully	* The gradient of position time graph give result to something (Area under the curve at the same time it makes the mathematical shape trapeze	

2. Why is it important for learners to know this?

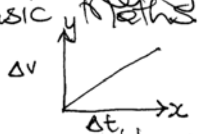
Key Idea A	Key Idea B	Key Idea C
* The definition of velocity is $\frac{\text{change in } x}{\text{change in } t}$ ∴ The objects position did not change it will be eg $V = \frac{2-2}{120} = \frac{0}{120} = 0\,m/s$ The distance of an object is the length of path travelled from start to finish	* To be able to recognise that we are dealing with Vectors & Scalars * There is a need to identify the origin and direction to re-present the info graphically * What does the statement imply ie Vivian walks 1m for each and every second	* To know that the position of an object is changing at the same rate * The constant velocity graphs produces nil acceleration though the position time graph produces constant (same gradient) * From the Δx/t graph the gradient can be calculated.
Key Idea D	**Key Idea E**	**Key Idea F**
* The gradient of x/t graph gives velocity * The gradient of v/t graph gives acceleration	* If the do not know how to calculate the position they can use their maths knowledge to find/get the answer e.g  $A = \frac{1}{2} b \times h$ (triangle) = ~~[illegible]~~ ×100 / 2 eg  A = l×b (rectangle) This ~~produces~~ (gives) displacement * Area under a/t graph ~~produces~~ (gives) velocity	

4

3. What else do you know about this idea (that you do not intend learners to know yet)?

Key Idea A	Key Idea B	Key Idea C
That the total distance covered, starting from rest is proportional to the square of the time	For now we used positive direction but its not always that an object will (increase) or travel in the positive direction always nor move at constant speed.	*That an object can be constant, accelerate, stop and decellerate eg  *That it will produce different v/t graph & also a/t graph.
Key Idea D	**Key Idea E**	**Key Idea F**
Motion with constant acceleration  *We must first get the tangent to the curve.	The total displacement of the object is just the sum of all these area's (AREA UNDER THE CURVE)	

4. What are the difficulties/limitations connected with teaching this idea?

Key Idea A	Key Idea B	Key Idea C
The learners might grasp the concept of constant not not moving in words but to represent it graphically might be challenging even the language might be the huge barrier, comprehension of info.	Miss understanding of starting point like Vivian is walking to the shop reference to the the library such might be problematic even deciding the direction	
Key Idea D	**Key Idea E**	**Key Idea F**
The is an application of Mathematics, It is therefore difficult to deal with this particularly with learners who are struggling with their basic Maths eg  $\frac{\Delta y}{\Delta x} = \frac{\Delta v}{\Delta t} = \frac{V_f - V_i}{t_f - t_i}$ Some might not be able to link it to their Maths.	*Identifying area under the curve might be easy to most but calculating either scientifically nor using basic maths its a challenge some cant even identify the shapes (Mathematical shapes) even recall their formulae). * Square * Rectangle * Triangle * Trapezium	

5. What is your knowledge about learners' thinking that influences your teaching of these ideas?

Key Idea A	Key Idea B	Key Idea C
That the pre-knowledge of word ~~pro~~ definition and understanding plus application of it.	To always to ~~con~~ take the reference point into consideration therefore the direction will be clearly indicated and identification as whether is + or − acceleration.	That constant velocity moves 1 step at a particular time eg 50m will take ~~50~~s from one place to the other.
Key Idea D	**Key Idea E**	**Key Idea F**
From their Maths they know the application of Gradient and calculating it, it makes it easy to link it with Physical Science although some might confuse x_f x_i as the x intercept.	Their pre-knowledge of shapes & calculating of area from Mathematics nor previous grades.	

7. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key Idea A	Key Idea B	Key Idea C
		The use of a ticker timer, sometimes or mostly mis-understood when it comes to interpretation of the ticker tape and failure to calculate the velocity & acceleration because of miscalculation of displacement.
Key Idea D	**Key Idea E**	**Key Idea F**

8. Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).

Key Idea A	Key Idea B	Key Idea C
Key Idea D	**Key Idea E**	**Key Idea F**
	Equations of Motion might help to solve the misconception & confusion, although Maths skill might be a problem.	

Figure 4.3a: Miss MH's Content Representations

4.3.2 Analysis of the CoRes and the interview

The analysis of Miss. MH's CoRe and her interview follows below. The data are compared to the expert CoRe and graded in terms of the levels described in the TSPCK rubric.

Learners' prior knowledge

When prompted in the CoRe (Prompt Five) about learners' prior knowledge and learners' thinking, Miss. MH focused predominantly on the prior knowledge that should be in place but did not mention common misconceptions that she has encountered. During the interview (Question Four), Miss. MH seemed to have an understanding of the misconception about negative acceleration specified in the expert CoRe (Prompt Five, key idea C). She said:

> *"…if you say to them "deceleration", they do not understand that. Because they always think that "Aowa [no] a car has an accelerator so a car accelerates only" until you have to explain that [if] a car can stop, then a car can reduce speed."*

Closer inspection of the data, however, revealed that she possessed a misconception about negative acceleration. She revealed this misconception in Prompt Three, key idea C (see Figure 4.3b below) when she wrote down the concepts that learners did not have to learn yet. She said "… [learners do not need to learn yet that] an object can be constant, accelerate, stop and decelerate". She also constructed a position-time graph in the Figure below as an example to support her statement.

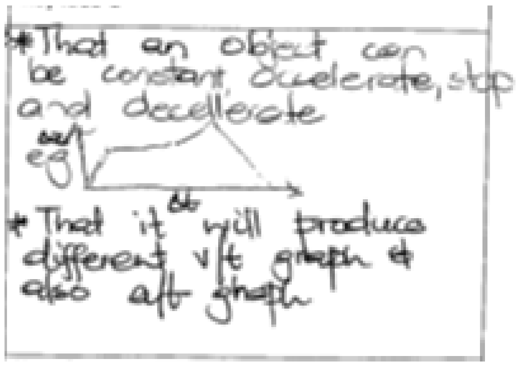


Figure 4.3b: Miss. MH's CoRe (Prompt three, key idea C)

The first three sections of the graph were described correctly whereas the last one revealed her misconception about negative acceleration. According to the graph, the object starts off at a constant velocity, then it accelerates and stops momentarily, which correctly matches her description. However, she said the object then decelerates, whereas the graph shows that the object is now moving at a constant velocity in the negative direction towards its starting point. This suggests that she believed that if an object is "decelerating", then it is moving towards its starting point.

The fact that Miss. MH revealed her own misconception when she attempted to describe that of the learners, suggested that she was not aware what the actual misconception entailed. When comparing Miss. MH's knowledge about learners' misconceptions to the TSPCK rubric, it can be seen that the first level of competence, "limited" best describes her knowledge.

Curricular saliency

The way Miss. MH organised and presented ideas about this component in the CoRe, was coherent. Some of the key ideas that she specified, namely gradient and area under the curve (key idea D and E), were similar to those referred to in the expert CoRe (Key idea D, E and F). She also indicated their sub-ordinate ideas, stating that; the gradient of a position-time and velocity-time graphs represent velocity and acceleration respectively (Prompt Two, key idea D). Furthermore, she mentioned that the area under a velocity-time graph represents displacement (Prompt Two, key idea E). During the interview, Miss. MH presented pre-concepts as key ideas, including "definitions" that she had also presented as a key idea (A) in her CoRe. The other pre-concepts that she presented as key ideas were; understanding reference points (key idea B), understanding the difference between a scalar and a vector, understanding position, displacement, velocity and acceleration (interview Question One).

It was also noticed that she considered "motion at constant velocity" to be a key idea (C) in her CoRe, which was regarded as a sub-ordinate idea in the expert CoRe. After careful analysis of her CoRe, it was found that she wrote her CoRes based on graphs indicating stationery objects and objects moving at constant velocities. Thus there was a valid reason why she considered learners' understanding of constant velocity as important in this section of the topic. Having said that her CoRe was limited to specific cases, she explicitly indicated the concepts that learners did not have to learn yet as they are related to acceleration (CoRe Prompt Three). During the interview however, she included hyperbolic functions, a concept that is not applicable to the topic. In response to Question Four in her interview, she said:

> *"…teaching them [learners] graphs from their maths knowledge will be best. If they know a linear graph, a hyperbola graph…"*

Miss. MH sequenced key ideas adequately in her CoRes and indicated how they were interrelated with each other, and with their corresponding sub-ordinate ideas. She indicated the importance of understanding how the three types of graphs of motion represent the state of rest (Prompt Two, key idea A), moving at a constant velocity (Prompt Two, key idea C) and acceleration (Prompt Three, key idea D). She also indicated the interrelatedness between the three graphs of motion with regard to the states of the motion in the same prompt, key idea D and E, where she explicitly outlined the importance of gradient or area.

In response to why it is important for learners to know these key ideas, she did not reveal any understanding of sequencing and scaffolding towards other topics, but only referred to the sub-ordinate ideas as such. During the interview, she still did not reveal any realisation of the significance of the topic towards scaffolding to subsequent ideas:

> *"For example, the importance of teaching a learner the area under a curve is to know the shortest distance, even if there's the longest route, but what is the shortest distance actually? What is the displacement in this?"*

Although she attempted to relate this topic with everyday life, what she related it to is impractical. Learning about distance and area is important for the purpose of learning this topic, however, the way she presented it did not show any progression to other topics.

According to the assessment criteria, Miss. MH's competence about the curricular saliency of this topic was classified as "basic". Although in her CoRes she adequately sequenced key ideas and also provided explanations of the interrelatedness between the ideas, her interview revealed aspects of poor PCK in terms of this component.

What is difficult to teach?

Miss. MH specified learners' difficulties in the topic, and contradicted herself in the process. She mentioned that learners find it difficult to represent the state of rest graphically (Prompt Four, key idea A) – an idea that was considered to be elementary and could easily be corrected. She contradicted herself during the interview when she said "I think drawing graphs is easy but interpreting them is difficult".

The other concepts that Miss. MH identified as difficult were:

- Learners found it difficult to denote reference points, as a result they found it difficult to indicate direction based on the points (Prompt Four, key idea B).
- Learners found it difficult to identify shapes under a velocity-time graph and subsequently they found it difficult to calculate their areas (Prompt Four, key idea E; question three).
- Learners thought that all graphs of motion represent motion at constant velocity.

The third difficulty was also mentioned in the interview where she said:

> *"The misconception that they have is that a graph will always be constant. They don't anticipate that an object cannot move with the same speed always"*

The fact that she wrote her CoRe based on motion at constant velocity suggested that she was comfortable teaching graphs of motion under this condition. Furthermore, it suggested that she spent most of her time explaining graphs of motion under these conditions which could have resulted in less emphasis being put on graphs of accelerated motion. Hence learners end up conceptualising all graphs of motion as representing motion at the same velocity.

The limiting factors that Miss. MH indicated for some of the above difficulties were; learners' proficiency in the language of instruction (Prompt Four, key idea A) and that their understanding of mathematics concepts was poor (Prompt Four, key idea D;

question three). These gate-keeping ideas were rather broad and general to teaching as they were not specifically linked to this topic.

Taking into account that Miss. MH identified a basic difficult concept, and contradicted herself and outlined general reasons to some of the difficulties, her competence according to the TSPCK rubric was classified as “basic”.

Representations including analogies

Miss. MH specified a representation (ticker timer experiment) that supported explanations of concepts in the topic in the CoRe (Prompt Seven, key idea C) and the interview (question six):

> *“In most cases I use a ticker timer, that’s the only thing... From the ticker, if they are able to calculate velocity and acceleration from the ticker timer, they would be able to draw a velocity-time graph, acceleration-time graph and even displacement-time graph”*

Despite saying that the experiment was the only representation that she used, as she continued with her interview she added simulations and videos found on the internet as other representations. However, she did not explain how simulations and videos helped support the teaching of concepts in the topic. The way she discussed how ticker timer experiments supported the teaching of this topic differed in the CoRe and the interview. In the CoRe, it appeared that she understood that displacement is the first variable to be determined from the data on the ticker tape, followed by calculations of velocity and acceleration. In the interview however, she mentioned that velocity was the first variable calculated form the data obtained, then acceleration. This data could then be used to construct graphs in the same order in which it was calculated. The way she approached the concept of displacement in this experiment seemed as if it only followed after the graphs of velocity and acceleration had been constructed (Question Six). Furthermore, she did not indicate how the variables were calculated and used to construct the graphs.

Although she was aware that the ticker-timer is a suitable representation to support concepts in this topic, she did not outline how the representation worked. When comparing her knowledge about representations in this topic to the rubric, it can be seen that the second level of competence describes her knowledge. Hence her competence in this component was regarded as “basic”.

Conceptual teaching strategies

Miss. MH regarded presenting the topic of graphs of motion from a mathematical perspective as a strategy that enhanced learners' understanding of the topic. During the interview she mentioned that if graphs of motion concepts were presented without reference to pre-concepts in mathematics, then learners often found it difficult to conceptually understand the concepts (Question Five):

> *"In most cases I firstly teach them the basics, what is area. But I think teaching them graphs from their maths knowledge will be best… when you just shoot straight for physical sciences you lose learners."*

However, the pre-concepts of mathematics that she specified included hyperbolic functions, which are not related to graphs of motion. This suggested that her content knowledge was not developed to a level that would have enabled her to realise that this pre-concept was not applicable to the topic. Miss. MH also indicated how new ideas develop from pre-concepts. She presented gradient in a general form, that is; the dependent variable divided by the independent variable (Prompt One, key idea D), indicating that new concepts will develop from it by substituting necessary variables. In the interview, she specified these concepts, saying (question five):

> *"I normally ask them the basics, like what is…from the graph, I would normally phrase it "find the gradient", then if they labelled the graph correctly, then I would say use your y-intercept and your x-intercept and form that scientifically, what is the gradient. For example if the y-intercept is displacement and the x-intercept is time then that will give them velocity."*

The part where she says "if they labelled the graph correctly" suggests that she involves learners by letting them construct graphs on their own. Furthermore, the correctness of the labels of their axes indicates their understanding of the variables represented by the gradients of the graphs.

The sequence in which concepts should be presented was adequate in Miss. MH's CoRe, but illogical in the interview. This was revealed when she specified another strategy, a representation that conceptually developed learners' understanding of concepts. She said:

> *"In most cases I use a ticker timer, that's the only thing. From the ticker timer, if they are able to calculate velocity and acceleration from the ticker timer, they would be able to draw a velocity-time graph, acceleration-time graph and even displacement-time graph."*

Before velocity and acceleration can be calculated, the displacement of the trolley must be found by measuring the distances between the dots. However, the way Miss.

MH explained how she used a ticker timer suggested that displacement was only determined after velocity and acceleration had been calculated. She also said "I start with a theory, then I go to the practical", suggesting that she incorporated representations after graphs of motion concepts have been explained. Judging by the nature of this topic, a ticker timer is a representation that should be used while graphs of motion are constructed, as it yields data that must be used to construct the graphs. When comparing Miss. MH's knowledge about strategies to teach this topic to the TSPCK rubric, it can be seen that the second level of competence (basic) describes her knowledge.

4.4 CASE STUDY 4 – MR. KZ

Mr. KZ is a physical sciences teacher who holds a B.Ed degree in science education. He has been teaching physical sciences at Grade 10 level for three years. At the time of this study he was teaching graphs of motion for the fourth consecutive year.

4.4.1 Data from the CoRes and interview

Mr. KZ's CoRes were not completed in full, the first four prompts were answered but the last four were not. Hence only the CoRe prompts that were completed are included in Figure 4.4a. As a result, his interview focused primarily on the information which could not be inferred from the CoRe. His interview transcript is available in Appendix IV

Section A

Think carefully about the way you teach Graphs of motion in Grade 10. List all the key ideas that you consider important in the teaching/learning of Graphs of motion.

Key idea A: START of BY TEACHING THE STRAIGHT LINE GRAPH.

Key idea B: HOW TO CALCULATE THE GRADIENT, AND THE AREA.

Key idea C: TEACH THE four LINES POSITIVE GRADIENT, NEGATIVE, ZERO & UNDEFINED

Key idea D: EXPLAIN THE MEANING of A NEGATIVE SIGN (DIRECTION)

Key idea E: THE Diff BETWEEN ONE DIMENSION, TWO DIMENSION & THREE D.

Key idea F: EXPLAIN THE CARTESIAN PLANE, (INDEPENDENT & DEPENDANT)

Key Idea G: - DETERMINE THE DISPLACEMENT of AN OBJECT BY FINDING THE

Key Idea H: AREA UNDER A VELOCITY-TIME GRAPH

Key Idea I: DERMINE THE ACCELERATION OF AN OBJECT BY FINDING THE (slope) V-t

Key Idea J: INFORMATION on A position time graph

Key Idea K: " VELOCITY

Key Idea L " acceleration

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Section B

Answer the following questions based on the Key ideas listed in Section A above.

1. What do you intend learners to learn about each of the ideas below?

Key Idea A	Key Idea B	Key Idea C
* FINDING THE VELOCITY & acceleration by finding the slope $a = \frac{\Delta V}{\Delta t}$ $V = \frac{\Delta x}{\Delta t}$ $m = \frac{y_2 - y_1}{x_2 - x_1}$	THE SIGN- positive slope & negative slope. THE SIGN IS JUST to show the direction.	Negative Velocity Represent a choice of direction. Negative acceleration the object is accelerating in the opposite direction of motion.
Key Idea D	**Key Idea E**	**Key Idea F**
IN ONE DIMENSION There is only one way in which an object can change the direction: forward backward up and down.	describe THE MOTION of an object. Direction of motion acceleration, velocity.	How to draw a corresponding displacement - time velocity- time and acceleration time

3

2. Why is it important for learners to know this?

Key Idea A	Key Idea B	Key Idea C
Because LEARNERS NEED TO KNOW THA CHANGE in y IS THE same as change in the DEPENDENT VARIABLE	LEARNERS NEED TO KNOW THA QUANTITIES CANNOT BE NEGATIVE. NEGATIVE IS MAINLY FOR DIRECTION.	If LEARNERS DO NOT KNOW THE DIMENSIONS THE WON'T KNOW THA IS ONLY IN ONE DIMENSION WHERE AN OBJECT NEED TO STOP - WHEN CHANGING DIRECTION
Key Idea D	**Key Idea E**	**Key Idea F**
By looking or studying the graph need to know how to describe the motion of an object.	NEED TO KNOW HOW TO USE THE INFORMATION TO DRAW THE REQUIRED GRAPH.	How to work form position to velocity and from velocity to acceleration. Work back words by calculating the area under the graph

4

3. What else do you know about this idea (that you do not intend learners to know yet)?

Key Idea A	Key Idea B	Key Idea C
The fine position time graph is in fact a parabolic graph. where we have a constant acceleration	and that the velocity is instantaneous.	
Key Idea D	**Key Idea E**	**Key Idea F**
that $\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$ $f(x) = ax^2 + bx + c$ $v_f = a\Delta t + v_i$ $y = mx + c$ It easy doing this was. but only in grade 12.		

5

4. What are the difficulties/limitations connected with teaching this idea?

Key Idea A	Key Idea B	Key Idea C
To limited. Restricted to use very few examples and information on the graphs of motion.		
Key Idea D	**Key Idea E**	**Key Idea F**

6

Figure 4.4a: Mr. KZ's Content Representations

4.4.2 Analysis of the CoRes and interview

Learners' prior knowledge

Mr. KZ did not indicate learners' misconceptions about this topic in the CoRes but referred to them in the interview (Question One), when he stated that:

> *"So if I have one dimension, if I were moving east, changing direction means I'm now moving west. In one dimension it is impossible to change direction in one dimension without stopping but in other dimensions an object can change without stopping, for example when a car curves, it changes direction but doesn't stop…Learners find difficult to understand this because they see objects in everyday life changing direction without stopping."*

According to what Mr. KZ said, learners believed that an object moving in a straight line (one dimension) could change direction without stopping. He also specified the factors that perpetuated this misconception – a lack of understanding of dimensions, and seeing objects changing directions without stopping. He also mentioned another misconception, where he said:

> *"Velocity goes with motion, if you say to the left it means the object is going to the left, but with acceleration, it can be against motion or reinforce motion …learners confuse direction of velocity and acceleration… [they don't understand that] if I have a negative acceleration it means the object will at some point stop and if the acceleration is positive, the object will go forever."*

According to this quote, learners find it difficult to understand that if velocity and acceleration are in the same direction the object speeds up, and if velocity and acceleration are in opposite directions then the object slows down to a stop. However, the way Mr. KZ presented this misconception suggested that objects with a negative acceleration slowed down to a stop regardless of the direction of motion. Presenting this concept this way could potentially induce the misconception specified in the expert CoRe (Prompt Five, key idea C) – learners would think that negative acceleration, regardless of the direction of motion, results in objects slowing down to a stop.

The misconceptions that Mr. KZ specified are regarded as major. When comparing Mr. KZ's knowledge about learners' misconception to the TSPCK rubric, it can be seen that the third level of competence describes his knowledge, despite the fact that he presented the misconception about the direction of velocity and acceleration poorly.

Curricular saliency

Mr. KZ chose key ideas similar to the ideas indicated in the expert CoRe. However, his key ideas were also mixed with pre-concepts and sub-ordinate ideas. The first six ideas (A – F) he indicated in the CoRe could be regarded as pre-concepts. Amongst those pre-concepts, he indicated direction (key idea D), which is regarded as a sub-ordinate idea for Mr. KZ's last three key ideas (J – L) in the exprt CoRe. During the interview Mr. KZ outlined a logical sequence of the key ideas and their interrelatedness with each other and with their corresponding sub-ordinate ideas. He mentioned that the gradient of a position-time graph represents velocity:

> *"Velocity is the rate of change of position, so when we look at our graph, y [vertical axis] represents position and x [horizontal axis] represents time, the gradient that I will have for a position-time graph is gonna give me velocity."*

He presented the same idea with reference to acceleration in key idea I. He also indicated in key idea H that the area under a velocity-time graph represents displacement.

Mr. KZ's understanding about sequencing and scaffolding of ideas in the topic could be elicited from his responses. In Prompt Two and in the interview, Mr. KZ did not reveal knowledge about how graphs of motion concepts enabled learners to understand subsequent related concepts in other topics. In response to Question One in the interview, Mr. KZ indicated the importance of pre-concepts in helping learners understand graphs of motion:

> *"In Maths y and x represent variables. X can represent number of people, animals and now in physics we change x and y in variables that learners need to know, for example x is always time and y is position, velocity or acceleration."*

He also indicated that learners' understanding of gradients of straight lines from a mathematical point of view enabled them to understand that the variable (for example velocity) represented by the gradient of a graph (position-time graph) stays constant if the graph is a straight line (interview Question One).

It was also noticed that Mr. KZ, when prompted about concepts that learners did not have to learn yet, specified concepts that were related to the topic. He mentioned that area was related to integration in calculus, which learners at Grade 10 level were not expected to know yet (interview question one). He also mentioned that graphs of motion were related to functions taught in mathematics which learners would only learn when they reached Grade 12 level (Prompt Three). However, Mr. KZ presented Newton's second law, a concept that learners at Grade 10 level were not expected to know yet, as a concept that helped him confront one of the misconceptions that he identified. Having mentioned that learners did not understand the implications of velocity and acceleration being in the same or opposite directions, he suggested a strategy to address that difficulty, where he said:

> *"If my car is slowing down, that means the net force in the car is applied in the opposite direction, so the motion must be overcome and the object must come to rest, so if it is negative, it means the acceleration is against motion but if it is positive it means the object is speeding up." (Question One)*

Although this explanation is correct for motion in the positive direction, the fact that it involves net force limits its effectiveness. Learners at Grade 10 level were not expected to learn about net forces as these were presented at Grade 11 level (CAPS, 2011).

When comparing Mr. KZ's knowledge about curricular saliency to the TSPCK rubric, it could be seen that the third level described his competence. Although some of the information he revealed was inadequate, the key ideas that he chose, the importance of pre-concepts in the topic, the sequencing and the interrelatedness of concepts, as well as the concepts that should and shouldn't be learnt yet were the reasons why his competence was regarded as developing.

What is difficult to teach?

As indicated by Mr. KZ in the interview (Question Four), learners found it difficult to interpret graphs:

> *"Learners tend to look at the shape of the graph…it's not only the shape, the shape won't just tell you everything…for example if you give a learner a graph…from zero and the gradient is positive, you ask them is the car speeding up or slowing down, learners will just say the car is speeding up, they don't even know if it's a position-time graph, it's velocity-time graph, it's acceleration-time graph."*

He also specified some of the features of graphs of motion that learners interpreted incorrectly, that is, as long as there was an increase in a graph, learners considered it to be an increase in velocity. This is similar to one of the difficulties referred to in the expert CoRe (Prompt Four, key idea B).

He also mentioned another difficulty:

> *"[learners do not that understand that] If I have a velocity-time graph, if a line cuts the x axis, this means the object has stopped and moved backwards (in the opposite direction)".*

For this difficulty Mr. KZ indicated a gate keeping concept – learners at FET level did not understand the significance of dimensions, thus they did not understand that an object moving in one dimension had to stop (have zero velocity) it could change direction.

Mr. KZ also revealed a misunderstanding that could potentially be induced by learning materials based on the way they presented information. He said:

> *"Area, I want to correct this, the book says it's the area under the graph but when I was doing it I found that it's not the area under the graph but the area between the graph and the x-axis"*

His argument was that referring to the area "under" a velocity-time graph could mislead learners, the idea should rather be presented as the area between the graph and the horizontal axis. This is because if the velocity-time graph was constructed below the horizontal axis, learners would not be aware that the area should now be calculated "above" the graph, as he further stated.

Mr. KZ's argument about the concept of area "under" a velocity-time graph showed that he was aware of the possibilities that the ways in which information was presented, could have led to incorrect interpretations. Based on that and the difficulties he indicated, including a gate keeping concept, his competence was regarded as developing.

Representations including analogies

In the interview Mr. KZ indicated a representation that he incorporated to support the teaching of graphs of motion. The representation, simulating graphs of motion by walking, is similar to the representation suggested in the expert CoRe (Prompt Seven, key idea A):

> *You cannot just write on the white board, you also have to walk around in class, sometime you ask the learners to stand up and walk the graphs.*

Mr. KZ did not, however, specify the conceptual development that would have been supported by such a representation. As a result, his knowledge about representations in the topic was, with reference to the rubric, considered to be basic.

Conceptual teaching strategies

Inferring from Mr. KZ's CoRes (key idea A – F) and interview (Question Two), he regarded presenting a lesson on graphs of motion from a mathematical perspective as important. The reason he had given was that:

> *"Our syllabus doesn't show the integration between physics and maths and we as physics teachers must teach both maths and physics…"*

Although he did not indicate how the prior knowledge of mathematics should have been incorporated, he indicated its importance and that the key ideas conceptually developed from it. He mentioned that learners had to understand that the horizontal and vertical axes represented independent and dependent variables respectively. Therefore, substituting variables correctly in the formula for gradient based on the graphs could have led to the development of concepts in the topic, which are acceleration and velocity being represented by the gradients of position-time and acceleration-time graphs respectively. Mr. KZ did not explicitly mention instantaneous and average velocity and did not indicate how he develops learners' understanding of these concepts. In terms of the concept of displacement being represented by the area under a velocity-time graph, Mr. KZ said:

> *"You know that velocity is equal to the change in position over change in time, so now for me to know this change in position I can take it back [make it the subject of the formula], when I take it back I'm gonna have delta x is equal to delta tv [delta t times v], so when I look at this, the base is the time and the height is the velocity. So I have to show them why the two are related. I can't just say calculate the area and when they say why? I say no that's how it is."*

Mr. KZ mentioned the importance of beginning the discussions of this concept from a mathematical point of view; the product of the length and the breadth of a rectangular shape. This would then followed by substituting one side with velocity and the other side with time, which would provide the area: the product of velocity and time. From their prior knowledge of mechanics, learners will have to recognise that the product of velocity and time is displacement, hence the area under a velocity-time graph represents displacement. This strategy is also referred to in the expert CoRe (Prompt Seven, key idea F) and it indicates that the teacher shows learners the origin of the concept.

Mr. KZ did not just reveal his awareness of learners' difficulties, he also revealed the strategies that he used to expose the difficulties. Having mentioned that learners focused on the slopes (or gradients) of the graphs instead of first checking which variables were represented in the graphs, he suggested a question that could explore this difficulty:

> *"I gave them a position-time graph, so this position-time graph that I gave them was in a way that one line started from zero with a positive gradient, the other line started from 20 metres with the negative gradient. And then the question was which car is moving faster than the other car. It*

was a position-time graph, and they said the one that started from Zero was moving faster because the gradient is going up [positive]."

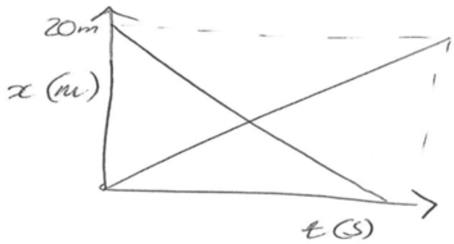


Figure 4.4b

The diagram in Figure 4.4b was constructed by Mr. KZ while he was responding to the first question in his interview. Not only did he specify the question that revealed the difficulty and the most prevalent response from learners, he also indicated a strategy that he used to confront it:

"In this case it's a position time graph, the other car starts from where I am, which is zero metres and the other car starts there 20 metres coming to me. Here they bypass each other in the opposite way, but they [learners] think it's overtaking. If this was a velocity-time graph when I have this the cars overtake each other…they don't look what graph you have they just answer the question without looking [at the type of graph]."

Mr. KZ also explained how the interpretation of the graph changed if the variable on the horizontal axis was velocity instead of position, which showed his conceptual understanding of the idea.

When assessing Mr. KZ's teaching strategies against the TSPCK rubric, it can be seen that the third level of competence describes his competence. Considering how Mr. KZ explained concepts from a mathematical point of view, and how he exposed difficulties and confronts them, his competence was regarded as developing.

5. CHAPTER 5: REVEALED PCK

This chapter presents and analyses the data which were collected during lesson observations, reflecting teachers' revealed PCK. The analysis of the lesson observations was also based on the five TSPCK components and answered the second sub-question of the study: How do teachers reveal their PCK about graphs of motion during lesson presentations? Just like the previous chapter, this chapter is organised into four cases, one case per teacher.

5.1 CASE STUDY 1 – MRS. VM

Mrs. VM was confident about the content that she was presenting to her learners. She asked learners questions and gave them opportunities to ask questions if they had any. The classroom atmosphere was light-hearted and conducive to learning. Furthermore, Mrs. VM would at times move around while she was teaching to ensure that all the learners got the attention that they needed.

She used transparencies with graphs and calculations already done on them, and there were definitions of velocity ($v = \frac{\Delta x}{\Delta t}$) and acceleration ($a = \frac{\Delta v}{\Delta t}$), presented as formulae, which were used in previous lessons, written on the white board. She also had pamphlets that she handed out to the learners during the lesson. The hand-outs contained the same information that was displayed on the transparencies so they didn't have to write it down.

5.1.1 Analysis of Mrs. VM's lesson

Learners' prior knowledge

Mrs. VM facilitated discussions, usually by asking questions, to explore learners' prior knowledge. However, she did not give learners adequate time to answer those questions. Instead she mostly helped them by initiating suitable statements that she left incomplete for learners to call out the missing part of the statement. For example, she asked learners: "If the object is moving with a constant velocity, is it accelerating?" and as they were attempting to answer she said: "No, because acceleration is the change in…?" and learners just said "velocity". Other questions that she asked included "can acceleration be negative, if so, when is it negative?" and "looking at the graph [positive velocity-time graph], can you say the object is moving with a constant acceleration?". If learners completed the statement correctly, she concluded that they understood the concepts and continued with the lesson.

As she mentioned in the CoRe that learners believed time could be negative, she used the diagram in Figure 5.1a to facilitate a discussion that explored and addressed the misconception.

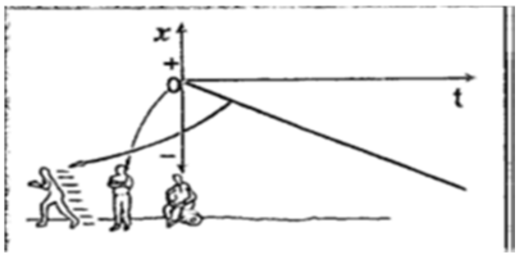


Figure 5.1a

Mrs. VM: "Here's the zero point, from rest, at a constant velocity I'm moving west (literally walking)…so I am moving to the other side now. Do you see that that line is no longer in the positive displacement quadrant?"

Learners: "Yes"

Mrs. VM: "Are we ever gonna use these two [quadrants] (pointing to two and three, where the horizontal axis is negative)?"

Learners: "Yes"

Mrs. VM: "NOO!...why not?...because if you have the ability to go minus 1 seconds, minus 2 seconds, minus 3 seconds, minus 4 seconds please come see me after class, I need to get back a few years. Remember, time will be negative in those quadrants"

Mrs. VM did not ask learners to state the reasons why they thought those quadrants could be used. This would have provided a deeper insight into understanding the roots of this misconception. Furthermore, she did not adequately confront this difficulty, as she did not complete and label the Cartesian plane, which would have shown learners that time was negative in the second and third quadrant.

This practice of asking questions exposed a confusion that was similar to the one she indicated in the CoRe – learners confused the direction of position and velocity. In this case they believed that the magnitude of the displacement of an object moving in the negative direction was decreasing (refer to Figure 5.1a):

Mrs. VM: "So what happens to the magnitude of the displacement of this guy?"

Learners: "It is decreasing"

Mrs. VM: "Why?"

Learners: "He is moving to the negative side"

Mrs. VM: "No" "what is displacement?"

Learners: (one learner was asked to answer) "shortest distance from where we start to where we end"

Mrs. VM: "Look at me, I'm standing up now, zero seconds, I'm moving west with a constant velocity. How is my distance [displacement] not increasing (pointing where she is and where she started as she's asking this question)

Learners: "ohhhhoooo"

Mrs. VM addressed this misconception adequately; she started by ensuring that learners understand what displacement is and also incorporated a representation to confront it.

Mrs. VM facilitated discussions that explored learners' misconceptions. However, the quality of the methods she used to confront the misconceptions varied. One of the misconceptions (about displacement) was confronted fairly adequately, the one about negative time was not addressed effectively and the other misconception (about velocity and acceleration) showed limited PCK. As a result, her revealed competence about transforming content through understanding learners' prior knowledge was classified as basic.

Curricular saliency

When the key ideas Mrs. VM discussed in her lesson were compared to the expert CoRe, it was evident that she had omitted other important key ideas. She discussed position-time graphs, velocity-time graphs and the idea that velocity, including instantaneous velocity, are represented, respectively, by the gradient of a position-time graph and that of the tangent to a curved position-time graph. The ideas that acceleration and displacement are represented by the gradient of a velocity-time graph and area under such a graph, were not discussed. Consequently she did not teach acceleration-time graphs.

Her explanation of the idea that the gradient of a position-time graph represents velocity was unsatisfactory. She began by exploring learners' understanding of gradient:

Mrs. VM: "who can tell me what the word gradient means?"

Learners: (very few) "the steepness" (one learner said) "change in units of x and change in units of y"

Mrs. VM: "ok, so it's the rate of change between x and y, is that what I'm getting here?...ok"

Mrs. VM: "If we do the gradient or the slope [of a position-time graph], you gonna say it's still delta x over delta t. We are going to say the velocity of this athlete is equal to the gradient of this graph".

Mrs. VM did not ensure that learners possessed a thorough understanding of gradient and did not present it as the change in y over the change in x (as it is explained in mathematics). She also did not thoroughly explain velocity as a variable represented by the gradient of a position-time graph.

Although Mrs. VM left out central key ideas, she adequately sequenced the key ideas that she decided to teach. However, her discussions of the interrelatedness between the key ideas and their sub-ordinate ideas were unsatisfactory. She did not show learners that the variables on the vertical and the horizontal axes in the gradient formula represented position and time, thus representing velocity. She showed learners calculations of gradients of different points on the position-time graph and the subsequent velocity-time graph, which were already done on a transparency. She then said:

> "*Because he is moving with a constant velocity, the graph next to that, a velocity-time graph, is a straight line [horizontal line], why?"*

Before learners could respond she said:

> "*Because his velocity is…?"*

Learners then completed this sentence by saying

> "*Constant*".

She did not relate constant velocity to the calculations of gradient of the position-time graph at different points, even though values of the gradients were identical.

Mrs. VM's enacted PCK about curricular saliency was affected by the fact that she discussed some of the key ideas indicated in the expert CoRe, but not all of them. She also explained the interrelatedness between the ideas poorly, despite sequencing them fairly adequately. As a result, her revealed competence in curricular saliency was regarded as basic.

What is difficult to teach?

The concepts that were identified as difficult to teach by Mrs. VM in the CoRes and the interview were:

- Learners found it difficult to understand how graphs of motion are related to one another.

- Learners found it difficult to interpret graphs to infer direction and whether the object is stationery, moving with a constant velocity or accelerating. This was because they thought that all graphs of motion are position-time graphs because they did not read the headings or labels on the axes.

Although she realised that learners found it difficult to understand the relationship between graphs of motion, she limited her discussion to position-time and velocity-time graphs only, not mentioning acceleration-time graphs. Furthermore, she poorly explained the idea that the gradient of a position-time graph represents velocity. Firstly she did not clearly show how gradient represented the change in position over change in time, which is velocity. Secondly, she did not perform the calculations of the gradient of the position-time graph with learners and used the values to construct the corresponding velocity-time graph, she instead showed these to learners on the transparency. As indicated earlier, Mrs. VM did not discuss the following major ideas: acceleration and displacement are respectively represented by the gradient of a velocity-time graph and the area under such a graph. As a result, she did not show learners how position-time and acceleration-time graphs developed from a velocity-time graph. This suggests that her attempt to address the first difficulty was limited.

Having said that learners find it difficult to interpret graphs, she drew the position-time graph in Figure 5.1b (below) and interpreted it adequately while she simulated it by walking:

Mrs. VM: "Now before we start, let me walk this graph for you. From A to B you see is 2 seconds and 8 metres. Now this is my point of origin, time zero second. Time 1 second, 4 metres, time 2 second, 8 metres. And I'm travelling west. Between B and C what happens there? I…"

Learners: "you are moving with a constant velocity"

Mrs. VM: "no it's not a constant velocity, this is a position-time graph. My position is 8 metres and I remain here from time 2 to 4 seconds. Now what do I need to do? I must turn around I must travel time 5 seconds and time 6 seconds [travelling to the east]. Where am I at time 6 second?"

Learners: "point of origin"

Mrs. VM: "Point of origin. Then I travel time 7 seconds, time 8 seconds, my position is minus 8 metres [traveling west]. And for time 8 seconds to 10 seconds, what must I do?"

Learners: "stop"

Mrs. VM: "I'm standing still, I'm not moving because it's a straight line [horizontal line]. What must I do then?"

Learners: "go back to your point of origin"

Mrs. VM: "so I move for time 10 second, 11 seconds, 12 seconds [traveling to the west] then I'm exactly where I started. What is my displacement for the whole trip?"

Learners: "zero"

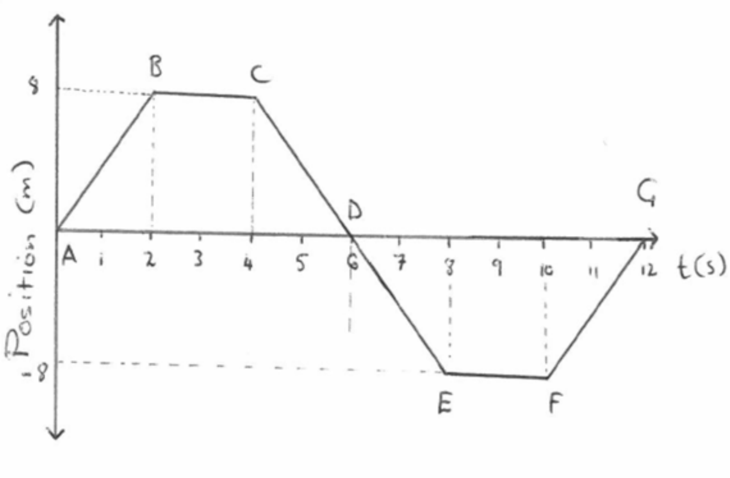


Figure 5.1b

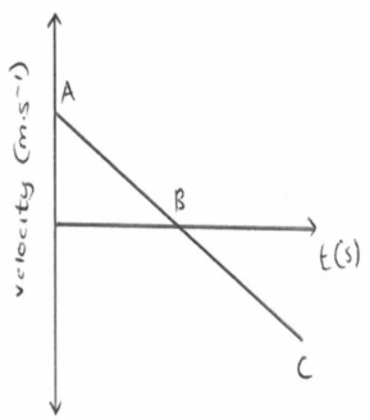


Figure 5.1c

Although she interpreted the graph in Figure 5.1c correctly, she did not convey her interpretation in a way that ensured conceptual understanding in learners, because by means of direct teaching, she told learners:

> *"The velocity of this athlete from A to B is decreasing, and at B the athlete stops. Then the velocity from B to C increases, but in the opposite direction".*

Numbering the axes would have helped learners understand that the velocity was decreasing from a positive magnitude at A to zero at B, and then it increased to a negative magnitude at C, where the negative sign indicated direction.

According to the criteria in the rubric, Mrs. VM's revealed competence about knowledge of this component was classified as basic. This was based on the way she approached only some of the concepts that she indicated as difficult. Furthermore, the discussions of those difficult concepts that were addressed, included adequate confrontations for some of the concepts and inadequate confrontations for the others.

Representations including analogies

Although Mrs. VM used representations in certain instances in her lesson, there were concepts that required basic representations (drawings, labels) that she did not incorporate. When she was explaining the idea that graphs of motion could not be drawn in quadrant two and three, she did not label the Cartesian plane to show learners that time was negative in those quadrants. When she explained that the gradient of the tangent to a curved position-time graph represents instantaneous velocity, she did not draw the tangent. Furthermore, she interpreted the velocity-time graph in Figure 5.1c verbally only. As the axes were not labelled, it is assumed that it was difficult for learners to understand its interpretation.

Nevertheless, Mrs. VM interpreted the position-time graph in Figure 5.1b while simulating it by walking and also confronted a misconception as she was explaining the graph in Figure 5.1e as indicated earlier. The drawings that she displayed on the transparencies included bodies that simulate the motion represented by the graphs (see Figure 5.1a, 5.1d and 5.1e). Notice that these diagrams have the potential to induce misconceptions. The athlete in Figure 5.1d appears to be running faster and faster, whereas the corresponding graph shows movement at constant velocity. As Mrs. VM did not comment on the potential misconceptions that may be induced, one may conclude that she did not notice them.

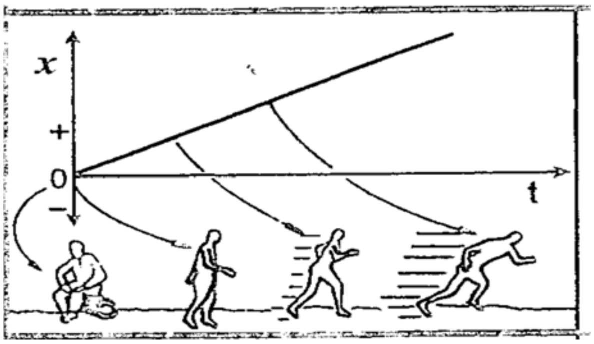


Figure 5.1d

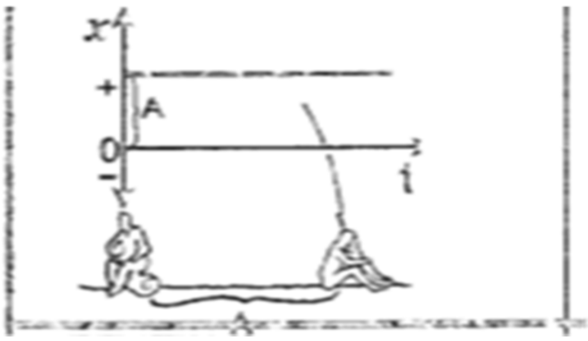


Figure 5.1e

Mrs. VM used a real life application to explain the drawing on Figure 5.1e. She said:

> *"The next one [Figure 5.1e], oh this is a good one, this is a clever one, after break this one…we sit there, the bell rings trrrrrrrrr. As time continues, you remain (learners joined in) seated"*

Mrs. VM's understanding of when and how to use representations was not fully developed as she didn't use them in all the instances where they were necessary. Furthermore, some of her representations have the potential to induce misconceptions, something she did not comment on in the lesson. As a result, her competence in this component when comparing it to the criteria in the rubric was scored basic.

Conceptual teaching strategies

Mrs. VM generally explained the major concepts in the topic unsatisfactorily. As indicated earlier, she did not ensure that learners understood gradient before incorporating it in the lesson. As a result, she poorly developed the idea that velocity and acceleration are represented by the gradients of position-time and velocity-time graphs respectively. Her explanation of the concept of instantaneous velocity was also inadequate. She presented the graphs in Figure 5.1f and 5.1g on the transparency before explaining the construct verbally, saying:

> *"With such a graph [5.1f], the gradient of the tangent to this graph shows instantaneous velocity, using a triangle is not going to work because the graph is curved can you see? But you can choose a point and then draw a triangle that includes the point and then calculate the gradient of the line cutting through the point".*

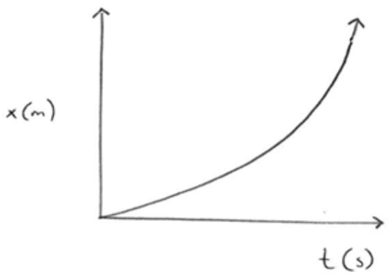


Figure 5.1f

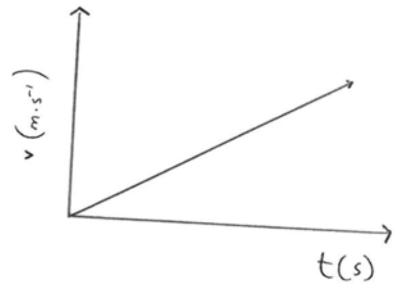


Figure 5.1g

Firstly, she did not confirm whether learners understood the word "tangent" and what it entails. Although she indicated that the gradient of the position-time graph was increasing, this was not used as the basis of the idea that the velocity was also increasing. Mrs. VM did not explicitly mention that the gradient of the position-time graph represented velocity and that this velocity was represented on the velocity-time graph in Figure 5.1g. She instead emphasised the fact that the velocity increased because the change in the position of the object kept increasing for the same time intervals. As a result, the velocity-time graph was not explicitly related to the gradient of the curved position-time graph and learners were not shown how the graph came about. Although she mentioned that the increase in velocity meant there was acceleration, she did not discuss the idea that the acceleration was represented by the gradient of the velocity-time graph.

After finishing teaching a concept, Mrs. VM asked questions to confirm whether learners understood the concepts. The questions she asked required learners to apply knowledge and respond in such a way that they revealed their understanding of the concepts. However, her insight in the level of understanding of the learners was limited by the ways in which she assessed their responses. After having inadequately explained that the gradient of a position-time graph represents velocity, she drew two positive gradient position-time graphs on the same set of axes and labelled them A and B. A had a steeper gradient than B. She then asked learners which object was faster and why. After learners said B ass faster, she gave them a strange look suggesting that they were incorrect, which then made them to say A was faster. She then told them that the steeper the gradient, the higher the velocity, hence A was faster. Although she asked good questions, she did not probe learners' understanding further by asking follow up questions or asking learners to substantiate their responses.

As it was indicated earlier, Mrs. VM revealed a poorly developed understanding of the use of representations. She explained some graphs without constructing them (instantaneous velocity-time graph) or without numbering their axes (Figure 5.1c, p. 82). Furthermore, some of the diagrams had the potential to induce misconceptions based on the way they presented information. There were also those concepts (Figure 5.1b, p. 82) that were explained fairly adequately incorporating the necessary representations.

Mrs. VM's revealed competence about the strategies of teaching this topic was regarded as basic, according to the rubric. Despite her asking higher order questions, the way she utilised learners' responses was inadequate. She also did not adequately show the development of sub-ordinate ideas from the major concepts, as a result, she poorly indicated the interrelatedness between the major concepts. Furthermore, she poorly incorporated representations in her discussions of some of the concepts, although a few concepts were adequately discussed using representations.

5.2 CASE STUDY 2 – MRS. SC

Mrs. SC was confident about the content she was presenting to her learners. She would ask questions and also responded to the questions that learners asked her. The questions asked were posed to learners at random, whether they had raised their hands or not.

She presented the whole lesson mostly standing by the board, and hardly moved around. She also spent most of her time talking and seldom wrote on the board. After she had explained the necessary concepts, she then used the transparency with summaries for learners to copy down and keep in their books.

5.2.1 Analysis of Mrs. SC's lesson

Learners' prior knowledge

Mrs. SC revealed awareness of some of the most important pre-concepts that need to be in place, however, in most cases, she explored them poorly. Before introducing the idea that velocity is represented by the gradient of a position-time graph, the following transpired:

> *Mrs. SC: "you've dealt with graphs in maths since grade 8 and you've been using x and y as abstract values, they didn't have meaning. In science we substitute the x and the y with something that has meaning to it. So the moment I substitute my y value in my formula for my gradient and my x value in my formula for my gradient, my gradient now has meaning. Where do you know that formula from [delta x over delta t]?*
>
> *Learners: "Velocity"*
>
> *Mrs. SC: "it's $y_2 – y_1$ over $x_2 – x_1$, that's what you're taught in Maths am I right? But we don't use x, we gave it meaning [time]. We don't use y, we gave it meaning [position]. But the basis of the formula stays the same"*

She did not ask learners to use their prior knowledge to define gradient. Instead she reminded them what gradient is and asked them to confirm if she had a correct understanding of it. She also spoon-fed learners with the necessary knowledge of the formulae used to calculate the areas of applicable shapes, without exploring their understanding through questions. This limited her insight into understanding learners' difficulties with regard to gradient and area from their prior learning. When she asked: "what is the gradient of a diagonal straight line", to explore the learners' prior knowledge, they answered "one". The answer she expected was "constant". Upon picking this misconception up, she addressed it using direct instruction, telling them without showing them that "the gradient of a straight line is not always one, it is rather always constant".

Although she was aware of the necessary pre-concepts that needed to be in place, she did not adequately explore the extent to which learners understood them. Furthermore, she hardly facilitated discussions that exposed learners' misconceptions. As a result, her revealed knowledge about learners' prior knowledge according to the rubric was classified as basic.

Curricular saliency

Mrs. SC discussed the majority of the key ideas indicated in the expert CoRe. However, some of the ideas were given more attention than others as she spent most of her time explaining graphs of motion at constant velocity.

Mrs. SC logically sequenced the key ideas, explaining how they were interrelated to each other and to their corresponding sub-ordinate ideas. She showed learners how velocity and acceleration are represented by gradients of a position-time and a velocity-time graph respectively. She started from the general formula for gradient and then substituted the necessary variables deduced from the graphs of motion. She then calculated the gradients and used the values to construct the graphs represented by the variables:

> *Mrs. SC: "if I use this graph [position-time] and I try to redraw a velocity-time graph, let's use our time 3 and time 6 again. What is my velocity going to be at time 3?"*
>
> *Learner 1: "positive one"*
>
> *Mrs. SC: "I'm going to the positive side of my graph and it's going to be at one. And at time 6 what is my velocity going to be?*
>
> *Learner 2: "one"*
>
> *Mrs. SC: "still plus one. So you agree with me for every time in between, my velocity is going to be one. Yes? Everyone with me?" [She then connected the points with a line]*
>
> *Learners: "yes"*
>
> *Mrs. SC: "I said if I have a velocity-time graph, I can use the gradient of that graph which is then y over x which is my velocity over time now. Where do you know that velocity over time from?"*
>
> *Learners: "acceleration"*

Mrs. SC also discussed the construction of a position-time graph from calculating the area under a velocity-time graph. However, the information available to assess Mrs. SC's knowledge about curricular saliency was only adequate in her teaching of graphs of motion at constant velocity and not accelerated motion (see "What is difficult to teach" below).

As Mrs. SC presented key ideas and their sub-ordinate ideas adequately and also showed the interrelatedness between the ideas, her competence was regarded as developing. However, she enacted this level of competence only in her discussion of graphs of motion at constant velocity.

What is difficult to teach?

As indicated in Chapter Four, the concepts that Mrs. SC identified as difficult were;

- Learners found it difficult to calculate gradients of graphs of motion and they don't understand what those gradients represent.
- Learners found it difficult to divide complex shapes into squares, rectangles and triangles in order to calculate the area under a graph.
- Learners found it difficult to understand how graphs of motion develop from each other.

Although Mrs. SC poorly explored learners' prior understanding of gradient and area, which the researcher regarded as the gatekeeping concepts for the identified difficulties, she adequately explained the ideas that velocity and acceleration are represented by the gradients of position-time and velocity-time graphs respectively. She started from the general formula for gradient and then substituted x and y with the relevant science variables. She then asked learners to identify the variables calculated by the formulae that have emerged from the gradients. Area was included in the explanation of graphs of motion at constant velocity, but Mrs. SC calculated the area of a rectangle only. As a result, the difficulty that learners had about the area of shapes other than squares, rectangles and triangles was not addressed in the presence of the researcher. Thus it cannot be concluded whether she had the knowledge to address the second difficulty.

As reported above, Mrs. SC adequately explained the interrelatedness between key ideas for graphs of motion at constant velocity but her discussion of graphs of accelerated motion was cursory (see curricular saliency):

Mrs. SC: "what happens if I have my change in displacement, but look at the gradient of the graph. can you see once again, my displacement is increasing in a direction, but the gradient of the graph changes, can you see that?"

Learners: (silence)

Mrs. SC: "it goes from a zero gradient, increasing increasing increasing [showing the increase by placing her hand on different points on the graph]. So what does this tell me about my velocity?"

Learners: (silence) one learner said "it's increasing"

Mrs. SC: "where does it start?"

Learners: (silence) one learner said "zero"

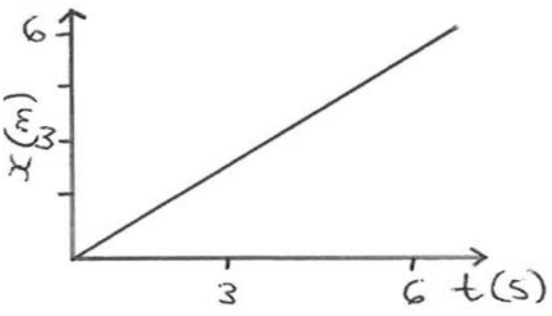
> *Mrs. SC: "So my velocity starts at zero, and it's increasing according to the values on this gradient that I gave you"*

Mrs. SC did not mention tangents or secants, and did not construct them on different points on the position-time graph. Subsequently, she did not calculate their gradients to demonstrate the increase in gradient and thus the velocity. Furthermore, the corresponding velocity-time and acceleration-time graphs were already displayed on the projector and as a result learners were not involved in the conceptual thinking that linked these graphs with one another.

It was evident that Mrs. SC discussed the concepts that she indicated as difficult. Although no judgements can be made about her confrontation of the second difficulty, the first difficulty was confronted fairly well and the third was adequate for graphs of motion at constant velocity and poor for graphs of accelerated motion. As a result, her revealed competence about transforming content through understanding learners' difficulties was regarded as basic.

Representations including analogies

The explanation of graphs of accelerated motion by Mrs. SC revealed that she did not seem to possess a thoroughly developed understanding of how to select appropriate representations and when to use them. As already reported, she did not draw a tangent or a secant to a curved position-time graph and calculate their gradients to show learners how it changed. After calculating the gradient of the graph in Figure 5.2b below, which was negative, she explained that the negative sign indicates direction by incorporating a representation. She firstly simulated the motion depicted by the graph in Figure 5.2a below by walking to the chosen "positive direction", and then walked in the opposite direction simulating the motion described by Figure 5.2b. As she did not explain more complex graphs with a combination of features (such as motion at constant velocity and accelerated motion), one would argue that the simulation supported the explanation of an elementary concept. Based on the information inferred from the lesson, Mrs. SC revealed basic competence about knowledge of transforming this topic's content through representations.



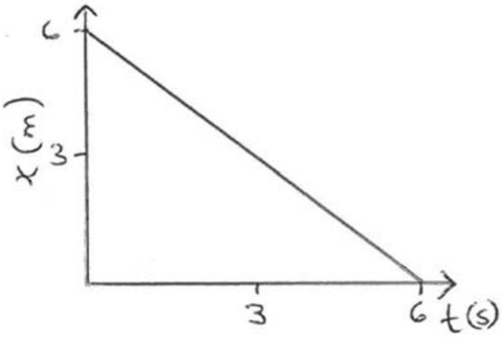


Figure 5.2a

Figure 5.2b

Conceptual teaching strategies

The way Mrs. SC introduced her lesson suggested that she had a limited understanding of the importance of exploring learners' prior knowledge, misconceptions and correct conceptions, before presenting new knowledge. She hardly explored learners' prior knowledge by asking questions that required them to apply what they already knew and thus expose their understanding. She did not ask recall questions about the definition of gradient and the formulae used to calculate areas of various shapes, she instead gave this information to learners using direct instruction.

Despite poorly exploring learners' prior understanding of gradient, she used the concept to conceptually develop the idea that the gradient of position-time and velocity-time graphs represent velocity and acceleration respectively. She also guided learners into understanding how one graph developed from another through using gradient or area. Mrs. SC also referred learners to the summary, see Figure 5.2c below, that was aimed at reminding them whether to calculate gradient or area in a graph to infer motion variables from the graphs.

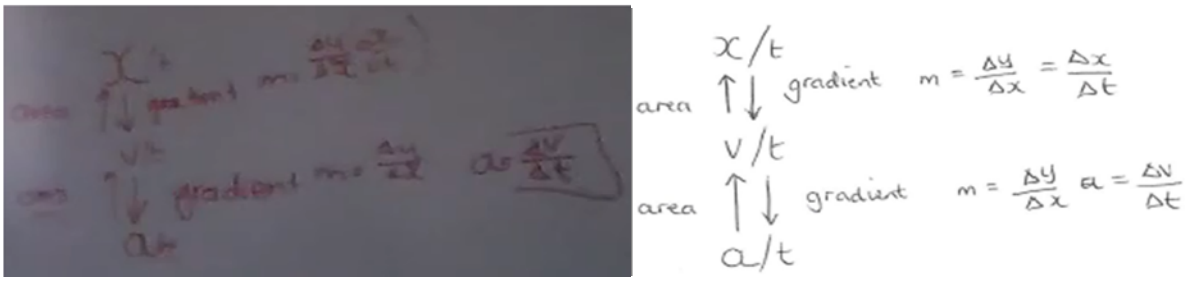


Figure 5.2c

When the gradient of a decreasing position-time came out negative (Figure 5.2b, p. 90), she explained the idea that the sign indicated direction by firstly walking in the direction depicted by positive velocity and then walked in the opposite direction. She also revealed that it is important that learners had to understand all graphs of motion with reference to the information about the same motion. She drew a constant gradient position-time graph and then asked:

> *"Explain to me the movement in this graph. Let's say this is a car drive. Explain to me how this is driving. Take into consideration; the displacement [position], the velocity and the acceleration…if you can do one of the three [position, velocity and acceleration]"*

This conceptual development was, however, only limited to motion with a constant velocity. After drawing a velocity-time graph (horizontal line) emerging from a position-time graph (positive gradient straight line), she asked one of her learners:

> *Mrs. SC: "what is the gradient of this graph [horizontal line]?"*
>
> *Learner 1: "it's one"*
>
> *Learners: (after realising that the answer given by learners 1is incorrect) "it's zero!"*
>
> *Mrs. SC: "How do I calculate the gradient, quickly help?...delta v over delta t, yes?*
>
> *Learners: (silence)*
>
> *Mrs. SC: "at t = 6 my velocity is 1 and at t = 3 it is also 1. So it's 1 – 1 over 6 – 3 which is zero…any horizontal line has got a gradient of zero.*

Although she did not ask the learners to elaborate on his answer, notice that she also did not tell the learner that his answer was incorrect. Instead she guided him and the rest of the class towards the correct answer, even though most learners revealed a solid understanding. As described earlier, she appropriately explained the most important graphs concepts in relation to constant motion, but did not use the same conceptual strategies to develop concepts related to accelerated motion and more complex graphs.

The way Mrs. SC presented graphs of motion at constant velocity revealed features of developing competence about teaching strategies. However, graphs of accelerated motion revealed limited PCK due to a lack of necessary representations and poor indication of the interrelatedness between ideas. As a result, her overall competence as enacted during the lesson presentation was regarded as basic.

5.3 CASE STUDY 3 – MISS. MH

Miss. MH teaches in an under resourced school where classes are overcrowded. During her lesson she gave learners graph papers as she wanted them to draw graphs according to scale. She also allowed time for the learners to calculate variables and draw graphs on their own and then demonstrating their workings on the board. When a learner responded to her questions correctly, she encouraged the rest of the class to applaud him or her.

Miss. MH was very strict with time management such that when the time allowed for the learners to work on their own was finished, she commanded them to stop and listen. She asked learners questions and although they were given the opportunity to ask questions, they hardly ever did. When explaining concepts, Miss. MH stood mostly in one place and seldom moved around the class.

5.3.1 Analysis of Miss. MH's lesson

Learners' prior knowledge

Miss. MH began her lesson by exploring learners' prior knowledge, for example the SI unit of time, position and learners' understanding of variables. The way she elicited learners' prior knowledge about position was inadequate:

> *Miss. MH: "What is position?"*
>
> *Learner 1: "Measurement of a position"*
>
> *Miss. MH: "Measurement? No…Yes (pointing to learner 2)"*
>
> *Learner 2: "It's a point where you are standing"*
>
> *Miss. MH: "Not really…It's a point where you can find something. Now what is displacement?"*

The answer given by learner 2 meant the same as the one Miss. MH provided as a correction. The fact that she attempted to improve a correct statement could have potentially induced a misunderstanding since learners could have thought that their classmate's description of position was incorrect, because of the trust they had for whatever their teacher said (Arshiyan & Pishkar, 2015). Furthermore, she did not point out that position is measured relative to a fixed point and that it is a vector.

After having explored learners' understanding of position, she then asked a question which explicitly displayed her incorrect understanding of position and had potential to induce a misunderstanding. She asked:

> *"Which one between the two is a scalar, between position and displacement and which one is a vector? Then you will tell me, what is the difference between a scalar quantity and a vector quantity?"*

Learners answered the question saying position is a scalar and displacement is a vector, which Miss. MH accepted as correct. It is evident that she did not know that both position and displacement are vectors.

In her discussion of position and displacement she did not point out that the difference between them is that position shows location in a certain direction from the point of reference and displacement shows how far the object was displaced from one location to another and the direction in which it was displaced, that is, the difference between the final and the initial position vector. In addition, she communicated incorrect information and therefore her exploration of learners' prior knowledge was inadequate. Consequently her revealed competence about learners' prior knowledge was regarded as limited.

Curricular saliency

During the lessons observed for this study, Miss. MH limited her teaching of graphs of motion to motion with constant velocity, similar to the focus of her CoRes. Furthermore, she did not teach all the key ideas and their sub-ordinate ideas associated with such graphs. Miss. MH revealed a limited understanding of the importance and sequencing of concepts in this topic as discussed below.

She did not explain the idea that the area under a velocity-time graph represents displacement. Hence the development of a position-time graph from a velocity-time graph was not discussed.

When calculations of variables (vectors) were conducted, Miss. MH did not comment on the idea that their signs represented direction (a sub-ordinate idea).

She mentioned that gradient is a concept that is related to this topic, but she did not explain how it formed part of the concepts in the topic. Velocity and acceleration were calculated using their definitions, inferring the necessary data from the corresponding graphs. Miss. MH did not emphasise the fact that those definitions (of velocity and acceleration) were the gradients of position-time and velocity-time graphs respectively. Although the calculations of velocity and acceleration were correct and the corresponding graphs were constructed correctly, the importance of gradient in this regard was not emphasised. Hence there was no indication of the interrelatedness of the graphs through the concepts of gradient and area.

Miss. MH's revealed competence about curricular saliency was considered to be limited, due to the fact that she poorly discussed the interrelatedness between key ideas and their corresponding sub-ordinate ideas in that gradient and area were not emphasised as concepts that linked corresponding graphs of motion with each other.

What is difficult to teach?

As it was indicated in Chapter Four, the concepts that Miss. MH identified as difficult to teach were:

- Learners found it difficult to represent the state of rest graphically.
- Learners thought that all graphs of motion represent motion at constant velocity.
- Learners found it difficult to infer or denote starting points, as a result they find it difficult to indicate direction relative to the points.
- Learners found it difficult to interpret graphs of motion, although they could easily construct them.
- Learners found it difficult to identify shapes under a velocity-time graph and subsequently they found it difficult to calculate the areas.

Miss. MH treated the first difficulty in the list above as any other concept in the lesson. The way she presented it did not convince the researcher that she regarded it as a difficult concept. This may be related to her remark in the interview, when she said that constructing graphs was not as challenging for learners as interpreting them (difficulty number four).

The second difficult concept was also approached as any other concept in the lesson. The fact that she constructed graphs of a stationery object and another object moving at constant velocity suggested that she attempted to address the difficulty. She did not ask learners questions that could have revealed any confusion linked with the difficult concepts, which might have been a starting point towards confronting those concepts.

Miss. MH addressed the third difficulty when she requested learners to describe the location of furniture in the classroom in terms of direction with reference to her location. Through this activity she managed to get the majority of learners to understand position in terms of direction. However, the activity did not alert her to the fact that she earlier described position as a scalar quantity, which was incorrect.

Her explanation of direction in a position-time graph could be linked to learners' difficulties about interpreting graphs, the fourth difficulty on the list above. This is how she explained direction in relation to position-time graphs:

> *"If your Cartesian plane is like this, you are expecting a graph that will go from here to here (from the origin diagonally down in quadrant four), to show that it's a negative; it's not going to work like that. We are dealing with positive numbers; we still use the first quadrant. We use y positive and x positive but our graph [object] goes to the opposite [side]"*

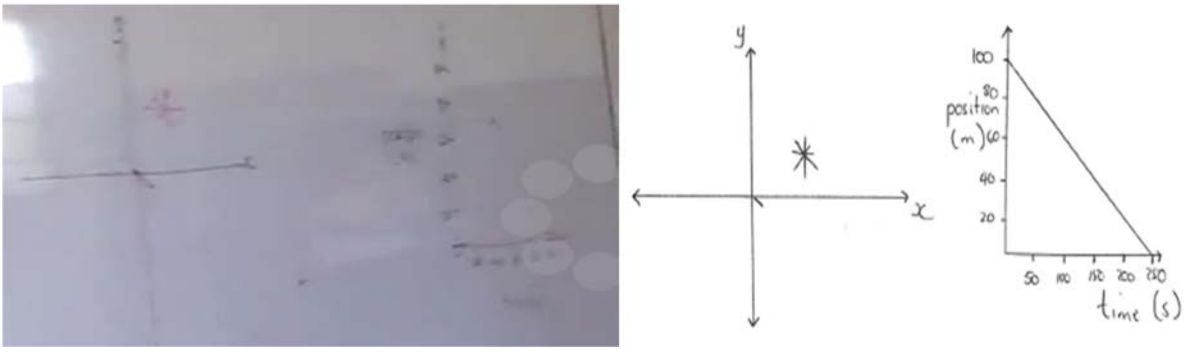


Figure 5.3

Key: the asterisk (*) represents the quadrant in which graphs will be drawn according to Miss. MH.

She explained to learners that when constructing a position-time graph representing an object moving in the negative direction, they did not necessarily have use the fourth quadrant where the vertical axis was negative. However, her explanation showed a misunderstanding on her part. The fact that she conceptualised position as a scalar quantity was also revealed in the quote above where she told learners that only positive numbers, hence the first quadrant, would be used in position-time graphs. Furthermore, she did not mention that a position-time graph could be constructed in the fourth quadrant where the vertical axis (in this case position) was negative. Nevertheless, she correctly showed learners that an object can move in the negative direction while the position was positive. She also did not indicate that the construction of such graphs depended on starting points and where the object was located relative to the starting point. Furthermore, she did not include in her explanation that the direction in which it is moving is not necessarily determined by its position.

As indicated earlier (see first paragraph on curricular saliency), she did not discuss the idea that displacement is represented by the area under a velocity-time graph, hence the fifth difficulty was not explored and addressed in the presence of the researcher.

Miss. MH seldom clarified concepts that she identified as difficult to teach. Although she addressed a few of those concepts, the way she approached them did not convince the researcher that she regarded them as more difficult than any other of the key concepts. It seemed that Miss. MH found those concepts difficult to teach because she did not have an adequate content knowledge about them. As a result, she revealed limited competence about learners' difficulties inferring from her lessons that were observed.

Representations including analogies

Miss. MH seldom incorporated representations in her lesson. The only times she used representations was when she asked learners to describe the positions of furniture in terms of direction in the classroom, and when she used a real example of a bus ride. She read from the textbook about a girl who had been waiting for a bus for two minutes and requested that learners help her, Miss. MH, construct the girl's position-time graph for the two minute interval. During the lesson, there were concepts that Miss. MH could have enhanced by incorporating suitable representations. For example, she could have demonstrated walking in a direction opposite to her position to explain a position-time graph with a negative gradient. When comparing her use of representations to the rubric, her revealed competence was regarded as limited.

Conceptual teaching strategies

Miss. MH introduced her lesson by exploring learners' prior knowledge. However, the questions she asked did not require learners to apply knowledge but rather to recall it. Furthermore, the way she assessed their prior knowledge revealed her own misunderstandings about concepts. These misunderstandings could have been transferred to the learners and would have prevented the correct understanding of concepts.

In terms of the concept of gradient, she did not fully explore all aspects of the concept and thus she poorly explained how new concepts developed from it. Although she attempted to explain the idea that velocity is represented by the gradient of a position-time graph, she did not explain the idea that the gradient of a velocity-time graph represents acceleration. This is how she attempted to explain the idea that velocity is represented by the gradient of a position-time graph:

> *Miss. MH: "I want to introduce your maths word, which is gradient. How do you calculate gradient in your maths?"*
>
> *Learners: "$y_2 - y_1$ over $x_2 - x_1$"*
>
> *Miss. MH: "what do we call, what is the word that when we calculate it we use displacement over time [which variable is calculated using displacement over time]"*
>
> *Learner 1: "Velocity"*
>
> *Miss. MH: "which means in Physical sciences, when we say calculate the velocity it's like we are saying find the gradient…particularly if your graph is going to be constant"*

It was noticed that Miss. MH did not explicitly point out how "x" and "y" from mathematics related to "x" and "t" in the definition of velocity. What was evident in her lesson was that she had a limited understanding of the concept of position, regarding it as a scalar yet at a later stage she considered it to be the same as displacement. In the dialogue above, she started with a position-time graph and then she erased "position" on the vertical axis and wrote "displacement", keeping the graph the same. Although a displacement-time graph and a position-time graph can be the same, the condition is that the displacement must be measured from a fixed zero position reference point. This is not how the displacement-time graph was treated in Miss. MH's lesson, thus it was explained incorrectly. Furthermore, it seemed that Miss. MH could not link velocity with position but rather with displacement. In the dialogue above, she made reference to displacement and not position, in fact she did not indicate how the gradient of a position-time graph represented "displacement over time". Furthermore, she defined velocity as the rate of change of displacement. She then constructed the corresponding velocity and acceleration-time graphs using definitions of velocity and acceleration, without emphasising the fact that they were the gradients of the corresponding graphs.

As it was indicated earlier, Miss. MH hardly incorporated representations, although there were concepts that could have been explained better, had she used them. The involvement of learners in Miss. MH's lesson was adequate, however, their understanding of concepts was limited by the fact that Miss. MH put less emphasis on the concept of gradient. She asked them to infer data from graphs of motion, and she substituted it in definitions of velocity and acceleration without emphasising the fact that those definitions were the gradients of a position-time and a velocity-time graph respectively. Although some of the data that learners called out were incorrect, she still substituted them and then allowed time for the learners to assess the correctness of the values they suggested. Eventually some of the learners realised that there had been values that were incorrectly substituted. This strategy was to promote independence as she told them that they had to be responsible for their own learning. Learners were also requested to infer data from a table to construct a position-time graph and use such a graph to construct other corresponding graphs of motion on their own. She then randomly selected learners to present their calculations and graphs on the board for the rest of the class.

Miss. MH's teaching strategy may have been effective, especially inferring from the ways in which she involved learners, if she had adequate SMK about graphs of motion. Her limited understanding of concepts could have been transferred to learners as she presented concepts incorrectly. Thus she poorly explained key ideas and poorly indicated how they were interrelated with each other and with their sub-ordinate ideas. She also hardly incorporated representations to support her explanations of concepts. As a result, her competence was considered to be limited.

5.4 CASE STUDY 4 – MR. KZ

Mr. KZ was confident when he was teaching graphs of motion to his learners. He explained concepts thoroughly until he was convinced that learners understood before moving on. Mr. KZ also let learners voice their answers, in some instances he corrected them by reasoning with them, and in other instances he provided them with correct answers using direct instruction.

5.4.1 Analysis of Mr. KZ's lesson

Learners' prior knowledge

Mr. KZ seldom explored learners' prior knowledge by asking questions that revealed what they already knew or possible misconceptions. He also attempted to prevent misconceptions by voicing possible misunderstandings. For example, after constructing positive vertical and horizontal axes, he asked:

> *"Why don't we have the negative y and the negative x on this graph? Because time cannot be negative, remember time is a scalar quantity therefore you can't say negative time represents the opposite direction"*

The question Mr. KZ asked referred to both the vertical and horizontal axis, but his response focused only on time, a variable put on the horizontal axis. This could potentially induce a misconception in learners – they would think that graphs of motion should be constructed on the quadrant where both the dependent and independent variables were positive. The way he attempted to prevent this possible misconception was limited by the fact that he did not let learners respond to the question, he responded before they could. This was the same behaviour that Chapoo et al. (2014) regarded as a strategy that revealed poor PCK.

Mr. KZ facilitated a discussion that explored the existence of one of the misconceptions that he had specified in the interview – the belief that objects moving in a straight line can change direction without stopping. He asked if it is possible to change direction without stopping, but did not specify the number of dimensions in which the motion was conceptualised. Some learners responded in the affirmative. Upon realising that they were mistaken, he then discussed dimensions and incorporated a representation (walking) to show them that in two dimensions direction could be changed without stopping, but the same could not be done when the motion is in a straight line (in one dimension).

His competence was regarded as basic since he confronted only one misconception adequately and attempted to prevent another by spoon-feeding learners with the correct concept.

Curricular saliency

Mr. KZ spent most of his time explaining graphs of motion at constant velocity rather than accelerated motion. As a result, key ideas associated with acceleration were not thoroughly discussed. He did not explore the idea that instantaneous and average velocity are respectively represented by the gradient of a tangent and a secant to a curved position-time graph. It was noticed that Mr. KZ also omitted key ideas that could have been discussed in relation to graphs of motion at constant velocity. The only key ideas he discussed were position-time graph, its gradient and what it represents (velocity), and the subsequent velocity-time graph. Mr. KZ also constructed a velocity-time graph in Figure 5.4 below which represented accelerated motion. However, in his descriptions of the motion, he did not mention the term “acceleration”.

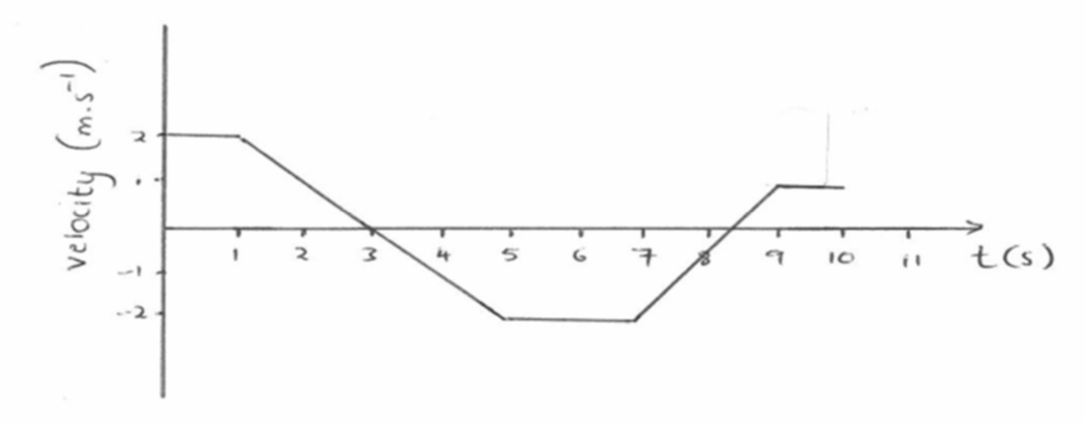


Figure 5.4

Learners were asked questions based on the graph (also see "what is difficult to teach?"). Although he asked learners to comment on the sections of the graph where the object is slowing down, moving faster or being stationery, he did not link these ideas with acceleration, having indicated during the interview that learners had misconceptions related to acceleration. He also did not teach learners how to calculate displacement and acceleration by calculating the area under the graph and the gradient of different sections of the graph. Subsequently, position-time and acceleration-time graphs were not constructed and related to a velocity-time graph.

His revealed competence about this component was regarded as basic. This was based on the idea that he omitted a large number of key ideas in the lesson, which limited the sequencing and the discussion of the interrelatedness of the key ideas.

What is difficult to teach?

As indicated in chapter four, the concepts that Mr. KZ indicated as difficult in the interview were:

- Learners focused on the slopes of graphs to make decisions about the motion of the moving object. As a result they thought that an increasing constant gradient position-time graph represents motion of an object that is speeding up.
- Learners found it difficult to interpret a velocity-time graph when it indicated an object stopping and changing direction as they did not understand that in one dimension, an object must stop before it changes direction.
- Learners did not have a clear understanding of the phrase; calculate the area "under" a velocity-time graph.

Mr. KZ facilitated discussions that revealed the first two difficulties indicated in the list above and confronted them. After constructing an increasing position-time graph (diagonal line), the following discussion took place:

> *Mr. KZ: "is the object speeding up or slowing down?"*
>
> *Learners: (most of them) "speeding up"*
>
> *Mr. KZ: "It's not speeding up or slowing down, why am I saying that? Because the gradient of the line stays the same throughout, you can't say the gradient of a straight line will change somewhere…"*
>
> *Mr. KZ: (expanding further) "Guys, the formula is y = mx + c, this m is the same throughout the line, this m is not going to change because this is a straight line…the gradient will stay the same throughout…when you say constant velocity you mean the gradient is remaining the same throughout".*

Although he referred to the learners' prior knowledge of straight line graphs, he reverted to rote teaching and did not allow learners to substantiate why they thought the object was speeding up. This could have enabled him to pin down the gate keeping concepts that the learners might have lacked. In his confrontation of the difficulty about velocity-time graphs he also interrupted a learner while she was explaining why objects could stop without changing direction. He corrected her before she could complete her sentence, and once again this limited his insight of the gate keeping concepts that the learner may have lacked. After constructing the velocity-time graph in Figure 5.4, the following discussion occurred:

> *Mr. KZ: "…does the object stop, even for an instant? If so, when does this happen and how do you know this?"*
>
> *Learner A: "Yes it does, it stops when it [the line/graph] crosses the x-axis [horizontal axis]"*
>
> *Learner B: "But Sir, isn't it that it doesn't stop but it only changes the direction?"*
>
> *Mr. KZ: "But is it possible to change direction without stopping?"*
>
> *Learner B: "But sir…" (Mr. KZ interrupts)*
>
> *Mr. KZ: "Listen to me, I said one dimension isn't it? I'm gonna change the direction in two ways and tell me which one is the one that we're doing… (While walking), I'm changing the direction, but this one I do not have to stop, it's not in one dimension. I'm talking about one dimension, is it possible to change the direction without stopping (while walking and demonstrating that it is not)?"*
>
> *Learners: "No"*

Despite interrupting the learner, he addressed the difficulty about stopping and changing direction fairly adequately – he confirmed that indeed objects can change direction without stopping and also specified cases in which this happens. He then showed learners, while walking, that in one dimension (straight line) he had to stop before he could change direction and go back to where he came from. After his discussion of dimensions, he then proceeded with questions based on the graph. He asked learners to comment on the intervals where the object was slowing down, speeding up and moving at a constant velocity. Some learners focused on the slopes and said the object was slowing down from three second to five seconds. To address this misunderstanding, he mentioned that the negative gradient did not show a decrease but rather the direction in which the object was moving. He further explained that objects are slowing down if the velocity-time graph is approaching zero, as zero velocity means no movement, and that the object's velocity is increasing when the graph moves away from zero regardless of the direction. After explaining this idea learners were then able to understand that the velocity was decreasing from one to three seconds and from seven to just after eight seconds.

As he did not discuss the idea that displacement is represented by the area under a velocity-time graph, it was not observed whether he used the phrase "the area under the velocity-time graph" as it was in learning materials or as he had suggested in the interview – "the area between the graph and the horizontal axis".

As Mr. KZ facilitated discussions that revealed the difficulties that he indicated in the interview, and confronted some of them by incorporating representations where necessary, his revealed knowledge about learners' difficulties was considered to be developing.

Representations including analogies

Mr. KZ used representations in his lesson mostly to enhance his learners understanding of concepts identified as difficult to teach. Having mentioned that his learners believed it was possible for an object moving in a straight line to change direction without stopping, he incorporated a representation ("walking") showing them that it was not. To further clarify this concept, he threw a marker pen up into the air, caught it later and mentioned that it stopped at its maximum height, before it changed direction. But because this was so sudden and one could not easily detect it with the naked eye, Mr. KZ said:

> *"If you can get a video and view it in slow motion you can see that in fact the object is going to stop. When you throw this up, look, when you throw this up but I'm telling you, it will go up and when it gets to the maximum height it must stop and it changes the direction"*

Mr. KZ's competence about representations according to the rubric was developing as the representations were used to explain concepts identified as difficult for learners.

Conceptual teaching strategies

As mentioned earlier, Mr. KZ hardly explored learners' prior knowledge for the purpose of identifying gaps and misconceptions. He instead attempted to prevent a possible misconception by spoon-feeding learners with the correct understanding of the concept. He introduced his lesson by presenting a table with position and time data, which was used to construct a position-time graph. While constructing the graph, he mentioned the necessary ideas linked with constructing graphs, for example that time is an independent variable and thus should be on the horizontal axis. From the graph, he adequately explained that its gradient represented velocity:

> *Mr. KZ: "and now we know how to calculate the gradient, let's do it…tell me the gradient formula?"*
>
> *Learners: "M equals $y_2 - y_1$ divided by $x_2 - x_1$" (Mr. KZ wrote it on the board)*
>
> *Mr. KZ: "Now when you look at the graph what is your y? Your y is x can you see that? (pointing to the graph)…which means you have $x_2 - x_1$ and for the x we have t which means it's gonna be $t_2 - t_1$" (Mr. KZ wrote this under the standardised formula for gradient)*
>
> *Mr. KZ: "Now if I want to write this in a different form I can say $x_f - x_i$ all over $t_f - t_i$…then change in x is the same as delta x and change in t is the same as delta t…now when I look at this I can see this is nothing but the?*
>
> *Learners: (some of them) "velocity"*
>
> *Mr. KZ: "Then from this I can conclude and say the gradient of a position-time graph is going to give me the velocity"*

He then constructed a velocity-time graph by inferring data from the position-time graph through calculating its gradient. Mr. KZ did not proceed using this velocity-time graph to explain that its gradient and area respectively represent acceleration and displacement. This could have then been followed by the construction of an acceleration-time and a position-time graph. Hence there was no evidence that the conceptual development of these graphs was attained.

As indicated earlier, his lesson was devoted to the three key ideas: position-time graph, its gradient and the velocity-time graphs. It was also indicated that those ideas that were discussed were explained fairly adequately. Furthermore, despite not allowing learners to substantiate their answers, he confronted the difficulties they revealed when they responded to the questions he asked. The questions required them to apply knowledge instead of recalling it. He also incorporated representations where necessary.

Mr. KZ explained the key and subordinate ideas fairly adequately. His competence could have been classified as developing had he let learners substantiate their answers and had he indicated progression from one key idea to the other. Thus the absence of some of the important key ideas resulted in a lack of explanations of how ideas were interrelated and how they should be sequenced. As a result, his competence was considered to be basic.

6. CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In Chapter Four and Five the data collected throughout this study was presented and discussed to provide answers to the sub-questions that guided the study. In this chapter, the captured PCK discussed in Chapter Four and the revealed PCK discussed in Chapter Five, are compared. The cases of each teacher are presented separately. Table 6.1 – 6.4 summarises the competences of the teachers in the TSPCK components which were discussed in detail in Chapter Four and Five. The inferred conclusions also answer the main question of this study, which is: How does teachers' captured PCK compare to the PCK they reveal when teaching graphs of motion? The final section of the chapter outlines recommendations for future practice and research, based on the findings.

6.2 COMPARISON OF TEACHERS' CAPTURED AND REVEALED PCK

6.2.1 Mrs. VM

Table 6.1: Mrs. VM's competencies in the captured and revealed PCK

	Captured PCK (CoRes and interviews)				Revealed PCK (lesson presentations)			
TSPCK components	Limited	Basic	Developing	Exemplary	Limited	Basic	Developing	Exemplary
Learners' prior knowledge		X				X		
Curricular saliency	X					X		
What is difficult to teach?		X				X		
Representations including analogies			X			X		
Conceptual teaching strategies		X				X		

Learners' prior knowledge

During her lesson presentation, Mrs. VM revealed a level of PCK for this component that did not vary significantly from the level captured by her CoRes and interview data. The way she presented learners' misconceptions in her captured PCK suggested that she was not equally competent with regard to the separate misconceptions. A similar variation was also observed during the lesson presentation. There were cases where she adequately addressed learners' misconceptions, and cases where she guided learners into answering her questions correctly, which according to Chapoo et al. (2014) was a feature of poor PCK. The misconceptions she explored during her lesson, compared to those that she had specified in her captured PCK, suggested that she was aware of more misconceptions than she indicated. Furthermore, she explored only some of the misconceptions indicated in her captured PCK. This revealed the tacit nature of PCK. It seemed Mrs. VM struggled to recognise the importance of specifying all misconceptions she was aware of in her captured PCK, and addressing them during the lesson.

Curricular saliency

Mrs. VM articulated a poor PCK base about curricular saliency when it was captured through CoRes, whereas during the lesson she enacted a higher PCK base. The major difference was that she presented more ideas than she had indicated in her captured PCK during her lesson. The discussion of the ideas enabled the researcher to explore the sequence in which Mrs. VM presented them, which was found to be logical. This sequence was not evident in her captured PCK because the ideas themselves were minimal. It is important to note that Mrs. VM did not necessarily discuss all the ideas in this topic during her lesson presentation, but she discussed more than her captured PCK had suggested. This suggested that she was aware of the importance of more ideas in the topic than her captured PCK had suggested. She seemingly did not consider the importance of mentioning them in the CoRe and the interview. This inadequacy of key ideas also led to a lack of information about the interrelatedness between key ideas in the captured PCK, whereas in the revealed PCK, the interrelatedness was limited to the ideas that were discussed. It was noticed that the way she explained the interrelatedness was inadequate because she, for example, did not thoroughly explain that velocity is represented by the gradient of a position-time graph. Thus her lesson revealed instances where her PCK was adequately revealed and other instances where it was not. The difference in revealed and captured PCK may suggest that she was aware of the importance of the concepts that she taught, but did not see the importance of mentioning them in the captured PCK.

What is difficult to teach?

Mrs. VM approached the two ideas that she had indicated as difficult in her captured PCK; the interrelatedness between, and the interpretation of, graphs of motion. The way she approached the first difficult idea in her lesson was different from the way her captured PCK had suggested. Firstly, her approach did not convey the impression that she considered it as particularly difficult, following that she did not explore learners' difficulties regarding it and did not assess learners' understanding while discussing it. Secondly, she began her discussion from a gate keeping concept, gradient, that she had deliberately omitted in her CoRes. The way she approached the second difficulty revealed instances where she incorporated strategies (a representation) suggested by her captured PCK, and instances where she did not. She interpreted some of the graphs while "walking the graph", and interpreted some of the graphs only verbally. She discussed position-time graphs better than she discussed the other graphs of motion. Thus her knowledge about learners' difficulties varied from one difficulty to another. Having said that learners consider all graphs to be position-time graphs, it could be that she emphasised position-time graphs over the other types of graphs of motion.

Representations

Mrs. VM's captured PCK suggested that she had a developed understanding of a representation ("walking-the-graph") that supported the teaching of graphs of motion concepts. She had also specified that the representation helped address learners' misconceptions and difficulties. During the lesson, Mrs. VM indeed incorporated the representation to support her explanation of some of the concepts. However, there were instances in which she could have utilised the same representation, but she did not. She also incorporated diagrams as representations, which she had not indicated in her captured PCK. The way the diagrams presented information had potential to induce misconceptions, which she did not comment on. It could be that she did not pick it up or that her content knowledge was not developed to such a level that would have enabled her to recognise its deficiency, thus it affected her PCK (Rollnick et al., 2008; Mdolo & Mundalamo, 2015). One could argue that the drastic difference in the PCK levels was induced by the fact that she limited her discussion of representations in her captured PCK to just one concept, whereas she taught a number of concepts during lesson presentation.

Conceptual teaching strategies

Mrs. VM's captured PCK indicated little information about her knowledge base of conceptual strategies of teaching this topic, following the shortage of key ideas. It was however evident from her captured PCK that a direct instruction was amongst the strategies that she incorporates in her lessons. During the lesson, this strategy was evident. However, it was a bit different from the way it initially appeared in the captured PCK. The difference was that direct instruction was used when she responded to her own questions instead of probing further, or rephrasing a question for learners to be able to answer. It should be mentioned that Mrs. VM asked questions that required learners to apply knowledge, it was so unfortunate that learners were denied the opportunity to respond to them. The absence of the majority of key ideas in Mrs. VM's captured PCK limited the researchers' insight towards understanding the strategies that she incorporated to conceptually develop learners' understanding of the topic. Although she discussed a few more ideas in the lesson, learners were seldom involved in the conceptual thinking that led to the development of the concepts. Calculations of gradient and the corresponding graphs of motion were presented to the learners on a transparency. The lesson presentation further revealed that Mrs. VM's teaching strategies also varied from concept to concept. Her discussions of graphs of motion at constant velocity was not of a high quality, but it was better than her discussions of graphs of accelerated motion. Although both her competences were scored basic, the revealed PCK was of a slightly higher quality than the captured PCK.

6.2.2 Mrs. SC

Table 6.2: Mrs. SC's competencies in the captured and revealed PCK

	Captured PCK (CoRes and interview)				Revealed PCK (lesson presentation)			
TSPCK components	Limited	Basic	Developing	Exemplary	Limited	Basic	Developing	Exemplary
Learners' prior knowledge		x				x		
Curricular saliency		X					X	
What is difficult to teach?		X				X		

Representations including analogies		X				X		
Conceptual teaching strategies		X				X		

Learners' prior knowledge

Mrs. SC introduced her lesson by discussing mathematics concepts that were applicable to this topic as her captured PCK had suggested. Although her captured PCK did not indicate how she engaged with the concepts, her lesson revealed that she reverted to rote teaching. This was also evident in her discussions of some of the prior knowledge that she had identified in her captured PCK as confusing for learners. She hardly facilitated discussions to explore the confusions, she instead discussed the knowledge using direct instruction. Having not identified learners' misconceptions regarding this topic, she also did not explore them during the lesson. Mrs. SC's competences with regard to learners' prior knowledge were regarded as basic in both the captured and the revealed PCK, indicating that the quality of her PCK regarding this component did not vary significantly.

Curricular saliency

The way Mrs. SC presented her lesson revealed that her PCK was of a higher quality than her CoRe and interview suggested. In her captured PCK she presented key ideas as separate concepts, having not shown how they were interrelated. During the interview, she also indicated a logical sequence in which the ideas should be presented. Her revealed PCK was of a significantly higher quality because she not only sequenced her teaching of the concepts adequately, she also presented them as a unit. She discussed the interrelatedness between key ideas adequately, showing how new knowledge develops from pre-concepts. However, this adequate discussion of the interrelatedness was only evident in her discussion of graphs of motion at constant velocity. Thus it indicated that the level of developed PCK was not evident for all concepts, and that in some instances the revealed PCK was at a similar lower level as the PCK suggested by her CoRe and the interview. It was also observed that Mrs. SC discussed more key ideas during her lesson presentation than was suggested by her captured PCK. Thus it seemed that Mrs. SC appreciated the importance of key ideas and their interrelatedness only during the presentation of the lesson, as opposed to merely mentioning them in her captured PCK.

What is difficult to teach?

Mrs. SC did not articulate her PCK about learners' difficult concepts adequately, despite identifying some difficulties presented in the expert CoRe, because she did not explicitly link them to graphs of motion. The ideas that she had identified as difficult were: inferring data from one graph and using it to construct another, and dividing complex shapes into workable ones for calculating the area under graphs. Although she discussed the majority of the concepts that she had indicated as difficult, the confrontational strategies utilised varied from concept to concept and also varied in terms of their effectiveness. The first difficult idea was adequately confronted in the discussion of graphs of motion at constant velocity. It was not observed how she would have helped learners divide complex shapes into workable ones. This could have been due to time constrains as she started rushing through the lesson, especially when she discussed graphs of accelerated motion. As a result, judgement cannot be made about her level of competence with regard to that difficulty until she is physically observed confronting it.

Representations

Mrs. SC's lesson observation revealed that she did not incorporate the representations, ticker timer experiments and complex shapes, which she had specified in her interview. She incorporated a representation that she had not mentioned in her captured PCK when she demonstrated, by walking, that negative and positive values of gradient represented direction. This showed that she was aware of a variety of representations in the topic, however, she did not mention some of them in the captured PCK and did not realise the need to incorporate others during the lesson. It was also observed that Mrs. SC only utilised the representation once despite a majority of concepts that could have been explained better, had she incorporated the representation.

Conceptual teaching strategies

The way Mrs. SC said she taught this topic, as she indicated in the interview, was practised during the actual lesson. She introduced her lesson by discussing learners' prior knowledge of mathematics, just as her captured PCK had suggested. Her captured PCK had also suggested that she used direct instruction as a teaching strategy, which is, presenting a summary that shows learners how the motion variables were related through the area and gradients of graphs. She indeed presented the summary during her lesson, however, she did not just show the learners when to calculate gradient and area, but she showed them how to calculate gradient and area and how they provide information about motion variables. She also used the inferred data to construct the corresponding graphs. Thus learners were involved in the conceptual thinking that led to the development of the summary. It was also observed that Mrs. SC's teaching strategy was not of the same quality, that is, it was only adequate in her discussion of graphs of motion at constant velocity and inadequate in her discussion of accelerated graphs. Her discussion of graphs of accelerated motion did not differ significantly from the way her captured PCK had suggested, that is, there was no conceptual development from pre-concepts to new concepts, despite the fact that she sequenced the concepts adequately. Although her captured and revealed PCK were considered to be basic, the competence was slightly higher in the lesson than was suggested by the captured PCK.

6.2.3 Miss. MH

Table 6.3: Miss. MH's competencies in the captured and revealed PCK

	Captured PCK (CoRes and interview)				Revealed PCK (lesson presentation)			
TSPCK components	Limited	Basic	Developing	Exemplary	Limited	Basic	Developing	Exemplary
Learners' prior knowledge	X				X			
Curricular saliency			X		X			
What is difficult to teach?		X			X			
Representations including analogies		X			X			
Conceptual teaching strategies		X			X			

Learners' prior knowledge

The way Miss. MH articulated her PCK about learners' prior knowledge, and the way she revealed it during the lesson had similar features. In her discussions in the CoRe and interview about learner difficulties it became clear that she herself had several misconceptions about concepts in the topic. In her captured PCK, she revealed her own misconception when she indicated how she intended to discuss “deceleration” in the lesson, but since she did not address acceleration in the lesson, it was not observed how she would have treated the concept of deceleration. In the lesson she did not teach graphs of accelerated motion, hence it was not observed how she would have taught deceleration in comparison to her captured PCK. During her lesson, she revealed her own misconception about the concepts of position and displacement that did not emerge in her captured PCK. Although the misconceptions that she revealed in the captured and the revealed PCK were different, the lesson observation revealed that she possessed more misconceptions than her captured PCK suggested. Furthermore, the observation also confirmed the assumption the researcher had that there was a possibility that Miss. MH would transfer her own misconceptions to learners during lesson presentation. Thus Miss. MH enacted her PCK about learners’ prior knowledge almost similar to the way her captured PCK about the same component had suggested.

Curricular saliency

Miss. MH’s captured PCK, based on graphs of motion at constant velocity, revealed features of basic competence. Although the information she had shared in the CoRe was deserving of a developing competence, her interview revealed aspects of poor PCK about curricular saliency. In the CoRe, she revealed awareness of key ideas, logical sequencing and the interrelatedness of the ideas whereas in the interview this information was poorly discussed. Although she only taught graphs of motion at constant velocity, she revealed a lower level of competence in her lesson. The sequencing of concepts during the lesson was almost similar to the sequencing indicated in the captured PCK, the major difference was in the interrelatedness between ideas – gradient and area were partly discussed and utilised in the lesson. She inferred data from graphs using the definition of velocity and acceleration without mentioning the fact that those definitions were in fact gradients of a position-time and a velocity-time graph respectively, and used the data to construct corresponding graphs. As a result, her revealed PCK was of a poor quality compared to her captured PCK. It is unclear why Miss. MH’s levels of captured and revealed PCK were different. However, it suggested that she considered gradient and area as difficult concepts to discuss in the topic, especially in the presence of the researcher. Thus she involved simpler concepts that led to the same calculations and graphs, instead of using gradient and area. Miss. MH had a developed understanding of the curricular saliency of the topic, however, she portrayed it more adequately in her captured PCK than the revealed PCK. It was possible that learners' conceptual development could have been affected as the revealed PCK that impacted their learning was of a poor quality.

What is difficult to teach?

The way Miss. MH mentioned concepts that were difficult to teach in the captured PCK revealed that she could not clearly specify what it was that was difficult to teach. During the lesson, the way she approached some of the concepts that she had identified as difficult, suggested that she did not really consider them as problematic, because she did not spend more time or elaborated more on these than on any of the other concepts. Furthermore, she did not confirm whether learners indeed had difficulties regarding those concepts, neither did she confirm whether they had adequate understanding of the concepts after discussing them. Some of the major difficulties that Miss. MH identified in the CoRe and the interview were not discussed in the lesson. These concepts were: learners consider all graphs of motion to be indicating motion at constant velocity, learners find it difficult to identify shapes and calculate the areas of those shapes under a velocity-time graph. It is not known why she did not discuss those concepts despite the fact that a number of opportunities to address these presented themselves. However, like previously indicated, it could be that she was aware of some of the major difficulties in the topic, but decided not to discuss them in the presence of the researcher due to the complexity of the concepts (Childs & McNicholl, 2007). She attempted to explain how to interpret direction in a position-time graph, which the researcher linked to the difficulty that she had identified about the interpretation of graphs of motion. Her explanation of the concept was limited and lacked the use of necessary representations, for example "walking the graph", as discussed previously.

Representations

Miss. MH hardly incorporated representations in her lesson contrary to what her captured suggested. The representations she had indicated were simulations and ticker timer experiments. The only time she used representations was when she shaded the horizontal axis for graphs showing zero magnitude. Although she had indicated the use of representations in her captured PCK, the fact that she did not adequately explain how they worked and how they supported the discussions of concepts resulted in her PCK being regarded as basic. Her revealed PCK was regarded as limited based on the fact that representations were seldom incorporated in the lesson.

Conceptual teaching strategies

Miss. MH did not begin her lesson from a mathematical point of view, although she indicated in the interview that it was important to do so. Her lesson presentation revealed that her content knowledge about this topic was poor. One of the aspects that revealed a possible poor content knowledge was the fact that she asked simple recall questions and apparently did not have the confidence to ask questions that required higher order thinking skills (Childs & McNicholl, 2007). This lack of content knowledge was not as evident in the captured PCK, probably because her CoRe focused on motion at a constant velocity; a key idea she felt comfortable with. Although Miss. MH did not explicitly outline strategies that she had intended to incorporate in her lesson, she appeared to have a developed understanding of the conceptual development of new concepts from pre-concepts as far as motion at a constant velocity was concerned. In her lesson, she discussed concepts in the same logical sequence that her captured PCK had suggested, with the difference that she inadequately explained the conceptual development of new concepts from pre-concepts. According to her captured PCK, she was going to incorporate representations to engage with some of the concepts in the lesson. However, she did not incorporate any representation anytime during the lesson. What was interesting to observe was that learners were highly involved in the lesson, however, the involvement could not lead to conceptual understanding because concepts were discussed incorrectly. The difference in the way she presented her lesson and the way she portrayed her PCK in the CoRes and interview suggested that she might have been intimidated by the presence of the researcher. Thus she decided to involve concepts that were easy, so she could have less trouble presenting them and assessing learners' understanding of them. The level of pedagogical knowledge that she enacted suggested that with a higher level of content knowledge and confidence, she could have easily transferred the content into a teachable form.

6.2.4 Mr. KZ

Table 6.4: Mr. KZ's competencies in the captured and revealed PCK

	Captured PCK				Revealed PCK			
TSPCK components	Limited	Basic	Developing	Exemplary	Limited	Basic	Developing	Exemplary
Learners' prior knowledge			X			X		
Curricular saliency			X			X		
What is difficult to teach?			X				X	
Representations including analogies		X					X	
Conceptual teaching strategies			X			X		

Learners' prior knowledge

During the lesson, Mr. KZ approached learners' prior knowledge slightly differently from the way his captured PCK had suggested. His captured PCK showed that he was aware of the major misconceptions in the topic and that he was aware of strategies that addressed those misconceptions. He only explored and addressed one of the misconceptions that he had identified in the captured PCK – the belief learners had that objects moving in a straight line can change direction without stopping. Despite an awareness of learners' misconceptions regarding velocity and acceleration that he indicated in his captured PCK, he did not explore and address those during the lesson. His lesson presentation also revealed teaching approaches that were not portrayed in his captured PCK, he attempted to prevent a misconception from emerging (see Paragraph 5.4.1). The fact that this particular misconception was not mentioned in his captured PCK suggested that he was aware of more misconceptions than he indicated, and that he did not explore all the misconceptions that he was aware of during his lesson presentation. This further confirmed the complex nature of PCK, because he articulated a higher PCK in the interview than he revealed during his lesson.

Curricular saliency

Mr. KZ's captured PCK had suggested that he possessed a developed understanding of the curricular saliency of this topic. His revealed PCK on the other hand indicated that although he was aware of key ideas, their interrelatedness and a logical sequence of teaching the ideas, he did not effectively translate that knowledge into practice. He discussed only a few key ideas, thus limiting learners' understanding of the interrelatedness between ideas to only those he addressed. Nevertheless, he adequately explained how velocity is represented by the gradient of a position-time graph and, subsequently, inferred data using the same concept and used it to construct the corresponding velocity-time graph. The lesson presentation thus indicated that his captured PCK was not reflected in practice – Mr. KZ portrayed a higher level of PCK when it was written down and discussed than when he revealed it in practice. This is based on the fact that he failed to recognise the importance of discussing the majority of concepts in the topic during lesson presentation, despite being aware of those. Thus his revealed PCK was drastically lower than was suggested by his captured PCK.

What is difficult to teach?

Mr. KZ's awareness of concepts that learners find difficult, as identified in the captured PCK, was evident during his lesson presentation. Having indicated that learners focus on slopes when interpreting graphs of motion, he facilitated discussions that revealed and addressed the difficulty in different cases. Thus he enacted PCK that was similar to the PCK that he had portrayed in his interview with regard to this difficulty. This was revealed when he started by addressing the gate keeping concepts (motion in one or more dimensions) before addressing the difficulty; the lack of understanding that objects moving in a straight line must stop before changing direction. Thus Mr. KZ enacted a PCK base that was almost the same as the PCK that was suggested by his CoRes and interview.

Representations

Mr. KZ's lesson presentation revealed that he incorporated the representation that he had indicated in his captured PCK – simulating graphs of motion by walking. His enacted PCK revealed features of developing competence whereas his captured PCK had suggested that his competence was basic. Mr. KZ had not indicated the concepts that were supported by using such a representation, whereas during his lesson, he used the representation to support his confrontation of learners' misconceptions and difficulties. Thus his captured PCK was limited by the fact that he did not recognise the importance of specifying the supported concepts. Furthermore, his captured competence about representations was thus not a true indication of his competence about representations.

Conceptual teaching strategies

The PCK that Mr. KZ enacted in his lesson presentation was drastically lower than the PCK that was suggested by his interview. He did not introduce his lesson from a mathematical point of view, having indicated the importance of incorporating mathematics concepts in this topic. However, the major difference in the captured and revealed PCK was that he did not discuss all the relevant key ideas and thus denied learners the conceptual understanding of the interrelatedness between concepts. Nevertheless, the ideas he decided to teach were presented according to the way his captured PCK had suggested. He started from pre-concepts and developed learners' conceptual understanding of the new concepts that emerged. Thus, if only he had discussed more key ideas than he actually did, his revealed PCK would have been almost the same level as his captured PCK. Mr. KZ incorporated representations, including one that he had indicated in his captured PCK. During the lesson, the representations were used to address learners' difficulties, whereas in the captured PCK Mr. KZ had not elaborated on how he used the representations and which concepts were supported by such representations. Mr. KZ also involved learners in his lesson, through questions that explored their difficulties and understanding of concepts, almost similar to the suggestion made in his captured PCK, and addressed those difficulties.

6.3 DISCUSSIONS OF THE RESULTS

The results of this study supported the claim by Park and Oliver (2008) that teachers' PCK is not fixed, and that its application depends on context and interaction with learners. The participants in this study portrayed different levels of PCK when using different data collection strategies. Mrs. SC and Mr. KZ poorly articulated their PCK in the CoRe tool, whereas they expressed an improved PCK base during their interviews. Miss. MH on the other hand poorly portrayed her PCK during her interview having articulated a higher PCK base in the CoRe. Although the interviews and the CoRes were combined to describe teachers' captured PCK, it is important to remember that the PCK of the teachers was not necessarily portrayed the same way in those two instruments. As mentioned by Park and Oliver (2008), the presence of and interaction with learners during lesson presentation developed the PCK of teachers. In this study learners provided a platform that further challenged teachers' PCK and thus revealed strengths and weaknesses in their PCK. These strengths and weaknesses were not exposed in the captured PCK. Mr. KZ and Mrs. SC, upon realising that learners did not understand some of the concepts, incorporated representations that they had not indicated in their captured PCK to support their explanations. Although Mrs. VM utilised a representation that she had specified in her captured PCK, she used it to confront a misconception that was apparently not anticipated, as it was not indicated in the captured PCK.

6.4 CONCLUDING REMARKS

The results of this study, in relation to the sub-questions, indicated that the participating teachers seldom portrayed the same level of competence in the five TSPCK components, but typically displayed similar competence in at least three of the five components in the captured and the revealed PCK. In relation to the main question, the results have indicated instances where teachers' captured and revealed competences varied. The most frequent outcome was that teachers revealed higher or the same levels of competence in their captured PCK compared to their revealed PCK. In rare instances however, Mrs. SC and Mr. KZ revealed higher competences in some of the components during lesson presentation than suggested by their captured PCK. Furthermore, the differences in captured and revealed PCK did not vary by more than one level, for example limited and basic.

These results then led to the following concluding remarks: a teacher's level of competence in one component is not necessarily an indication of his or her competence in the other components that define PCK and subsequently in his/her overall captured or revealed PCK. Furthermore, the level of competence in a component in the captured PCK is not necessarily an indication of the level of competence within that component that the teacher would reveal during lesson presentation. The level may be the same, slightly different (higher or lower) or even be drastically different in the lesson than suggested by the captured PCK. This indicates that teachers' captured PCK is not necessarily a true reflection of the PCK they reveal during lesson presentation.

6.5 LIMITATIONS AND RECOMMENDATIONS

Limitations of the study

As stated by Maree (2010), the goal of qualitative research is not to generalise findings to the whole population, but to understand the behaviour of the participants involved. As a result, the first limitation is that the findings in this study are limited to the participants who were involved. The second limitation is that this study cannot be replicated using other research designs because the questions that guided it could only be answered using case study research design (Maree, 2010). The third limitation is the fact that there was no incentive for the teachers who participated in this study. This is believed to be the reason why teachers' CoRes were not completed in full or in greater detail. However, the interviews helped gather the data that could not be gathered through CoRes. The fourth limitation is the researcher's bias. As a physical sciences teacher, the researcher has his own beliefs about ways in which graphs of motion should be taught to learners. This belief may have influenced the way he assessed the quality of the teachers' captured and revealed PCK. However, the interpretation of the data by his supervisors minimised the researcher's bias in the study.

Recommendations for future research

The way teachers' PCK was accessed and interpreted in this study has been reported in literature, however, there is still a paucity of information about the comparison between captured and revealed PCK. This study contributes in a sense that it separates two manifestations of PCK and compares them to establish whether CoRes and interviews reflect the PCK that teachers enact during lesson presentations or not. The other contribution is that the researcher developed rubrics to assess teachers' captured and the revealed PCK about graphs of motion. Although the captured PCK rubric was adapted from many rubrics found in literature, the revealed PCK rubric was developed from captured PCK rubrics because there were no revealed PCK rubrics in literature.

The researcher recommends that other studies may be conducted to investigate the comparison of the two manifestations of PCK in other topics. In this study there were no interventions aimed at improving teachers' PCK about graphs of motion. The researcher recommends that the two manifestations can be compared after an intervention has been administered to teachers to improve their PCK.

Recommendations for future practice

The results have revealed the importance of exploring and assessing PCK through a spectrum of components that define it, because competence in one component doesn't define competence in the other components. Furthermore, teachers' competences should also be explored in relation to a variety of key ideas within the topic. While CoRes were originally developed as a tool that helps teachers articulate their PCK, it is not a sufficient tool for evaluating one's PCK. Thus it is imperative that teachers are observed in practice to assess the quality of their revealed PCK as this is the PCK that ultimately impacts learning.

7. LIST OF REFERENCES

Arshiyan, P., & Pishkar, K. (2015). A survey of the lecturers' perceptions about EFL Azad University students' autonomy versus actual level of autonomy. *Theory and practise in language studies. 5* (11). 2277 - 2286.

Ary, D., Jacobs, L. C., Razavieh, A., & Sorensen, C. (2006). *Introduction to research in education* (7th ed.). Belmont, C.A: Wadsworth.

Barclay, W., L. (1985) Graphing Misconceptions and Possible Remedies Using Microcomputer-Based Labs. Cambridge, MA: Technical Education Research Centre.

Baxter, J., A, & Lederman, N., G. (1999). Assessment and Measurement of Pedagogical Content Knowledge. In J. Gess-Newsome & N. Lederman, G, (Eds.), *Examining Pedagogical Content Knowledge* (pp. 147 - 161). Netherlands: Kluwer Academic Publishers.

Bertram, A., & Loughran, J. (2012). Science teachers' views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education, 42*(6), 1027-1047.

Bertram, A., & Loughran, J. (2012). Science teachers' views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education, 42*(6), 1027-1047.

Brasell, H. (1987). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of research in science teaching, 24*(4), 385-395.

Bukova-Güzel, E. (2010). An investigation of pre-service mathematics teachers' pedagogical content knowledge, using solid objects. *Scientific Research and Essays, 5*(14), 1872-1880.

Bukova-Güzel, E., Kula, S., Uğurel, I., & Özgür, Z. (2010). Sufficiency of undergraduate education in developing mathematical pedagogical content knowledge: Student teachers' views. *Procedia-Social and Behavioral Sciences, 2*(2), 2222-2226.

Buschang, R., E, Chung, G., K, W, K, Delacruz, G., C, & Baker, E., L. (2012). Validating measures of Algebra teacher Subject Matter Knowledge and Pedagogical Knowledge. *Educational Assessment, 17*(1), 1 - 21.

Chantaranima, T., & Yuenyong, C. (2014). The Pedagogical Content Knowledge Exploration from the Thai Expert Physics Teacher's Class. *Procedia-Social and Behavioral Sciences, 116*, 389-393.

Chapoo, S., Thathong, K., & Halim, L. (2014). Understanding Biology Teacher's Pedagogical Content Knowledge for Teaching "The Nature of Organism". *Procedia-Social and Behavioral Sciences, 116*, 464-471.

Chapoo, S., Thathong, K., & Halim, L. (2014). Biology Teacher's Pedagogical Content Knowledge in Thailand: Understanding & Practice. Procedia-Social and Behavioral Sciences, 116, 442-447.

Childs, A., & McNicholl, J. (2007). Investigating the relationship between subject content knowledge and pedagogical practice through the analysis of classroom discourse. *International Journal of Science Education, 29*(13), 1629-1653.

Chordnork, B., & Yuenyong, C. (2014). Constructing CoRe as a Methodological for Capturing Pedagogical Content Knowledge: A Case Study of Thailand Teachers Teaching Global Warming. *Procedia - Social and Behavioral Sciences, 116*, 421 - 425.

Clement, J. (1985). *Misconceptions in graphing.* Paper presented at the Proceedings of the Ninth International Conference for the Psychology of Mathematics Education.

Clermont, C. P., Borko, H., & Krajcik, J. S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of research in science teaching, 31*(4), 419-441.

Clermont, C. P., Krajcik, J. S., & Borko, H. (1993). The influence of an intensive in-service workshop on pedagogical content knowledge growth among novice chemical demonstrators. *Journal of research in science teaching, 30*(1), 21-43.

Cochran, K. F, King, R. A, DeRuiter, J. A. (1991). Pedagogical Content Knowledge: A Tentative Model for Teacher Preparation. East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service No. ED340683)

Consise Oxford English Dictionary. United States: Oxford University Press. 2011.

Cooper, R., Loughran, J., & Berry, A. (2015). Science Teachers' PCK. *Berry, A.; Friedrichsen, P.; Loughran, J. Re-examining Pedagogical Content Knowledge in Science Education, Taylor & Francis: NY*, 60-74.

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). State of the Profession: Study Measures Status of Professional Development. *Journal of Staff Development, 30*(2), 42.

Davidowitz, B., Potgieter, M., & Vokwana, N. (2014). *Exploring the relationship between Content Knowledge of organic chemistry and topic specific PCK.* Paper presented at the 22nd Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE), Port Elizabeth, South Africa.

Department of Basic Education (2011). Curriculum and Assessment Policy Statement Physical sciences. Pretoria: Government Printer.

Department of Basic Education (2014). National Senior Certicicate Examination: Diagnostic report. Pretoria: Government Printer.

Eames, C. W., Williams, P. J., Hume, A. C., & Lockley, J. (2011). CoRe: A way to build pedagogical content knowledge for beginning teachers.

Garritz, A., Alvarado, C., Canada, F., & Mellado, V. (2013). PCK by CoRes and PaP-eRs for teaching Acids and Bases at High school. Paper presented at the proceeding of the National Association for Research in Science Teaching conference, Rio Grande, Puerto Rico.

Garritz, A., Porro, S., Rembado, F., & Trinidad, R (2007). *Latin-American teachers' pedagogical content knowledge of the particulate nature of matter. Submitted to the proceedings of the Congress of the European Science Education Research Association (ESERA).* Paper presented at the Symposium on Understanding science teachers' PCK in the context of curriculum reform, de Jong, O.(coord.).

Geddis, A. N., & Wood, E. (1997). Transforming subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education, 13*(6), 611-626.

Grossman, P., L. (1990). *The making of a teacher: Teacher knowledge and teacher education.* New York: Teachers college press.

Halloun, I. A., & Hestenes, D. (1985). Common sense concepts about motion. *American journal of physics, 53*(11), 1056-1065.

Hancock, B. (2002). *Trent Focus for Research and Development in Primary Health Care: An Introduction to Qualitative Research*. Book. University of Nottingham. Nottingham.

Henze, I., van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education, 30*(10), 1321-1342.

Hesse-Biber, S. N., & Leavy, P. (2011). *The practice of qualitative research* (2nd ed.). London: SAGE Publications.

Hewson, M. G., & Hewson, P. W. (1983). Effects of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Reasearch in Science Teaching, 20,* 731 – 743.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. *Computers & education, 36*(2), 183-204.

Jüttner, M., & Neuhaus, B. J. (2012). Development of items for a pedagogical content knowledge test based on empirical analysis of pupils' errors. *International Journal of Science Education, 34*(7), 1125-1143.

Jüttner, M., Boone, W., Park, S., & Neuhaus, B. J. (2013). Development and use of a test instrument to measure biology teachers' content knowledge (CK) and pedagogical content knowledge (PCK). *Educational Assessment, Evaluation and Accountability, 25*(1), 45-67.

Kagan, D. M. (1990). Ways of evaluating teacher cognition: Inferences concerning the Goldilocks principle. *Review of educational research, 60*(3), 419-469.

Käpylä, M., Heikkinen, J. P., & Asunta, T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education, 31*(10), 1395-1415.

Kaya, O., N. (2009). The Nature of Relationships among the Components of Pedagogical Content Knowledge of Preservice Science Teachers: 'Ozone layer depletion' as an example. *International Journal of Science Education, 31*(7), 961 - 988.

Khosa, G. (2014). *Systemic School Improvement Interventions in South Africa: Some Practical Lessons from Development Practitioners*: African Minds.

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in science education, 45*(2), 169-204.

Lane, R. (2015). Experienced geography teachers' PCK of students' ideas and beliefs about learning and teaching. *International Research in Geographical and Environmental Education*, *24*(1), 43-57.

Lapp, D. A., & Cyrus, V. F. (2000). Using data-collection devices to enhance students' understanding. *Mathematics Teacher, 93*(6), 504-510.

Lederman, N. G., Gess-Newsome, J., & Latz, M. S. (1994). The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. *Journal of Research in Science Teaching, 31*(2), 129-146.

Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1343-1363.

Lee, E., Brown, M. N., Luft, J. A., & Roehrig, G. H. (2007). Assessing beginning secondary science teachers' PCK: Pilot year results. *School Science and Mathematics, 107*(2), 52-60.

Lemmer, M. (2013). Nature, cause and effect of students' intuitive conceptions regarding changes in velocity. *International Journal of Science Education, 35*(2), 239-261.

Loewenberg Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching what makes it special? Journal of teacher education, 59(5), 389-407.

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. Rotterdam, The Netherlands: Sense Publishers.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of research in science teaching, 41*(4), 370-391.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education. *International Journal of Science Education, 30*(10), 1301-1320.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching *Examining pedagogical content knowledge* (pp. 95-132): Springer.

Malcom, S., A, & Mavhunga, E. (2015). *The development and validation of an instrument measuring Topic Specific PCK instoichiometry: Preliminary findings.* Paper presented at the 23rd Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education, Maputo, Mozambique.

Maree, J. G. (2010). *First steps in research*. Pretoria: Van Schaik Publishers.

Maryati, & Susilowati. (2015). *The comparison between daily lesson plan of Indonesia and CoRes (Content Reapresentations) as lesson plan model in Pedagogical Content Knowledge (PCK) to develop professional science teaching.* Paper presented at the Proceeding of International Conference on Research, Implementation and Education of Mathematics And Sciences, Yogyakarta State University, Indonesia.

Mavhunga, E. (2012). *Explicit inclusion of topic specific knowledge for teaching and the development of PCK in pre-service science teachers.* (Doctoral thesis), University of Witwatersrand, Johannesburg.

Mavhunga, E. (2014). Improving PCK and CK in pre-service chemistry teachers. *Exploring mathematics and science teachers' knowledge: Windows into teacher thinking*, 31-48.

Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science and Technology Education, 17*(1-2), 113-125.

McDermott, L. C., Rosenquist, M. L., & Van Zee, E. H. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American journal of physics, 55*(6), 503-513.

Mdolo, M. M., & Mundalamo, F. J. (2015). Teacher knowledge shaping the teaching of genetics: a case study of two underqualified teachers in Malawi. *African Journal of Research in Mathematics, Science and Technology Education, 19*(1), 1-11.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *The Teachers College Record, 108*(6), 1017-1054.

Mizzi, D. (2013). The Challenges Faced by Science Teachers when Teaching Outside Their Specific Science Specialism. *Acta Didactica Napocensia, 6*(4), 1.

Muhl, J. C. (2014). *Organisational Trust: Measurement, Impact and the Role of Management Accountants*. Switzerland: Springer International Publishing.

Ndlovu, M. (2014). *The design of an instrument to measure physical science teachers' Topic Specific Pedagogical Content Knowledge in Electrochemistry.* (Masters dissertation), University of Witwatersrand, Johannesburg.

Nemirovsky, R., & Rubin, A. (1992). Students' Tendency To Assume Resemblances between a Function and Its Derivative.

Nilsson, P. (2008). Teaching for Understanding: The complex nature of pedagogical content knowledge in pre-service education. *International Journal of Science Education, 30*(10), 1281-1299.

Padilla, K., Ponce-de-León, A. M., Rembado, F. M., & Garritz, A. (2008). Undergraduate professors' pedagogical content knowledge: The case of 'amount of substance'. *International Journal of Science Education, 30*(10), 1389-1404.

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, 38(3), 261-284.

Park, S., Jang, J. Y., Chen, Y. C., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. *Research in Science Education, 41*(2), 245-260.

Periago, C., Pejuan, A., Jaen, X., & Bohigas, X. (2009). *Misconceptions about the Propagation of Sound Waves.* Paper presented at the European association for education in electrical and information engineering annual conference, Valencia, Spain.

Pitjeng, P. (2014). Novice Unqualified graduate science teachers' topic specific pedagogical content knowledge and their beliefs about teaching. In H. Venkat, M. Rollnick, M. Askew & J. Loughran (Eds.), *Exploring mathematics and science teachers' knowledge: Windows into teacher thinking*. Oxford: Routledge.

Rohaan, E. J., Taconis, R., & Jochems, W. M. (2009). Measuring teachers' pedagogical content knowledge in primary technology education. *Research in Science & Technological Education, 27*(3), 327-338.

Rollnick, M., & Mavhunga, E. (2014). PCK of teaching electrochemistry in chemistry teachers: A case in Johannesburg, Gauteng Province, South Africa. *Educación Química, 25*(3), 354-362.

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education, 30*(10), 1365 - 1387.

Shemwell, J. T. (2011). *A Role for Simulative Mental Models in Science Concept Representation: The Case of Instantaneous Speed.* STANFORD UNIVERSITY.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard educational review, 57*(1), 1-23.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational researcher*, 4-14.

Thomas, R. M. (1998). *Conducting educational research: A comparative review*. United States of America: Greenwood Publishing group.

Thompson, F., & Logue, S. (2006). An exploration of common student misconceptions in science. *Internal Education Journal, 7*(4), 553 - 559.

Tsang, E., W, K. (2014). Case studies and generalization in information systems research: A critical realist perspective. *Journal of Strategic Information System, 23*, 174 - 186.

Van Der Valk, T., & Broekman, H. (1999). The lesson preparation method: A way of investigating pre-service teachers' pedagogical content knowledge. *European Journal of Teacher Education, 22*(1), 11-22.

Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagogical content knowledge. *Science Education, 86*(4), 572-590.

Van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of research in science teaching, 35*(6), 673-695.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical Content Knowledge taxonomies. *Electronic Journal of Science Education, 3*(4).

Veal, W. R., Tippins, D. J., & Bell, J. (1999). The Evolution of Pedagogical Content Knowledge in Prospective Secondary Physics Teachers.

Vokwana, N. Q. (2013). *Development and validation of instruments to assess content knowledge and topic specific pedagogical content knowledge of teachers of organic chemistry.* (Masters dissertation), University of Cape Town.

Williams, J., & Lockley, J. (2012). Using CoRes to Develop the Pedagogical Content Knowledge (PCK) of Early Career Science and Technology Teachers.

Yang, C., Noh, T., Scharmann, L. C., & Kang, S. (2014). A study on the elementary school teachers' awareness of students' alternative conceptions about change of states and dissolution. *The Asia-Pacific Education Researcher*, *23*(3), 683-698.

Yin, R. K. (2003). Case study research design and methods third edition. *Applied social research methods series, 5*. Sage Publishers.

Zimmerman, G. J. (2015). *The design and validation of an instrument to measure the Topic Specific Pedagogical Content Knowledge of physical sciences teachers in electric circuits.* (Master's dissertation), University of Witwatersrand, Johannesburg.

8. APPENDICES

Appendix i: Content Representation tool completed by the researcher and experts: expert CoRe

Section A

Think carefully about the way you teach Graphs of motion in Grade 10. List all the key ideas that you consider important in the teaching/learning of Graphs of motion.

Key ideas	**Sub-ordinate idea**
Understand these graphs: • **Key idea A**: Position-time graph • **Key idea B**: Velocity-time graph • **Key idea C**: Acceleration-time graph	Understand the graphs under these conditions: • Stationery object in the origin, positive and negative direction • Constant velocity in the positive and negative direction. • Constant acceleration in the positive or negative direction.
Key idea D: Gradient of a position-time graph (including tangents and secants)	Represents velocity (instantaneous velocity and average velocity)
Key Idea E: Gradient of a velocity-time graph	Represents acceleration.
Key idea F: Area under a velocity-time graph	Represents displacement, a change in position.

Section B

Answer the following questions based on the Key ideas listed in Section A above.

1. **What do you intend learners to learn about each of the ideas below?**

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<tr><th>Key Idea A</th><th>Key Idea B</th><th>Key Idea C</th></tr>
<tr>
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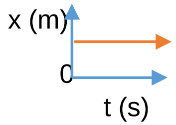
stationery object

positive


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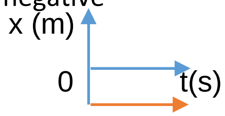
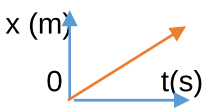
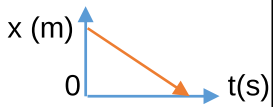
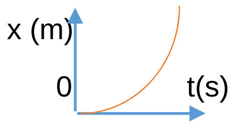


constant velocity

positive


negative


constant acceleration

positive


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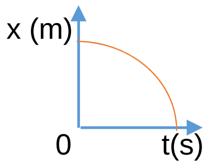

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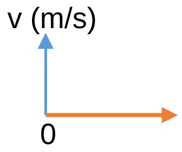
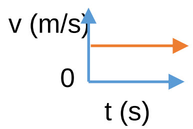
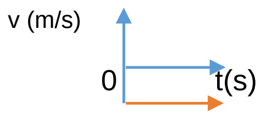
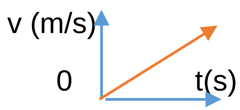
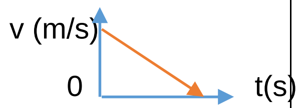
Stationery object


Constant velocity
Positive


negative


Constant acceleration
positive


negative


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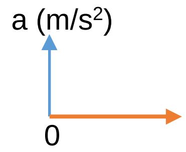
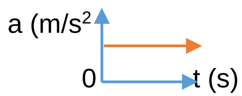
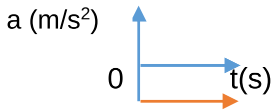
Stationery object and constant velocity


Constant acceleration
Positive


negative


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</table>

Key Idea D	**Key Idea E**	**Key Idea F**
Learners must learn that the gradient of a position-time graph represents the change in position divided by the change in time, which is velocity. For a curved position-time graph, the gradient of a tangent or secant to the graph represents instantaneous or average velocity respectively.	Learners must learn that the gradient of a velocity-time graph represents a change in velocity divided by a change in time, which is acceleration.	Learners must learn that the area under a velocity-time graph (between the graph and the horizontal axis) represents displacement.

2. Why is it important for learners to know this?

Key Idea A	**Key Idea B**	**Key Idea C**
Interpretation: Learners have to understand position-time graphs and their interpretations. This will enable them to construct corresponding velocity-time graphs.	Just like key idea A. it is important that learners understand the representations of a velocity-time graph. This graph is very important because according to the CAPS document, it should be used to construct position-time and acceleration-time graphs respectively.	It is important that learners also understand the interpretation of acceleration-time graphs as well. The acceleration-time graphs can be related to velocity-time graphs – what the acceleration means about the velocity of an object.
Key Idea D	**Key Idea E**	**Key Idea F**
The understanding of the importance of gradients in graphs would help learners infer variables in other topics that involve graphs. for example: • The gradient of a voltage-current graph represents resistance. • The gradient of a momentum-time graph represents net force. • The gradient of an energy-time graph represents power.	(Continuation of key idea D since the reasons are identical) This understanding is also important in the topic itself. Learners would be able to interpret graphs, by merely looking at the magnitude and the sign of the gradient of the graph and infer information about the variables represented by the gradients. Upon inferring this information, they would use it to construct the corresponding graphs of motion.	Although the curriculum doesn't emphasise understanding the area under an acceleration-time graph, it is important for learners to understand that area is the opposite of gradient. This means that the area under an acceleration-time and a velocity-time graph represent **CHANGES** in velocity and position (hence displacement). This knowledge would enable learners to infer information by calculating the area and construct graphs.

3. What else do you know about this idea (that you do not intend learners to know yet)?

<table>
<tr><th>Key Idea A</th><th>Key Idea B</th><th>Key Idea C</th></tr>
<tr><td colspan="3">The conditions of these graphs can be used to determine variables that learners at Grade 10 level are not necessarily familiar with. A stationery object indicates that all forces acting in an object are balanced in static equilibrium. Therefore, the net force on the object and the moment (including the change in momentum are also zero). Moving at a constant velocity indicates that forces acting on the object are also balanced in dynamic equilibrium. This means that the net force and the change in momentum are both zero, but the momentum at any given point is not necessarily zero. These statements are inferred from Newton’s first law of motion. The presence of acceleration gives rise to Newton’s second law. Which means that the forces acting on the object are not balanced, the direction of the unbalanced (net force) determines the direction in which the object accelerates. This means that the momentum of the object is also changing due to the change in velocity.</td></tr>
<tr><th>Key Idea D</th><th>Key Idea E</th><th>Key Idea F</th></tr>
<tr><td>Gradient is differentiation in calculus. It represents the change in the vertical axis f(x) divided by the change in the horizontal axis (x).
Learners will only learn about this at Grade 12 level (DoBE, 2011).
The gradient of a vertical line is infinity, but learners at Grade 10 level are not necessarily expected to learn about this.</td><td>Same as key idea D</td><td>Having said earlier that the area is the opposite of gradient, in this case it represents a topic which is the opposite of differentiation; integration. This represents the product of the change in the horizontal axis f(x) and the vertical axis (x). Learners will only learn about integration at university level as the concept is not covered in high school (DoBE, 2011).</td></tr>
</table>

4. What are the difficulties/limitations connected with teaching this idea?

Key Idea A	**Key Idea B**	**Key Idea C**
Learners focus on shapes of graphs when interpreting the graphs. When required to simulate the graphs by walking, they walk in a path that resembles the graph itself (Clement, 1985). In a curved position-time graph they fail to recognise that the position is not changing at the same rate in the same time intervals.	Learners interpret a velocity-time graph like a position-time graph after having mastered a position-time graph. For example, they consider a horizontal non –zero line as a state of rest. They also struggle with direction in a velocity-time graph, especially in the case of slowing down (approaching the horizontal axis)	Learners confuse velocity with acceleration. They find it difficult to understand that zero acceleration doesn't necessarily indicate the state of rest. It indicates that the object's velocity, which could also be zero, is not changing.
Key Idea D	**Key Idea E**	**Key Idea F**
Difficulties associated with gradient are perpetuated by a poor understanding of gradient from a mathematical point of view. The major difficulty, as reported in literature (McDermott et al., 1987) is that learners focus on the height instead of the slope to determine variables. For example, in a diagonal position-time graph learners fail to understand that the velocity is the same throughout.	(Continuation from key idea D) Learners find it difficult to understand that the gradient of a curved line is not constant, thus the variable represented is also not constant.	Learners find it difficult to divide complex shapes (for example a trapezium) into simpler shapes: squares, rectangles and triangles to be able to calculate the area. A poor understanding of vectors and scalars makes it difficult for learners to adequately calculate distance (scalar) and displacement (vector) from the area under a velocity-time graph.

5. What is your knowledge about learners' thinking that influences your teaching of these ideas?

Key Idea A	Key Idea B	Key Idea C
Learners' difficulties in scalars and vectors makes it difficult for them to understand that position and displacement are vectors whereas distance is a scalar. Hence if required to construct a distance-time graph, it should be positive values only, which doesn't return to the horizontal axis. Learners also confuse position with the direction in which the object is moving.	The concept of velocity confuses learners, what average, instantaneous and constant velocity mean. They do not understand that; constant velocity means the velocity is the same at all times, average velocity is the average between two time intervals and that instantaneous velocity is the velocity at a single point in time. Relating these velocities to time is a major difficulty.	Learners confuse acceleration with velocity. They think that a higher velocity necessarily indicates a higher acceleration and vice versa (Lemmer, 2013). They also think that velocity and acceleration are always in the same direction. As a result they don't understand the outcome of having velocity and acceleration in the same or opposite direction. Learners also think that slowing down is necessarily accelerating in the negative direction instead of "slowing down"
Key Idea D	**Key Idea E**	**Key Idea F**
Learners understanding of vectors and scalar hinders them from understanding concepts correctly. They don't link the gradient of graphs of motion with direction. By merely looking on the shape of the graph, learners could easily infer the direction of the variable represented by the gradient of such a graph.	(Same as key idea D)	In mathematics, area is calculated using positive numbers only, whereas in graphs of motion both positive and negative numbers are involved. Thus it is important that learners understand vectors and scalar, and that displacement is a vector whereas distance is a scalar. It usually happens that learners forget these.

6. Are there any other factors that influence your teaching of these ideas?

Key Idea A	**Key Idea B**	**Key Idea C**
Graphs of motion are basically the graphs that learners at Grade 10 have most probably learned in mathematics in the past. A parabolic function is a curved position-time graph (the presence of acceleration), linear graphs are then the position-time graphs representing the state of rest and moving at constant velocity.	(Continuation of key idea A, as the factors are almost similar) The way learners are taught about these graphs is different. In mathematics, graphs are constructed on the negative horizontal axis, in graphs of motion that cannot be done because time cannot be negative and we start measuring it from zero.	In mathematics, learners do not learn about graphs that "break", which in acceleration-time graphs happens when acceleration changes from one amount to another.
Key Idea D	**Key Idea E**	**Key Idea F**
Mathematics presents a framework which science builds on. Science then brings out the applicability of mathematics concepts that learners always wonder about. Hence the effective learning of the importance of gradient in this topic will depend on the understanding of gradient by learners from their mathematical point of view.	(Same as key idea D)	(Same as key idea D) However, in this case it involves the area. If learners do not have an adequate understanding of area from their mathematical point of view, then it may negatively impact their understanding of this idea.

7. What are your teaching procedures (and particular reasons for using these to engage with this idea)?

Key Idea A	**Key Idea B**	**Key Idea C**
Mark magnitudes of distances on the floor, and walk through them while indicating the time taken to reach them. Once the data has been collected, construct a position-time graph. You can also conduct a ticker timer experiment, measure the displacement of the dots from a fixed dot so that this becomes position. Then you can construct the position-time graph.	In this case the velocity-time graph should develop from position-time graphs through calculating the gradients of the graphs using more than one set of points. This however requires that key idea D is discussed beforehand. Do the same in the case of average and instantaneous velocity.	Just like key ideas B, the acceleration-time graph should only be constructed from the gradients of velocity-time graphs using more than one set of points. This requires that key idea E is discussed beforehand.
Key Idea D	**Key Idea E**	**Key Idea F**
Start from the general formula for gradient, then relate it to the graph in front of the learners. Ask them which variable from the position-time graph represents the vertical axis, position, and the horizontal axis, time. Then substitute these variables in the formula for gradient. Ask learners to identify the variable that is represented by the new formula that emerges.	The same as key idea D. Substitute the variables in a velocity-time graph into the formula for gradient and ask learners to identify the variable represented by the emerging formula.	Begin this discussion from the area of a rectangle: height x breadth. Then substitute height with change in velocity and breadth with change in time. This will give you a product of a change in velocity and a change in time. Ask learners to identify the variable represented by such a formula, they most probably won't be able to. Then write down the definition of velocity, as a formula, and make the change in position the subject of the formula. This will enable learners to see that area represents displacement.

8. Specific ways of ascertaining learners' understanding or confusion around this idea (include a likely range of responses).

Key Idea A	Key Idea B	Key Idea C
Draw a position-time graph on the board and ask learners to walk according to it. Vary the sections of the graph; stationery, constant velocity in the positive and negative direction and acceleration.	From the graph in key idea A, ask learners to infer data using the relevant methods and construct a velocity-time graph. You can also ask learners to simulate such a graph by walking. This won't change as the two graphs represent the same motion.	Use the velocity-time graph (Key idea B) to construct a velocity-time graph by inferring data by calculating the gradient. It is important that learners understand all three graphs of motion with reference to the same information.
Key Idea D	**Key Idea E**	**Key Idea F**
Construct a position-time graph and vary the sections. Ask learners to comment on the magnitude of the velocity of the object in relation to the sections of the graph. In this activity learners do not necessarily have to calculate it, they have to infer it from the sign and the magnitude of the gradient.	This can also be done in the same manner as key idea D. Construct a velocity-time graph and ask learners to comment on the acceleration of the object based on the sections of the graph.	Ask learners to divide complex shapes into workable shapes to calculate the area under a velocity-time graph. Emphasis must also be put on negative and positive values. Although the department doesn't put much emphasis on the area under a velocity-time graph, ask learners to apply the same principle to determine what the area represents.

APPENDIX II: RUBRIC FOR THE SCORING OF TEACHERS' CAPTURED PCK

	Limited	Basic	Developing	Exemplary
Learners' prior knowledge	• No identification/ acknowledgement of learners' prior knowledge or misconceptions.	• Identified one major misconception and other minor misconceptions. • Identifies basic learner errors related to mathematical concepts without linking it to science concepts. • Revealed reflective knowledge of only one misconception.	• Identified two major misconceptions and other minor misconceptions.	• Identified three or more major misconceptions and other minor misconceptions.
Curricular saliency	• Identified irrelevant key ideas/ pre-concepts as key ideas • Illogical sequencing of concepts due to inadequate key ideas	• Identified two relevant key ideas without sub-ordinate ideas. • Pre-concepts are mixed with big ideas • Sequencing has at least, an illogical	• Identified three relevant key ideas • Identified supporting sub-ordinate ideas. • Key ideas are sequenced logically. • The indication of the	• Identified four or more big ideas • Identified sub-ordinate ideas and showed links with key ideas. • Concepts are sequenced logically

	• No indication of the interrelatedness between concepts due to inadequate key ideas • Reasons for the importance of concepts are absent.	placing of a key idea • Indication of the interrelatedness between concepts is clumsy due to the illogical placing of a key idea. • Reasons for the importance of concepts exclude scaffolding into subsequent topics.	interrelatedness between concepts is evident. • Reasons for the importance of concepts includes scaffolding, but the subsequent topics are not specified.	• The indication of the interrelatedness amongst concepts is adequate. • Reasons for the important of concepts includes scaffolding and the subsequent topics are specified.
What is difficult to teach?	• No indication of concepts/ideas that are difficult to teach. • Reasons for the difficulty or gate-keeping concepts are not specified.	• Identified broad concepts as difficult. • Reasons for the difficulties are not specific to the key ideas. e.g “their mathematics knowledge is poor”	• Identified specific concepts as difficult. • Outlined reasons related to learners’ common difficulties.	• Identified specific concepts as difficult. • Outlined gate keeping concepts as well as learners’ misconceptions perpetuating the difficulties.
Representations including analogies	• Representations not identified	• Identified a relevant representation. • No information about how the representation	• Identified a relevant representation. • Outlined how the representation supports the	• Identified a variety of relevant representations. • Outlined how the representations support the

		works and which concepts it supports.	explanations of concepts.	confrontation of misconceptions and difficult concepts.
Conceptual teaching strategies	• No strategy to expose learners' difficulties and misconceptions. • No strategy to confront and address misconceptions and difficulties • No indication of how key ideas will be explained. • No intentions to involve representations to engage with learners. • Overall highly teacher centred lesson.	• Evidence of activities to expose learners misconceptions and difficulties • Verbal confrontation of misconceptions and difficulties. • Indication of how some key ideas will be explained: no explanation of the interrelatedness. • Representations outlined but concepts to be supported are absent. • Limited involvement of learners.	• Evidence of activities to expose learners misconceptions and difficulties • Confrontations of difficulties and misconceptions evident. • Indication of how some key ideas will be explained and interrelated. • Representations identified to explain concepts in general. • There is evidence of learner involvement.	• Evidence of activities to expose learners misconceptions and difficulties • Confrontation addresses gate-keeping concepts (misconceptions) beforehand. • Indication of how all key ideas will be explained and interrelated. • Representations to be used to explain concepts in general and the ones identified as difficult. • Highly learner centred lesson.

APPENDIX III: RUBRIC FOR THE SCORING OF TEACHERS' REVEALED PCK

	Limited	Basic	Developing	Exemplary
Learner' prior knowledge	• No facilitation of discussions that expose learner' misconceptions. • Learners are spoon-fed with the necessary prior knowledge.	• Facilitates discussions that expose learners' misconceptions. • Confronts them by providing standardised definitions.	• Facilitates discussions that expose learners' misconceptions. • Confronts them by expanding and rephrasing further.	• Exposed learners' misconceptions through discussions • Confronts them by expanding and rephrasing further. • Confirms learners' understanding.
Curricular saliency	• Explains irrelevant concepts. • Leaves out important concepts in the topic. • Sequencing of key ideas is illogical. • The interconnection amongst concepts are not explained.	• Relevant key ideas are discussed but not given attention equally. • Sequencing has illogical placing of key ideas. • The interconnection amongst concepts is clumsy.	• Relevant concepts are explained and given enough attention. • Key ideas are sequenced logically, despite the concept of area being side-lined. • The interconnection amongst concepts is also logical.	• Explains concepts giving them the attention they deserve. • Concepts sequenced logically, in the order of importance. • Also explains the interconnections between concepts.
What is difficult to teach?	• No facilitation of discussions that expose difficulties • Identified difficult concepts are not confronted/confronted incorrectly	• Facilitation of discussions that reveal difficulties. • No expansion of explanations of the difficult concepts.	• Facilitation of discussions that reveal difficulties. • Teacher expands on the explanation of difficult concepts.	• Facilitation of discussions that reveal difficulties. • Confrontation starts from gate-keeping concepts and concepts are expanded.

				• Teacher confirms learners' understanding
Representations including analogies	• Representations not used in the lesson.	• Representations are seldom used. • Representations have potential to induce misconceptions.	• Representations are used to explain concepts and confront learners' difficulties.	• Representations used to confront and expand explanations of difficult concepts. • Representations used to confirm learners' understanding.
Conceptual teaching strategies	• Explains new concepts without exploring and developing prior knowledge • Concepts are sequenced illogically, and interconnections are not explained. • Teacher doesn't use representations to engage with concepts. • Lesson is highly teacher centred.	• Teachers asks closed ended questions • Confronts misconceptions but doesn't expand explanations. • Key ideas are explained in isolation as well as their interrelatedness. • Representations seldom used or used ineffectively to engage with concepts. • Limited involvement of learners.	• Teacher ask few higher order questions • Expands confrontation of misconceptions but doesn't confirm understanding. • Key ideas are almost sequenced logically with links (leaves out area). • Representations used to engage with concepts, but only the teacher uses them. • Evidence of encouraged learner involvement.	• Teacher asks higher order questions. • Expands confrontation of misconceptions and confirms understanding. • Key ideas are sequenced logically as well as the links between them consecutive concepts. • Representations used by learners as well to confirm understanding. • Generally, learner centred lesson.

APPENDIX IV: PARTICIPANTS' TRANSCRIBED AND CODED INTERVIEWS

Interview	Analysis of interview	
	TSPCK component and competences	**Comments**
Mrs. VM		
1. Interviewer: "What are the key concepts in graphs of motion?" **Interviewee**: "At firstly for me it is very important to…firstly let them know why we are using graphs. I refer to the textbooks containing about 30 % of the space in any science book is graphs. It is scientists pictures to help us illustrate data…a key concept especially for graphs of motion, they need to be able to draw, identify and use a graph to determine velocity speed acceleration and displacement…they must be able to draw velocity time, position-time and acceleration-time and interpret. They must be able to draw and interpret."	Curricular saliency	She indicated relevant and applicable key ideas: • Position-time graph • Velocity-time graph • Acceleration-time graph Identifying, interpreting and using these to determine variables.
2. Interviewer: "Why is it important for learners to learn these key ideas?" **Interviewee**: "For me more than a key idea it's about a skill. We teaching them a skill…because graphs is part of science."	Curricular saliency	Her explanation of the importance of concepts is unclear, no progression/scaffolding into other concepts.
3. Interviewer: "Talking about the teaching of graphs of motion, what are the difficulties or limitations associated with teaching graphs of motion?" **Interviewee**: "For me that time is negative, it can never be. And the learners find it very difficult to distinguish between	Learners' prior knowledge What is difficult to teach?	The negative time misconception that she identified is basic and can easily be dealt with.

when is it a position time, when is it a velocity time and to know that…ja they must look at the heading to tell them what graph it is. But they need to be able to read through the graph, otherwise they find it difficult to see that the person is moving away from the point of origin, in what direction, is it with a constant velocity, is it with increasing or decreasing acceleration…I don't know am I not understanding the question?" 4. **Interviewer: "You are, because I just want to know the limitation and difficulties…"** **Interviewee**: "They find it difficult to know when is it a position-time when is it a velocity-time when is it an acceleration-time. They tend to think all indicate motion. My learners find it difficult to know. But to describe the motion in words by making use of different graphs."		She identified a difficulty. Learners find it difficult to interpret graphs to infer information. The reason for this difficulty is that learners do not read the headings of the graphs. She added that learners believe that graphs of motion describe motion the same way.
5. **Interviewer: "What are learners' misconceptions in graphs of motion?"** **Interviewee**: "They think that all the graphs show position-time. They do not take the time to look at the heading to see what is measured on the x, what is measured on the y. they find it difficult to indicate direction in terms of motion as they confuse it with position. When is it going east, what is going west? What I try and do is tell them this is my point of origin, so even though I'm in the east side, I turn around and move direction west."	What is difficult to teach? Representations/Conceptual teaching strategies	As learners do not read headings, they consider all graphs to be position. Confronts a difficulty by simulating motion through walking. Shows aspects of knowledge about representations
6. **Interviewer: "How do you teach graphs of motion?"**	Curricular saliency	

Interviewee: "You start with the introduction, why do we use graphs? And then you say we are now gonna now use these graphs as an illustration to tell us what is happening. Time will always be measured on the x, then you tell them that if we moving to this side it will be to the positive side and if we are moving to this side it will be to the negative side. And then uhm, the best that I found that works best is let the learners do the walking or you do the walking while they observe, to make it just a bit more real to them."	Conceptual teaching strategies Conceptual teaching strategies/representations	The sequencing is not conceptually rich and doesn't show any interrelatedness amongst concepts. Lecture method of instruction as learners are "told". Learners are given the platform to simulate motion through walking (representations), hence they are involved in the lesson.
Mrs. SC		
1. **Interviewer: "What are the concepts that you consider important in graphs of motion?"** **Interviewee**: "I think…when I start with graphs of motion the most important thing for me is basics. Starting from the mathematical side. Because what I found was that the moment I start teaching graphs, they don't know the difference between the x and the y-axis, how to read a value off the y-axis, how to read a value off the x-axis. So the first thing is go to the basics of what is a graph? How do I compile a graph? When do I write what on the x-axis, when do I write what on the y-axis. Because those basics I found confuse them completely. Then if they don't know that they won't understand reading a velocity. Then the second thing I do is look at the gradient, explain to them what is the change in gradient, why is a straight line constant? Why is a parabola a change? Because I found that those as well confuse them. So I immediately go to the maths part before I even start looking at the physical quantities of velocity and acceleration. The third thing is definitions. Because I think because you can clearly show the change in a graph, they	Teaching strategy/ Curricular saliency Learners' prior knowledge Curricular saliency Teaching strategy/Sequencing	Re-teaching of the necessary prior knowledge before engaging with the topic. Difficulties in the prior knowledge of learners; gaps Sequencing of concepts is not conceptually developed and there is no explanation of the interconnection amongst concepts. Indicated key ideas are thinly developed

more easily understand the definitions because they can see the time changing and they can see the velocity changing, so there must be acceleration." **2. Interviewer: "So according to you, basics are important?"** **Interviewee**: "Definitely, honestly I think between the science and the math department in every school there must be a stronger collaboration between the two departments especially when it comes to things that overlap, like graphs. One thing I don't agree with at this stage, we did bring it up in the training as well, is we use different symbols in maths and science. In maths they use "s" for speed and we use the "v" for speed and velocity just with an arrow on top [for velocity]. And I know they use different symbols in Mechanical technology as well."	Learners prior knowledge/conceptual teaching strategies	Collaborative teaching, align the prior knowledge and teach it the same way across different subjects
3. Interviewer: "Why is it important for learners to understand graphs of motion concepts?" **Interviewee**: "I think overall, because of the diversity of the uses of a graph, not only in science but once you leave school, for example you go to university, a graph is number one visual, number two, easy to understandable, number three it is a very open language. It is very diverse, you don't have to understand the language to be able to understand the graph. So I think the basics of setting up graphs and understanding how a graph works, can in any job line enhance communication between any kinds of people, especially in the world we live in today."	Curricular Saliency	A general and vague reason for learning graphs. Did not mention progress to Grade 11 and 12 level concepts.

4. Interviewer: "What are learners' misconceptions in graphs of motion?" **Interviewee**: "In graphs specifically I would say the basics. Especially things like the area underneath the graph and especially the gradient. They don't understand how to calculate the gradient. If I show them this is point x, y that is point x, y then they can do it, but linking that to the science part they struggle with it. So I thought that maybe next year literally give them shapes, like they do in grade one. Start with the shapes say "ok, in this shape what is the area. How do you measure the area, how do you measure certain things in this shape". I found that when you graph doesn't start at zero, they completely confused on what values to use when calculating the area. They can't see that it's a square, rectangle or a triangle, they can't fit those shapes together. If the graphs starts at zero then they know what to do, if not then they struggle. Also, if you jump from one part of the graph to the other, like for example your position-time to your velocity, or velocity-time to acceleration. Those linkages confuse them a lot. Because now you jump from a constant like to a horizontal line."	Learner prior knowledge. What is difficult to teach? Conceptual teaching strategies/Representations.	She indicated gaps in prior knowledge/ not misconception. She indicated that learners find it difficult to link their pre-concepts (mathematics) with new concepts (graphs of motion). Learners can only identify and calculate areas of squares, rectangles and triangles. Thus learners find it difficult to understand the shift from one graph to the next. The gate-keeping concepts are the gaps that she identified. Representations (shapes) are intended for learners' difficulties. Mrs. SC uses a representation as a strategy to eradicate the difficulty.
5. Interviewer: "Are there any representations that you use when teaching graphs? By "representations" I mean some sort of an experiment or something visual that you use when teaching graphs of motion?" **Interviewee**: "At this stage we do the ticker timer experiment, to indicate the change in the graph. But the problem is still that linkage from data to a graph, they struggle with that immensely. At this stage I haven't figured	Representations. What is difficult to teach?	Ticker-timers are indicated as representations. There is however no information about how they work and the concepts they help explain. She mentions that she hasn't yet figured feasible representations. A lecture method is used as a method of instruction to help learners memorise when to use gradient or area without showing them how.

out a visual representation on how to show a pattern and how the pattern works. There are two things that I teach them, that's basically writing "p", then underneath it a "v" and underneath it an "a" and show them if you go one direction you use the gradient and if you go the other direction you use the area. But that is just the basic summary to help them to know when to use a gradient on a graph and when to use the area of a graph. Other than that I haven't figured out a practical way for them to visualise graphs."	Conceptual teaching strategies	
6. Interviewer: "How do you teach graphs of motion?" **Interviewee**: "Like I said I start basically from the math part, the basic maths graphs. I always tell them remember "science is just math that makes sense". So basically your maths gives you an unknown it gives you x and y values whereas in science we give meaning to x and y. calculating the gradient like you do in math, in math you say gradient equals y2 – y1 over x2 – x1. Then if you substitute that into your formula for gradient, they can immediately recognise the formulas that we used before we started graphs of motion."	Conceptual teaching strategies/curricular saliency. Curricular saliency	Re-teaching of the identified gaps. Shows development of graphs of motion concepts from their necessary pre-concepts
Miss. MH		
1. Interviewer: "What are the important concepts that learners must be taught in graphs of motion?" **Interviewee**: "I think it's important to know the definitions, before they can do application of graphs. If they know the	Curricular saliency	The indicated key ideas are pre-concepts

definitions then they are able to differentiate which one is a scalar, which one is a vector. Then all the definitions, like your position, your velocity…ok let me say position, displacement, velocity, acceleration. If they know the definition, I think, and their application in terms of their understanding of comprehending what do they actually mean, then drawing graphs might be easy because it will be easy to interpret even the graph."		
2. Interviewer: "Why is it important for learners to know graphs of motion concepts?" **Interviewee**: "I think, more than anything, graphs of motion have to do with our daily lives. As a science learner there are some of the things that you need to apply in your real life situations. For example, the importance of teaching a learner the area under a curve is to know the shortest distance, even if there's the longest route, but what is the shortest distance actually? What is the displacement in this?"	Curricular saliency	Vague importance of graphs of motion. The importance also doesn't show progression/scaffolding into other concepts or topics
3. Interviewer: "What do you consider easy or difficult to teach in graphs of motion?" **Interviewee**: "I'm not really sure, but I think if you have to explain to learners that an object is standing, and is not moving, a stationery object, it's sometimes difficult for learners to comprehend that. Although they know that sometimes you can stand, like if you waiting for a bus. They know that you have to wait for the bus for a certain time. But when it comes to applying they just forget the basics. I think	What is difficult to teach?	A very basic idea that she considers difficult. She mentions that drawing graphs is easy and interpreting them is difficult, she however doesn't expand this argument. Calculating the area is difficult. The reason for this difficulty is broad; poor mathematical background

drawing graphs is easy but interpreting them is difficult. And I think even calculating the area under the graphs that is difficult to learners. It is sometimes difficult for us sometimes because you will find that the background, maths background, the foundation is not there."		
4. Interviewer: "What are learners' misconceptions in graphs of motion?" **Interviewee**: "The misconception that they have is that a graph will always be constant. They don't anticipate that an object cannot move with the same speed always. They don't even consider, because when you use a car, if you say to them "deceleration", they do not understand that. Because they always think that "aowa a car has an accelerator so a car accelerates only" until you have to explain that a car can stop, then a car can reduce speed… such things, but when they plot they forget that."	What is difficult to teach? Learners' prior knowledge Conceptual teaching strategies/Curricular saliency	Learners believe that all graphs of motion show motion at constant velocity. Learners do not associate deceleration with slowing down and acceleration.
5. Interviewer: "What effective teaching strategies do you use when you teach graphs of motion? Basically, how do you teach graphs of motion?" **Interviewee**: "In most cases I firstly teach them the basics, what is area. But I think teaching them graphs from their maths knowledge will be best. If they know a linear graph, a hyperbola graph, then they know that sometimes a graph can be just constant, then a graph can be sometimes negative. Then you move from there, you apply the science part. That works for me. But when you just shoot straight for	Conceptual teaching strategies Curricular saliency	Re-teach the necessary prior knowledge before engaging with the topic. She makes reference to an irrelevant idea; hyperbolic functions.

physical sciences you lose learners. Unless if you got a colleague who can help you in maths, then by the time you're busy with graphs in physics then the colleague will be busy starting maybe with as linear graph, hyperbola graph, so that they remember "oh gradient" because I think they do that mostly in Grade 9, but when they get to Grade 10 they have forgotten. I normally ask them the basics, like what is…from the graph, I would normally phrase it "find the gradient", then if they labelled the graph correctly, then I would say use your y-intercept and your x-intercept and form that scientifically, what is the gradient. Fort example if the y-intercept is displacement and the x-displacement is time then that will give them velocity. I normally ask such, normally I move from known to unknown. Then from maths they know that the gradient is change in y over change in x, then from there they will know that if my change in y I labelled as displacement and change in x is time, then that defines velocity,. This mean this graph will produce this kind of velocity because we use maybe two or three points. From there, I would say "calculate the area under the curve" so that they know, from this graph what is my area under the curve, which will give me this and then this one will give me that. Sometimes I would say described the motion, it is important so that they will be able to interpret graphs."	Conceptual teaching strategies/Curricular saliency	This statements suggests the intention to involve learners in the lesson. Furthermore, it shows conceptual development of new concepts from pre-concepts.
6. Interviewer: "Which representations do you use when teaching graphs of motion? By "representation" we mean something that helps learners understand, like it can be an	Conceptual teaching strategies	

experiment. Anything that you use to enhance learners' understanding." **Interviewee**: "I start with a theory, then I go to the practical. In most cases I use a ticker timer, that's the only thing. . From the ticker, if they are able to calculate velocity and acceleration from the ticker timer, they would be able to draw a velocity-time graph, acceleration-time graph and even displacement-time graph. Not unless I would even suggest that they use Wi-Fi and google. There's this website, I forgot the name of the website, it has simulations…" 7. **Interviewer: "PHET simulations?"** **Interviewee**: "Yes. I would encourage them to do that, and before we had those simulations in our laptop. Then we would see, after, so that they will comprehend graphs of motion."	Representations Curricular saliency	Representations are used after concepts have been explained to reinforce them. Ticker-timers and simulations are the representations indicated As she explained how the representation works and the concepts it supports, she revealed an illogical sequence of concepts.
Mr. KZ		
1. **Interviewer: "What do you consider as key ideas in graphs of motion?"** **Interviewee**: "Learners need to understand maths first, because in this topic maths is integrated. For example when you look at gradient, gradient is the change in…so when you deal with motion, as I said to you we have one dimension, 2 dimension and 3 but now we doing one dimension. So if you talk about 1 dimension is derived from the Cartesian plane so we have the y and the x, so if you have and the x which in this case x represents the time		

because time is independent and the y is the variable we are going to deal with, for example y can be the position, velocity or acceleration. So when you talk about the gradient is the change in y over the change in x. so if you take to it to our physics is gonna be change in y over change in x. so for learners to know how to derive from position to velocity, because in Physics we just give them formulas and we tell them this is how we calculate velocity. In Maths its y and x, where y and x represent variables. x can represent number of people, animals and now in physics we change x and y in variables that learners need to know, for example x is always time and y is position, velocity or acceleration. Since gradient is a change, let's talk about velocity which can change in two ways. Velocity can increase where we have objects speeding up or decreasing where objects are slowing down. Velocity is the rate of change of position, so when we look at our graph, y represents position and x represents time, the gradient that I will have for a position-time graph is gonna give me velocity. So in this case we doing uniform motion which means the velocity will be the same throughout. In this case we will have a straight line and the gradient of a straight line is the same throughout. So when they calculate it, the velocity will be the same throughout. Learners need to know what graph you have, if you have a position-time graph, your gradient is velocity, if you have a velocity-time graph, your gradient is acceleration and if you have an acceleration-time graph, you cannot continue anymore because it will be a zero. You can work in reverse like I said, now why do you have to go to area…area, I want to correct this, the book says it's the area under the graph but when I was doing it I found that it's not the area under the graph but the area between the graph	Curricular saliency Learners' prior knowledge	Mr. KZ shows the link between pre-concepts (gradient) and new graphs of motion concepts. Mr. KZ commented about the possibility of a misconception that can be induced by the way information is presented by learning materials. Mr. KZ comments on the importance of showing learners the origin of the idea that the area under a velocity-time graphs represents displacement.

and the x-axis. Learners do not know what is integration and differentiation. At university we talk about integration but here we talk about the area, the area takes us back to position-time graph. velocity is change in position over change in time, so for me to know the change in position I can take it back, which is delta x equals delta t v, so the base is the time and the height is the velocity. So I have to show them how the two are related. With gradient we have four lines, the positive, negative, zero and undefined. In maths we have negatives and positives and we use them as they are, in Physics you must teach about scalars and vectors because negatives and positives represent directions. With velocity is easy, velocity can be forwards or backwards. If I have two cars approaching each other, now it's my choice to choose direction. Velocity goes with motion, if you say to the left it means the object is going to the left, but with acceleration, it can be against motion or reinforce motion. Why is it important to mention negative gradient line and a positive gradient line? Firstly learners confuse direction of velocity and acceleration. If my car is slowing down, that means the net force in the car is applied in the opposite direction, so the motion must be overcome and the object must come to rest, so if it is negative, it means the acceleration is against motion but if it is positive it means the object is speeding up. So if I have a negative acceleration it means the object will at some point stop and if the acceleration is positive, the object will go forever. And now dimensions, I think dimensions should be explained first before you even touch the topic. When you talk about 1 dimension you can only have forward and backwards, nothing else, no angles. So if I have one dimension, I I were moving east, changing direction means I'm now moving	Curricular saliency Conceptual teaching strategy Learners' prior knowledge Curricular saliency Conceptual teaching strategy Curricular saliency What is difficult to teach?	Mr. KZ's response suggest that he shows learners the origin of concepts. Learners do not understand the implications of velocity and acceleration being in the same or opposite directions. Mr. KZ refers to net force, an irrelevant yet useful concepts as learners in grade 10 are not expected to learn about newton's second law. Mr. KZ explains the implication of velocity and acceleration being in the same or opposite direction, however, he intends to incorporate an irrelevant concept. Mr. KZ mentioned the necessary pre-concepts, dimensions, as he intended to use them to confront learners' difficulties and enforce the idea that in one dimension, an object must stop before changing direction.

west. In one dimension it is impossible to change direction in one dimension without stopping but in other dimensions an object can change without stopping, for example when a car curves, it changes direction but doesn't stop. If I have a velocity-time graph, if a line cuts the x axis, the means the object has stopped and moved backwards. Learners find difficult to understand this because they see objects in everyday life changing direction without stopping. So you have to be specific that it's only in one dimension when you stop change direction or stop reverse."		
2. Interviewer: "What representations do you use when teaching graphs of motion?" **Interviewee**: "In class you have three groups, you have learners that understand, learners that are in between and learners that are lost. And all of them need different strategies when you teach them. You cannot just write on the white board you also have to walk around in class, sometime you ask the learners to stand up and walk the graphs. Our syllabus doesn't show the integration between physics and maths as we as physics teachers must teach both maths and physics. You ask learners what is gradient and they're like what is going on, you ask about the change in gradient and they're like what is going on? This means I must teach maths first, then physics which limits us because we do not have enough time."	Conceptual teaching strategies/Representations	Mr. KZ commented on the importance of involving learners by allowing them to simulate graphs by walking (representation) and enforce concepts by walking according to the graphs. Mr. KZ also emphasised the importance of re-teaching mathematics concepts firstly.
3. Interviewer: "How do you teach graphs of motion?"	Conceptual teaching strategies	Involvement of learners by allowing them to present their understanding of concepts.

Interviewee: "I group learners, I give every group a topic to present for the class. When they present I sit down and listen and I always stop them, correct them. I always tell them that this is a misconception, but we are just saying it this way so that you understand."		
4. **Interviewer: "Do you have specific misconceptions coming from learners in graphs of motion?"** **Interviewee**: "Learners tend to look at the shape of the graph…it's not only the shape, the shape won't just tell you everything…for example if you give a learner a graph…from zero and the gradient is positive, you ask them is the car speeding up or slowing down, learners will just say the car is speeding up, they don't even know if it's a position-time graph, it's velocity-time graph, it's acceleration-time graph. They have that thing of if the gradient is positive gradient then the car is speeding up. What if I have a position-time graph, therefore it's a different story. For example I gave them a position-time graph, so this position-time graph that I gave them was in a way that one line started from zero with a positive gradient, the other line started from 20 metres with the negative gradient. And then the question was which car is moving faster than the other car. It was a position-time graph, and they said the one that started from Zero was moving faster because the gradient is going up [positive]. In this case it's a position time graph, the other car starts from where I am, which is zero metres and the other car starts there 20 metres coming to me. Here they bypass each other in the opposite way, but they [learners]	What is difficult to teach? Conceptual teaching strategies	Mr. KZ mentioned that learners focus on shapes of graphs only, instead of also focusing on the type of graph. Mr. KZ mentioned how he had revealed this difficulty in learners through questions, he also explained the correct conception of the idea.

think it's overtaking. If this was a velocity-time graph when I have this the cars overtake each other…they don't look what graph you have they just answer the question without looking [at the type of graph]."		

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APPENDIX V: GDE LETTER

Dear Sir/ Madam.

Request to conduct research in Tshwane District schools

I hereby wish to apply for permission to conduct research in Tshwane District schools. My research project involves grade 10 teachers. My research topic is "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**".

In this study, teachers will be asked to complete a document called Content Representations (CoRes), which stipulates key points about the way they teach a topic (Loughran, Mulhall and Berry, 2004), in this case, Graphs of motion. I would also like to observe teachers teaching graphs of motion. I will be a passive observer whereby I will be video recording the lesson with as little as possible interruption to the lesson. I will ensure that it will not be possible to recognise learners on the videos.

This study will also involve semi-structured interviews, where the interview questions will emerge from the CoRes written by teachers and the observed lessons. The information gathered in every event of data collection will be kept confidential under any circumstances and will be used solely for the purpose of this study.

The findings of this study may be used to understand the comparison between lesson plans and lesson deliverance, that is, the extent to which teachers teach the way they planned to teach. These results may be useful to teacher trainers, subject advisors and other stakeholders involved with the development of teachers. The stakeholders may look at the results to see if teachers teach the way they planned to or not, and they may use these results as a starting point when developing educators.

Please find attached my full research proposal.

Yours sincerely

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Building and office number
Groenkloof Campus
University of Pretoria
PRETORIA 0002
Republic of South Africa

Telephone number:
Fax number:

E-mail address:
http://www.up.ac.za/faculty-of-education/

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Faculty of Education
Department of Science and Mathematics Education.

APPENDIX VI: PRINCIPAL LETTER

The Principal

XXX School

Pretoria

Request for Permission to Conduct Research

I am a Master's in Education (MEd) student at the University of Pretoria. One of the requirements for the degree is to conduct research and write up a report on my findings. I would like to ask if you would grant me permission to conduct research in your school with your staff and learners.

My study is titled "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**". Personally I find graphs of motion a rather complicated concept to explain to learners because it easily induces misconceptions in them. Research has shown that indeed learners do battle with Graphs of motion the way they battle with other Science concepts, for example, learners don't seem to grasp the idea that different graphs should be interpreted differently (Clement, 1985). This misconception, amongst others, and my personal teaching experience in Graphs of motion made me interested in finding out how teachers plan to utilise their content knowledge of Graphs of motion to make learners understand them with ease. During the research the teacher will be requested to complete a Content Representation (CoRe) document. This document will be asking the teacher about his/ her teaching of graphs of motion. The teacher will also be asked to teach in the presence of the researcher where the lesson will be video recorded. Lastly, the teacher will be interviewed. The total time required of the teacher for the purpose of this research is about 2 hours spread over 3 days. The completion of the CoRes and interview will take place at a venue and time that suits the teacher as I am trying by all means not to interfere with the normal running of the school. All the information gathered during the study will be used to compile a dissertation which will be uploaded on the open access repository, however, your schools' name, your staff's and your learners' names will be kept confidential at all times and only be used for the purpose of this study. Pseudonyms will be used when necessary.

If you allow me to conduct research in your school, please kindly fill in the consent letter below.

I, ____ (your name) the Principal of ______________________________ (your schools' name) agree/ do not agree (delete what is not applicable) to give permission to have the study entitled "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**" conducted in my school with my staff member(s) and learners. I am well aware that my staff member, the teacher, will be asked to complete CoRes, teach in the presence of the researcher while the lesson will be recorded and that the teacher will be interviewed.

I do understand the following ethical principles that will be put in place in the research, that is:

- Informed consent will be in place, meaning, all participants involved in this study will be informed about the purpose and the process of this study. Furthermore, participants will give consent for their participation in this study.
- Participation in this study is voluntary and I may, if need be, require my teacher to discontinue his/her involvement in this study.
- The teacher's name and the school's name will be kept confidential at all times.
- The transcribed interviews, video-recorded lessons and the content representation document will be confidential at all times, only the researcher and the supervisor will have access to them.

Principal's signature: __________________________ Date: ________________

Researcher's signature: ________________________ Date: _______________

Supervisor's signature: _________________________ Date: _______________

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APPENDIX VII: TEACHER LETTER

Dear Teacher

Informed consent to participate in research

I am a Master's in Education (MEd) student through the University of Pretoria. One of the requirements for the degree is to conduct research and write up a report on our findings. I would like to ask if you would be willing to participate in my research project.

My study is titled "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**". Personally I find Graphs of motion a rather complicated concept to explain to learners because it easily induces misconceptions in them. Research has shown that indeed learners do battle with Graphs of motion the way they battle with other Science concepts, for example, learners don't seem to grasp the idea that different graphs should be interpreted differently (Clement, 1985). This misconception, amongst others, and my personal teaching experience in Graphs of motion made me interested in finding out how teachers plan to utilise their content knowledge of Graphs of motion to make learners understand them with ease.

If you agree to participate in this study you will be kindly asked to complete a Content Representation (CoRe) tool. This document is asking questions about your teaching of graphs of motion. The researcher also asks permission to observe and video tape one or more of your classes while you are teaching the topic. You will also be required to be interviewed. The total time for your involvement in this study will be 2 hours divided in 3 days. The completion of CoRe documents and interviews will take place in a venue and at a time that will suit you. All the information gathered during the course of the research, including the video, will be treated as confidential under all circumstances and will be used for the purpose of this study only. The dissertation that will be compiled using the data collected will be uploaded onto the open access repository for anyone to read. However, your name and that of your school will be kept confidential at all times. When necessary pseudonyms will be used.

If you agree to take part in this study, please fill in the consent letter below.

I, ____ (your name) agree/ do not agree (delete the one that is not applicable) to participate in the study entitled "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**". I am aware of the fact that I will have to complete a content representation document, teach in the presence of the researcher and also be interviewed by the researcher.

I do understand the following ethical principles that will be put in place in the research, that is:

- Informed consent will be in place, meaning, all participants involved in this study will be informed about the purpose and the process of this study. Furthermore, only participants that gave consent will participate in this study.
- Participation in this study is voluntary and I may, if need be, discontinue my involvement in this study.
- My name, the schools' name and the learners' names will be kept confidential at all times.
- The transcribed interviews, recorded lessons and the content representation document will be confidential at all times, only the researcher and the supervisor will have access to them.

Teachers' signature: ___________________________ Date: ________________

Researcher's signature: _________________________ Date: ________________

Supervisor's signature: _________________________ Date: ________________

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Department of Science and Mathematics Education.

APPENDIX VIII: PARENT/GUARDIAN LETTER

Dear Parent/ Guardian.

I am a Masters student in Education (MEd) at the University of Pretoria. One of the requirements for the degree is to conduct research and write up a report on my findings. The title of my study is "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**". PCK is an acronym for Pedagogical Content Knowledge; which is, in short, teachers' knowledge about how to make their learners understand concepts with ease.

One of the data collection techniques that will be used in this study is observation, where your child's teacher will be observed and video-recorded while teaching Graphs of motion. I am kindly asking for consent to have your child present during the video-recording of the lesson. The video camera will not focus on the learners and the learners will not be interviewed. The lesson will take place like any other lesson as I will just be observing and recording the lesson without interrupting. Should your child turn and face the camera, I will block his/her face to protect his/her identity. The video recordings will always be kept confidential and will only be used solely for the purpose of this study. Furthermore, only my supervisor and I will have access to the video. The video will be transcribed/ narrated in the dissertation, but the names of people involved and institutions will be kept confidential. Please note that the dissertation will be uploaded onto the open access repository after completion of my degree.

If however, you do not allow your child to partake in this study, I will personally teach the lesson to your child so that s/he does not get left behind with the work and does not miss out on the topic. However, I will only cover the lesson after school. I would highly appreciate it if you would make necessary transport arrangements on the day you would like me to present the lesson to your child.

Please fill in the consent letter on the next page.

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I, ____ (your name), the parent/guardian of ____ (your child's name) in Grade 10 grant/do not grant (delete the one that is not applicable) my child to partake in the study entitled "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**". I am aware of the following:

- My child's identity will be protected.
- The video recorded will be kept confidential at all times and used solely for the purpose of this study.
- I may, if need be, stop my child from partaking in the above mentioned study at any time.
- If I do not grant my child permission to partake in the study, then he or she will miss out on the lesson. However, the researcher will teach the exact lesson to my child after school hours.

Parent signature: ______________________________ Date: ________________

Researcher's signature: _________________________ Date: _______________

Supervisor's signature: __________________________ Date: _______________

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APPENDIX IX: LEARNER LETTER

Dear Grade 10 learner.

I am a Master's in Education (MEd) student through the University of Pretoria. One of our requirements, amongst others, is to conduct research and write up a report on our findings. The title of my study is "**Teaching graphs of motion: translating Pedagogical Content Knowledge into practice**".

As part of the research, I have to observe a lesson, while video-recording it, where your Physical sciences teacher will be teaching Graphs of motion. I am kindly asking for your permission to be present during the lesson. I, the researcher, am not going to ask you or your teacher questions, I will just be video-recording the lesson without interrupting in any way. I undertake not to focus the camera on your face, however, should it happen that your face appears on the video it will be blocked to protect your identity. The video recorded will be used to compile a dissertation which will be uploaded onto the open access repository for anyone to read. However, the names of the people in the video will be kept confidential at all times, only my supervisor and I will have access to the video.

If you are willing to participate in this study, please sign this letter as a declaration of your assent, i.e. that you are granting the researcher permission to video-record a lesson in your presence and you know that may withdraw from the research project at any time if you want to. If you are not willing to participate, send this letter back to your teacher without your signature. Since you will not be present in the lesson, as your request, the researcher promises to cover the content that you may have missed in your absence. The researcher will arrange with you about the time and place that will suit you best. Your parent will also be notified about this.

Learners' name and surname: ____

Learner's signature: _________________________________ Date: _____________

Researcher's signature: ______________________________ Date: _____________

Supervisor's signature: _______________________________Date: _____________

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