

Teaching vertical projectile motion: the role of teaching experience in Pedagogical Content Knowledge development

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

In the Faculty of Education
at the
University of Pretoria

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Co-Supervisor: Dr Ernest Mazibe**

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DECLARATION

I, Daniël Rudolf du Toit, declare that the dissertation entitled, **Teaching vertical projectile motion: the role of teaching experience in Pedagogical Content Knowledge development**, which I hereby submit for the degree Magister Educationis, is my own work and has not been submitted before, by me, at any other institution.

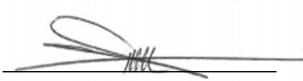
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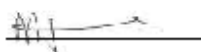
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Fakulteit Opvoedkunde
Lefapha la Thuto

DEDICATION

To my beloved children, Daniël and Lynné,

In the journey of life, there are few greater joys than the privilege of witnessing your growth and potential. As you read these pages, my dearest hope is that you discover the power that lies within you. Always remember, anything is possible when you set your mind to it. Through the countless hours and unwavering determination that have brought this research to fruition, I hope to impart to you the simple yet profound truth – believe in yourselves.

May you approach each day with unyielding confidence, knowing that you possess the ability to overcome challenges, push boundaries, and reach for the stars. Your potential is boundless, and your dreams are within reach. Keep your hearts open to the wonder of knowledge and the beauty of perseverance.

Always remember that our true strength comes from God. He is the source of our courage and resilience.

As you step into your own paths, know that this work is dedicated to both of you with infinite love and unwavering belief in your boundless potential. Dream big, work hard, and, above all, believe in yourselves.

I am compelled to also dedicate this research to my late grandfather, Chris Swanepoel, who recently passed on. His impact on my life has been immeasurable, and his legacy continues to shape my values and aspirations. Not only was he a loving grandfather, but he was also my role model, a beacon of wisdom, and an embodiment of resilience.

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ABSTRACT

This study investigated the PCK of novice teachers before and after their first teaching experience, teaching the topic of *vertical projectile motion*. The primary objective was to examine the impact of teaching experience on the development of PCK in novice teachers when addressing vertical projectile motion for the first time. The study assessed pPCK in three phases: (i) before teaching, (ii) during teaching, and (iii) after teaching. The analysis compared pPCK before and after teaching to assess potential improvements associated with teaching experience.

Three novice Physical Sciences teachers were purposefully and conveniently selected as participants for teaching the topic for the first time. The data collection methods included Content Representations (CoRes) and interviews to capture pPCK, while enacted PCK (ePCK) was observed during lessons and supplemented by video-stimulated recall (VSR) interviews.

The research framework drew from the Refined Consensus Model (RCM), specifically focusing on pPCK and ePCK. A rubric for analysing pre- and post-CoRes data were employed, as well as analysed data from the interviews. A second rubric was used to analyse the data from lesson observations, field notes, and recordings. Specifically, the study emphasised three components of topic-specific PCK: a) Knowledge and skills related to curricular salience, b) Knowledge and skills related to conceptual teaching strategies, and c) Knowledge and skills related to learners' understanding of science, asserting that these components inherently encompassed the others within the teaching strategy.

The results indicated that first-time teaching experience contributed to the development of teachers' PCK in most PCK components. Importantly, no instances were found where teachers' pPCK declined after teaching the topic for the first time. Results also indicated variations in teachers' competencies across components of PCK, reflected in both captured and revealed pPCK.

Key terms: Pedagogical Content Knowledge, Novice Teachers, Teaching Experience, Vertical Projectile Motion.

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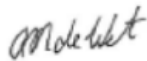
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LIST OF ABBREVIATIONS

TIMMS	Trends in International Mathematics and Science Study
DBE	Department of Basic Education
FET	Further Education and Training
NSC	National Senior Certificate
CAPS	Curriculum and Assessment Policy Statement
CK	Content Knowledge
PK	Pedagogical Knowledge
PCK	Pedagogical Content Knowledge
cPCK	collective Pedagogical Content Knowledge
pPCK	personal Pedagogical Content Knowledge
ePCK	enacted Pedagogical Content Knowledge
TSPCK	Topic-Specific Pedagogical Content Knowledge
RCM	Refined Consensus Model
CoRe	Content Representation
PaP-eR	Professional and Pedagogical experience Repertoire
KSU	Knowledge of students' understanding
KISR	Knowledge of instructional strategies and representations
SSI	Semi-Structured Interview
VSR	Video-Stimulated Recall

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CHAPTER ONE

INTRODUCTION AND STUDY BACKGROUND

1.1 INTRODUCTION

1.1.1 CHAPTER CONTENT

This chapter delves into the motivations behind conducting this specific study and briefly summarises its key aspects. The chapter commences with an introduction, offering background information relevant to South Africa. It proceeds to elucidate the pertinent concepts and articulate the problem statement. The study's purpose, aims, and research questions are presented. Finally, the chapter describes the study design and previews the next chapters.

1.1.2 CLARIFICATION OF CONCEPTS

- FET – phase: The educational phase known as Further Education and Training (FET) in the South African schooling system encompasses Grades 10 through 12.
- Learners: In South Africa, the term "learners" is commonly used to refer to individuals within the schooling system.
- Students: In South Africa, the term "students" is generally used to describe individuals who are enrolled in tertiary institutions or higher education establishments.
- Physical Sciences: In this study, the term pertains to the academic subject within the South African school curriculum during the FET phase, specifically covering Physics and Chemistry topics. Although these two disciplines are instructed and assessed independently, the scores are aggregated and contribute to an overall grade in Physical Sciences.
- Novice teacher: This is a teacher in the early stages of their teaching career who has limited experience in the field of education.
- Content Representations (CoRes): This tool was originally created and presented by Loughran et al. (2004) to capture a teacher's Pedagogical Content Knowledge (PCK) concerning a specific curriculum topic in written form.

1.2 INTRODUCTION AND BACKGROUND OF STUDY

1.2.1 SCIENCE LEARNING IN THE SOUTH AFRICAN CONTEXT

In South Africa, Grade 9 is a critical stage for learners as it is the time when they select certain subjects that they will pursue in Grade 10, including Physical Sciences. This decision

can significantly influence their future academic and career paths. Furthermore, Grade 9 is also the level at which the Trends in International Mathematics and Science Study (TIMSS) assesses learners' knowledge in South Africa.

TIMSS is a global study that evaluates the mathematics and science knowledge of fourth- and eighth-grade learners worldwide. However, a few countries, including South Africa, assess fifth and ninth-grade learners instead (Reddy et al., 2019). Despite South Africa showing an improvement from their previous assessment, the country was ranked last out of 39 countries in the science assessment (Reddy et al., 2019). According to a report released by TIMSS and the Department of Basic Education (DBE), 64% of learners in Grade 9 had not acquired basic science knowledge. This result highlights the importance of Grade 9 as a pivotal point in a learner's education journey in the South African context.

In the Further Education and Training (FET) phase, Grade 10 to Grade 12 in South Africa, Physical Sciences is offered as a subject consisting of Physics and Chemistry. A learner writing the National Senior Certificate (NSC) examination needs to obtain a mere 30% to pass Physical Sciences. In 2021, only 69% of learners enrolled for Physical Sciences achieved 30% and above (DBE, 2022a).

In the Waterberg District, where I am situated, 40.41% of learners obtained 40% and above, and only 22.60% obtained more than 50% (DBE, 2022b). However, to further their studies at the tertiary level, they need to obtain higher marks. For the past six years, less than 40% of learners who passed the NSC examination qualified for studies at the bachelor level. This poor quality in South African science education affects the ability of our young people to apply and study at tertiary institutions, thus impacting the skilled workforce in South Africa.

This discovery necessitated investigating the causes of the weak performance to enhance science pass rates. King'aru (2014) mentioned that the role of teachers and how effectively they convey subject matter to learners are pivotal factors in fostering learner achievement. In a study conducted by Ngema (2016) within the South African context, it was discerned that a factor contributing to the poor performance of learners in science was the insufficient specialised content knowledge among teachers. Hence, teachers play an immense role in imparting information to learners. A crucial element for teachers to effectively communicate information is through their PCK (Shulman, 1986).

1.2.2 SCIENCE TEACHING IN THE SOUTH AFRICAN CONTEXT

Mji and Makgato (2006) found that unqualified and underqualified teachers have contributed to substandard levels in the teaching and learning of physical sciences in South Africa. Semeon (2014) stated that some learners:

“Confess that some teachers do not teach them certain topic[s]. Other teachers either, ignore the topics they find challenging to them or just photocopy notes and give the learners without explaining to them what those notes mean. To me, such [an] approach shows an element of lack of understanding of the topic by those teachers in question”.

For learners to be successful in their learning, they must understand the content teachers teach. Teachers will aim to do precisely that by drawing on their content knowledge (CK) and pedagogical knowledge (PK) to make the subject matter understandable to others. Hence, CK and PK form the amalgam that is PCK (Shulman, 1987). Shulman (1986) also conceptualised PCK as including knowledge of “the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that makes it comprehensible for others” (p. 9). Kind (2009) argues that to establish what good science teaching is, we will need to explore the knowledge bases teachers use in the teaching process, such as PCK.

Kirschner et al. (2015) believe that one of the significant motives for studying PCK is that teachers with a higher level of PCK are more able to assist learners in learning. Building on this perspective, Podolsky et al. (2019) conducted a review of existing research and established a positive correlation between teaching experience and learner achievement. Moreover, teaching experience has been identified as an important factor in PCK development (Chan & Yung, 2018). Rice (2010) explains that the impact of experience is most potent during the first few years of a teacher’s career. It is, therefore, reasonable to investigate the influence experience might have on the development of a novice teacher’s PCK.

Aydin et al. (2014) suggest that for researchers to reach a shared conception of PCK, exploring teachers’ PCK about different topics is required. Understanding the topic-specific nature of PCK is essential because it allows teachers to tailor their teaching strategies to the specific content they are teaching, thereby enhancing the learning experience for learners. Mavhunga and Rollnick (2017) describe PCK at a topic level as “the knowledge to transform topic concepts into versions that are accessible for understanding by a learner” (p. 4). Topic-specific PCK (TSPCK) defines a teacher’s topic-level thinking for lesson planning and

instruction (Mavhunga et al., 2016). Therefore, discussing a specific topic in my research will allow for a more in-depth exploration of the intricacies of PCK in that particular topic.

In conclusion, enhancing teachers' PCK could significantly improve the quality of education in the country. Focusing on the development of PCK in novice teachers is particularly important. It not only equips them with the necessary skills to overcome the challenges they face in the classroom but also enhances their ability to facilitate meaningful learning experiences for their learners. By investing in the PCK development of novice teachers, we can improve the country's overall quality of education.

1.2.3 VERTICAL PROJECTILE MOTION IN THE SOUTH AFRICAN EDUCATION CURRICULUM

According to the Curriculum and Assessment Policy Statement (CAPS) (DBE, 2011), physical sciences consist of two question papers. Question paper two includes knowledge areas of chemistry, and question paper one includes knowledge areas of physics. Physics is made up of three knowledge areas, namely (i) mechanics, (ii) waves, sound and light and (iii) electricity and magnetism.

Vertical projectile motion forms part of the knowledge area of mechanics. Therefore, it is one of the topics examined in the NSC examination and is being developed from Grade 10. In this grade, learners have already been introduced to content such as vector and scalar quantities and motions in one dimension. At this grade level, the foundation of good conceptual understanding is conveyed to learners. Key concepts are being taught to learners so they can describe an object's motion in words, diagrams, graphs and equations. As stated by Mazibe (2017), the knowledge learners obtain from the Grade 10 topic *graphs of motion* is applied to other topics in Grade 11 and Grade 12, which includes vertical projectile motion.

Learners first explore Newton's Laws and the application of Newton's Laws, as well as two-dimensional vectors, in Grade 11. This prepares them to understand *vertical projectile motion* in Grade 12, a significant component of the mechanics knowledge area, accounting for 68 out of 150 marks in the final Grade 12 examination.

According to the diagnostic report released by the DBE for the 2021 learner cohort, the average score for vertical projectile motion was 32%. Figure 1.1 below shows the performance of nine content questions in Paper 1. *Vertical projectile motion* (Question 3) was the worst-answered question (DBE, 2022a). We already noted that sound PCK plays a role in learner outcomes. It is, therefore, fair to assume that improving teacher PCK can lead

to better learner performance in the topic, which can lead to better results obtained in Physical Sciences.

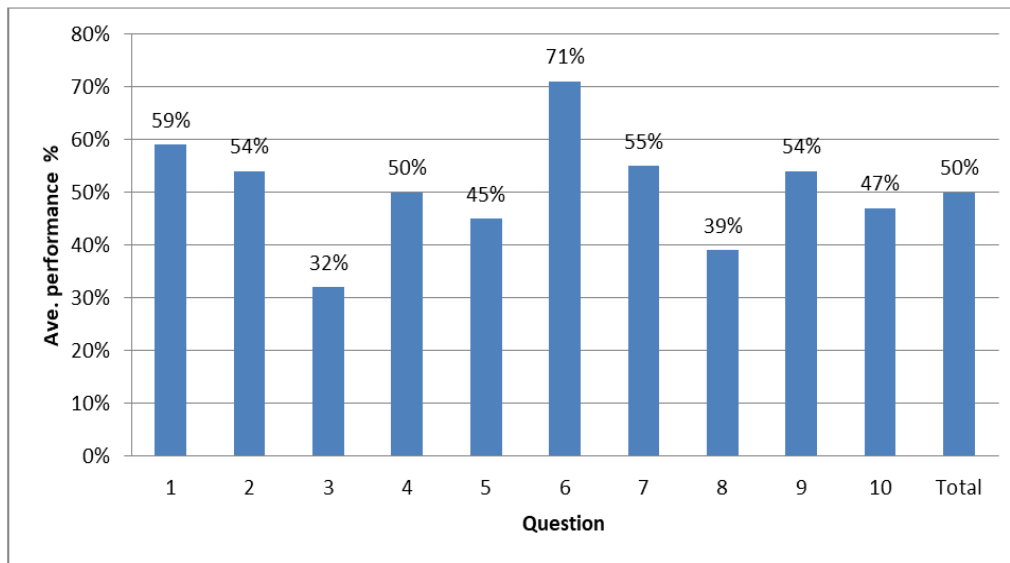


Figure 1.1: Average performance per question in Physical Sciences Paper 1, 2021

Consequently, I focused on this specific topic, namely *vertical projectile motion*, and explored the topic-specific PCK of novice teachers when they taught this topic for the first time and the development of their PCK about the topic due to this experience.

1.3 PROBLEM STATEMENT

Many studies have been conducted to investigate the influence of PCK on learner performance, and there were indications by researchers that well-developed PCK had a positive influence on learner performance (Baumert et al., 2010; Gaigher et al., 2020; Mji & Makgato, 2006; Schmelzing et al., 2013). Ogegbo et al. (2019) argue that continuous professional development is needed because of the poor performance of learners in physical sciences. This argument supports Kriek and Grayson (2009), who found that teachers must enhance their topic understanding, instructional methods, and professional attitudes for learners to succeed and pass with quality results in Physical Sciences.

Many factors contribute to the quality of teaching and learning of science in South Africa, of which the scarcity of sufficiently skilled teachers is unquestionably a significant element (Ogegbo et al., 2019). Kriek and Grayson (2009) stated that contributing factors to poor results include science teachers' inadequate CK, ineffectual teaching strategies, and unprofessional attitudes. A study conducted by Petrus (2018) in South Africa found that 15 out of 77 learners (19,48%) believed that teachers poor teaching methods contributed to poor learner performance in physical sciences. On the international front, studies conducted in the USA by Rice (2010) and Henry et al. (2012) highlighted an essential factor: teachers with less teaching experience are more likely to teach in low-income schools, resulting in

learners in inadequately resourced public schools being taught by novice or inexperienced teachers, which often leads to lower learner achievement.

Having rich PCK distinguishes expert teachers from novice teachers (Park & Oliver, 2008). Despite a qualifying pre-service teacher education, the novice teacher is generally not fully equipped for teaching (Wyatt & White, 2007). The expectations of learners, colleagues and administrators, to name a few, make the teaching profession challenging and put the novice teacher under pressure (Kozikoglu, 2017). One of the many challenges faced by novice teachers, as listed by Kozikoglu (2017), includes planning and implementation of teaching.

As teachers accumulate experience over time, they naturally develop their unique repertoire and teaching style. Shulman (1987) advocated for an educational approach that transcends mere information transmission, emphasising the need for a transformative journey rooted in deep understanding and introspection. Building on this notion, Vonk (1995) underscores that novice teachers can only achieve professional growth by reflecting on their experiences. This reflective process facilitates a deeper comprehension of teaching situations, helping them discern why certain actions prove effective in specific contexts while others do not.

Abell (2008) and Bertram and Loughran (2012) underscored the critical role of PCK in facilitating effective teaching. Furthermore, Clermont et al. (1993) observed that science teachers exhibit different levels of PCK, which continue improving throughout their teaching careers. This implies that classroom teaching experience is pivotal in cultivating teachers' PCK (Drechsler & Van Driel, 2008). Hume (2010) further supports this notion by highlighting teaching experience as a fundamental factor contributing to the development of teachers' PCK. Consequently, it is imperative to identify the influence of teaching experience on the development of teachers' PCK, especially novice teachers teaching a topic for the first time.

1.4 RATIONALE AND PURPOSE OF STUDY

Working in the curriculum section of education as a senior educational specialist, I focused my attention on poor-performing schools. Learners struggle to master the subject of physical sciences, and they achieve results that are too inadequate to further their studies at the tertiary level. These results may cause a shortage of skilled workers that can contribute to the economy of South Africa in the near future.

In my duties, I also have the advantage of working with all Grade 12 teachers in the district, which is rarely the case with other researchers. I realised that many novice teachers are expected to teach in the FET phase, Grade 12, during their first year of teaching. This is a challenging task for any educator to master, even more so for an inexperienced one. Grade

12 is the exit level for learners in secondary school, and this is where we want teachers with sound PCK to teach, which puts novice teachers under enormous pressure.

Mavhunga (2014) mentions two conditions for acquiring PCK: adequate content knowledge and experience. Novice teachers very seldom display the level of competence seen in experienced teachers, and the likelihood of finding quality PCK in novice teachers is slim (Mavhunga, 2014).

I realise that experience plays a vital role in the acquisition and development of PCK. Kind (2009) argues that in order for us to develop a complete insight into what good quality science teaching comprises, we need to understand how the PCK of teachers develops and how it is enacted in their practices. Therefore, we need to determine how to measure and improve the PCK of teachers, especially that of novice teachers.

Many research studies have investigated the PCK among pre-service teachers (Coetzee, 2018; Mavhunga, 2019; Mavhunga & Rollnick, 2013; Van Driel & De Jong, 2001). However, there has been very little previous research on the development of novice in-service teachers' PCK in terms of vertical projectile motion. Van Driel et al. (1998) identified teaching experience as the major source contributing to PCK. This viewpoint aligns with the finding made by Mavhunga (2014) that inexperienced teachers enacted low levels of PCK. For a novice teacher, the training is still fresh; capturing PCK before and after teaching for the first time may give us an idea of the degree to which experience contributes to the development of PCK.

1.5 RESEARCH QUESTIONS

1.5.1 PRIMARY RESEARCH QUESTION

The primary research question that guides the study is: How does the PCK of novice teachers about vertical projectile motion develop through teaching experience?

1.5.2 SECONDARY RESEARCH QUESTIONS

- 1 What is the level of novice teachers' PCK revealed before teaching vertical projectile motion for the first time?
- 2 What is the level of novice teachers' enacted PCK when teaching vertical projectile motion for the first time?
- 3 What is the level of novice teachers' PCK revealed after teaching a lesson on vertical projectile motion?

This study aimed to explore the role of teaching experience in the development of novice teachers' PCK when teaching vertical projectile motion for the first time. The objective was to

study the teachers' PCK in three phases: (i) before they teach, (ii) during teaching and (iii) after teaching. I compared the PCK before and after teaching to see if there was an improvement and whether it could be tied to the actual teaching experience.

1.6 SUMMARY OF THE RESEARCH DESIGN AND METHODOLOGY

This study adopted a qualitative research approach employing a case study methodology, which was deemed suitable for investigating the PCK of three novice teachers teaching the topic of vertical projectile motion for the first time. The research was firmly situated within an interpretative paradigm, enabling the observation and interpretation of teachers' actions and interactions with both the content and learners in their natural environments (Savenye & Robinson, 2005).

Three separate case studies were undertaken to conduct this study, each involving a novice in-service teacher who taught the topic of vertical projectile motion for the first time. A multi-site approach was conducted to ensure a comprehensive exploration of the subject. The primary focus was on the development of teachers' PCK after lesson presentations. The investigation into PCK was conducted at both the topic and concept levels, specifically relating to vertical projectile motion. The data collection process involved a combination of techniques spanning three phases, with direct engagement with the participating teachers.

In Phase 1, the planned PCK of the three teachers were captured using the Content Representations (CoRe) tool (pre-CoRe) before they presented their first lesson on vertical projectile motion. The data collected through this instrument were strengthened by employing a semi-structured interview.

Phase 2 focused on the enacted pedagogical content knowledge (ePCK) displayed by the teachers while teaching vertical projectile motion for the first time. This approach involved the observation of each teacher's two lesson presentations, which were video-recorded to be viewed during data analysis. A video-stimulated recall (VSR) followed a few days after the lesson presentations to strengthen the data obtained through the observations of the lessons. It should be noted that the objective of the VSR interview was not to prompt the recall of the teaching event itself or the precise thoughts and reasoning that occurred during the teaching event. Instead, the aim was to trigger the teacher's contemplation and reflection on their teaching when the event is brought to their attention (Denley & Bishop, 2010).

In Phase 3, each teacher completed a post-CoRe tool on vertical projectile motion, identical to the one completed prior to teaching the lessons (Phase 1). Responses to the post-CoRe

prompts were further enhanced through the interview conducted with each participant a few days after their lesson presentations.

A well-designed PCK rubric ensures the attainment of valid and high-quality assessment of PCK (Chan et al., 2019). The data collected in this study were assessed using two rubrics: one for captured PCK (before and after lesson presentations) and another for revealed PCK (during teaching). These rubrics are discussed in detail in Chapter 3.

1.7 OVERVIEW OF THE CHAPTERS

In this thesis, I present a comprehensive study spanning seven chapters. Focusing on the development of PCK among novice in-service teachers through the experience they obtained teaching the topic of vertical projectile motion for the first time. A brief overview of each chapter is provided below.

In Chapter 1, I delve into a discussion that acquaints the reader with the study's contextual background, elucidating its relevance within the South African context. I expound on the rationale behind this study and articulate the research questions that steer its course.

Chapter 2 offers a comprehensive exploration of the relevant literature. It commences with a discussion of the pivotal concept of Pedagogical Content Knowledge (PCK). It elaborates on the overarching framework employed in this study, which is situated within the Refined Consensus Model (RCM). The literature review further delves into various facets, encompassing PCK development, the methodologies for capturing and evaluating PCK, and the manifestation of enacted PCK. Within this, the chapter encompasses a review concerning PCK in the context of novice teachers teaching a specific topic for the first time, with a special focus on the intricacies of vertical projectile motion. Ultimately, the chapter culminates in presenting the conceptual framework underpinning the study.

Chapter 3 explores the methodology employed in this study, a qualitative approach. It encompasses the selection of the teacher sample, data collection and analysis procedures, and considerations related to the credibility and reliability of the findings. This chapter also offers a concise overview of the research design and the instruments used, concluding with a discussion of ethical considerations taken into careful account.

Chapter 4 comprises the interpretation of the pre-CoRe and interview data collected during the study's first phase. The results are presented per participant, focusing on the first three components suggested in the Grand Rubric and answering the first secondary research question of the study.

Chapter 5 provides an analysis of the data acquired in the second phase of the study, which focused on investigating the implementation of PCK by the three participants. This analysis aimed to address the second secondary research question. This chapter presents a thorough examination and discussion of the video-recorded lessons and interviews.

Chapter 6 presents the data collected during the third and last phase of the study. The data of the post-CoRe and interview were interpreted and analysed. The results obtained were qualitatively discussed to answer the study's third secondary research question.

Chapter 7 includes final thoughts about the research. I provide a concise overview of the study results and the responses to the research inquiries. I analyse the limitations of the study and provide potential directions for further investigation. The chapter finishes with a contemplation on the investigation.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Pedagogical Content Knowledge (PCK) is a multifaceted construct that is fundamental to effective teaching. In this chapter, we delve into the intricate web of PCK, examining its different components and exploring how teachers develop and utilise this specialised knowledge. The chapter begins by examining existing literature on PCK, encompassing models of PCK, topic-specific PCK, PCK development, and methods for capturing and measuring PCK. Subsequently, the literature is reviewed regarding the curriculum topic of *vertical projectile motion*, including an exploration of learner difficulties and misconceptions associated with the topic. The conceptual framework employed in the study is outlined in this chapter. A summary of the chapter is provided as a conclusion.

2.2 THE CONSTRUCT: PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

Pedagogical Content Knowledge (PCK) is a construct that encapsulates the unique blend of content and pedagogical knowledge essential for effective teaching (Shulman, 1986). Therefore, it is important to differentiate between the pedagogical knowledge (PK) of a teacher and the content knowledge (CK) the teacher possesses since these constructs (CK and PK) form the amalgam of PCK (Shulman, 1987). The PK base of teachers is well explained by Guerriero (2014), who indicates that it includes all the required cognitive knowledge for creating effective teaching and learning environments. On the other hand, CK indicates the domain in which the teacher specialises and the sound understanding of the structures portrayed by the teacher in this domain. According to Shulman (1986), it is not only important for the teacher to understand a concept in a subject, but it is also important for the teacher to understand why it is so. Shulman (1987) further describes PCK as: “that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding (p. 8).” Pedagogical Content Knowledge is the knowledge a teacher has that gives rise to that unique ability to combine PK and CK so that the learner can grasp what the teacher is teaching them. Magnusson et al. (1999) argued that effective teaching involves more than just a thorough understanding of a subject and that learning involves more than memorising information.

Pedagogical Content Knowledge is a unique expertise that educators develop and refine through their teaching experiences. This knowledge and skills pertain to effective methods and strategies to convey specific subject matter, thereby enhancing learner comprehension (Loughran et al., 2012). It is crucial to understand that PCK is not a uniform concept but a

personalised expertise with unique attributes and substantial variations. These variations are influenced by factors such as the teaching environment, subject content, and the educator's experience (Loughran et al., 2012). Despite these differences, PCK remains a fundamental aspect of teachers' professional knowledge and competence, highlighting its importance in research aimed at improving educational practices.

Research has indicated that PCK significantly influences everyday classroom activities (Gess-Newsome, 2002). It includes teachers' ability to present and formulate subject matter in a way that is understandable to learners, as well as their understanding of the specific challenges learners may face and misconceptions learners have when learning particular topics (Van Driel et al., 1998).

In summary, PCK is a complex entity that varies among teachers based on factors such as teaching context, content, and experience. Regardless of these variations, it is a cornerstone of teachers' professional knowledge and expertise (Abell, 2008).

2.2.1 MODELS OF PCK

Pedagogical Content Knowledge was first introduced by Shulman (1986). Since then, many models describing PCK have been circulating in the science community, making it difficult to compare and contrast research findings across topics and contexts (Carlson et al., 2019). A summit was held in 2012 to resolve the issue, allowing PCK researchers to share ideas to establish a common understanding of PCK, which was developed and later published by Gess-Newsome (2015). However, over the years, the affordances and limitations of the model became evident (Carlson et al., 2019). In 2016, a second summit was convened to drive the PCK discussion further, which led to the development of the Refined Consensus Model (RCM), illustrated in Figure 2.1.

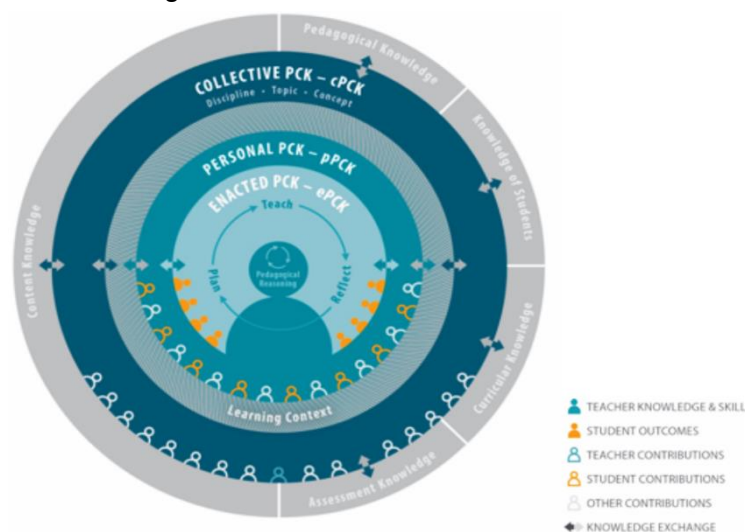


Figure 2.1: Representation of the 2017 refined consensus model of PCK resulting from conversations at the PCK summit

A key feature of the RCM model is the identification of three distinct realms of PCK, namely, collective PCK (cPCK), personal PCK (pPCK) and enacted PCK (ePCK). The mentioned concepts represent three distinct but interrelated realms of PCK. Carlson et al. (2019) suggested that these realms serve as a framework for the specific professional knowledge possessed by science teachers in various environments. This ranges from the shared knowledge comprehended by many to the distinct knowledge subset an individual teacher utilises.

According to Carlson et al. (2019), cPCK is a:

“specialised knowledge base for teaching that has been articulated and is shared among a group of professionals related to teaching that particular subject matter knowledge to particular students in a particular learning context” (p. 12).

Coetzee et al. (2020) state that we can regard cPCK as agreed knowledge, which is dynamic and continuously growing through interactions in the educational community.

Personal PCK serves as a dynamic reservoir, as highlighted by Carlson et al. (2019) from which teachers draw in their instructional practices. This reservoir accumulates a wealth of skills and knowledge shaped not only by the individual teacher's experiences but also by the broader educational community, which is cPCK (Carlson et al., 2019). However, Carlson et al. (2019) emphasised that no teacher utilises their entire set of pedagogical moves encapsulated in their pPCK in any single teaching interaction.

Building on this understanding, it becomes evident that cPCK plays a crucial role in shaping and informing the pPCK of a teacher. The information and skills acquired from the broader science community or educational institutions become personalised and are strategically employed by the teachers in their classroom practices. This larger community encompasses various stakeholders such as colleagues, researchers, scientists, and content specialists. Conversely, the pPCK of a teacher, enriched through their teaching experiences, contributes back to the cPCK when shared within the science community, creating a reciprocal relationship (Carlson et al., 2019).

Expanding on the intricate relationship between cPCK and pPCK established earlier, the dynamic nature of this interplay comes to the forefront. As classroom interactions unfold in a single moment, teachers are faced with the challenge of responding to learner engagements within mere seconds. Quick pedagogical reasoning and flexible implementation of various pedagogies are needed for effective teaching (Morrison & Luttenegger, 2015). Whenever a teacher uses their repertoire of teaching skills to engage in the act of teaching or planning of instruction, implementing the plan or reflecting on the instruction, the teacher uses ePCK

(Carlson et al., 2019). A significant feature of ePCK is how a teacher uses specific knowledge and skills in a particular environment with particular learners, aiming for those learners to learn certain content or concepts (Carlson et al., 2019). It is, therefore, important that teachers know their learners and have sound knowledge of the subject matter. Factors like language, background knowledge, and cognitive abilities are just a few aspects teachers should consider when practising ePCK effectively (Carlson et al., 2019).

The RCM acknowledges that a teacher's PCK is fundamentally rooted in broader professional knowledge bases, and the learning context in which a teacher operates can significantly influence the teaching and learning process (Carlson et al., 2019). This model has sparked extensive discussions and analyses within the science-education community, with research groups worldwide contemplating its implications (Behling et al., 2022).

To conclude, the RCM offers a holistic framework for comprehending and investigating PCK. It recognises the intricacies of teaching practice and provides a structure for scrutinising various facets of this practice. The model's focus on collective, personal, and enacted PCK yields valuable insights into how teachers' knowledge and experiences mould their teaching techniques and strategies.

2.2.2 TOPIC-SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE

In 1999, Veal and MaKinster proposed a taxonomy of PCK consisting of three levels: "(a) General PCK, (b) Domain-specific PCK and (c) Topic-specific PCK" (Veal & MaKinster, 1999, p. 11).

General PCK outlines pedagogical concepts and applies them to various subjects. At this level, we can refer to the strategies teachers will use to teach the subject of a specific discipline. These strategies will, of course, also apply to other disciplines and, for that reason, can overlap.

Domain-specific PCK probes more deeply into a particular domain than general PCK. The emphasis falls more on one of the discipline's domains (Veal & MaKinster, 1999). For example, Physical Sciences, as a school subject in South Africa, consists of two domains: physics and chemistry.

Topic-specific PCK is considered by Veal and Makinster (1999) as the most specific and novel level of their taxonomy. All teachers have this type of PCK, some are just well-developed, and others are not. A teacher with this type of well-developed PCK could have a solid repertoire of skills and abilities in all three levels. As we have established, there are two

domains in physical sciences: physics and chemistry. Each of these domains has topics specific to that domain. Topics specific to a domain may be taught differently, but common concepts within domains can also be taught differently (Veal & MaKinster, 1999). The topic chosen for this study, *Vertical projectile motion*, falls under the domain of physics.

The theoretical framework for topic-specific PCK (TSPCK) stems from Shulman (1987) seminal assertion that: “comprehended ideas must be transformed in some manner if they are to be taught” (p. 16). Expanding upon this notion, Geddis (1993) emphasised the necessity of possessing comprehensive knowledge about various specific aspects of CK to facilitate the essential transformation. Geddis (1993) identified five key components essential for this purpose: (1) students’ existing knowledge including their misconceptions, (2) curricular saliency, (3) the factors that make a topic simple or difficult to grasp, (4) the use of representations such as analogies, and (5) conceptual teaching strategies. Mavhunga and Rollnick (2013) subsequently adopted these components as integral elements of TSPCK.

Mavhunga and Rollnick (2017) describe PCK at a topic level as “the knowledge to transform topic concepts into versions that are accessible for understanding by a learner” (p. 4). Mavhunga suggest five components to be assessed in the grand rubric, “a) learner prior knowledge, b) curricular saliency, c) what is difficult to understand, d) representations, and e) conceptual teaching strategies” (Mvahunaga, 2018, p. 967), of which a teacher should have sound knowledge when teaching a specific topic: (These five content-specific components are considered to result in the pedagogical transformation of topic-specific concepts and are discussed in Section 2.2.5).

Examining PCK from this perspective provides a chance to delve into the topic-specific PCK that a teacher may possess. As Mazibe (2017) points out, different topics necessitate a unique set of content knowledge transformations. Consequently, my attention is directed explicitly towards *vertical projectile motion* and the development of the teacher’s PCK through topic-specific components.

2.2.3 THE DEVELOPMENT OF PCK

The development of PCK is understood as the blend of subject matter knowledge and pedagogy knowledge (Shulman, 1986), a synthesis that evolves across various areas of teaching and learning simultaneously (Van Driel et al., 1998). Expert teachers are widely acknowledged to cultivate their PCK over time, while novice teachers must acquire diverse skills and new knowledge to attain proficiency in their fields (Williams & Lockley, 2012).

Consequently, both prospective and novice teachers often find themselves with insufficient PCK at their disposal (Shing et al., 2018).

To underscore the significance of experience in this process, Mientus et al. (2022) emphasise that practical teaching experiences, such as those offered in university-based education programs, play a pivotal role in individual PCK development. Previous research has explored the development of PCK during pre-service teacher training (Coetzee, 2018; Mavhunga, 2012) and in-service teacher training (Kind, 2009; Mavhunga, 2014).

Given that quality PCK is a hallmark of effective teaching, novice teachers should actively strive to develop it through their teaching experiences. Scholars widely concur that PCK development is intertwined with classroom practice (Nilsson, 2008; Van Driel et al., 1998), as teachers derive PCK from their practical experiences and formal training. It is suggested that successful teachers possess "well-developed" PCK, and interventions such as short-term, skills-oriented workshops can enhance novice teachers' PCK (Clermont et al., 1993).

Grossman (1990) identified four aspects contributing to PCK development: "a) disciplinary education, b) observation of lessons conducted by others, c) teaching experience, and d) courses or workshops during training" (Grossman, 1990, p. 8). A study conducted by Nilsson (2008) highlighted the importance of teaching experience and reflection in science teacher education, and their value in understanding the many components that make up a knowledge basis for teaching. The study emphasises the importance of student-teachers engaging in experiences that promote the development of pedagogical content knowledge (PCK), portraying PCK development as a transformational process.

Experienced educators possess a vast amount of information and prior teaching experiences that they may use as a valuable asset to develop topic-specific Pedagogical Content information (PCK) while instructing unfamiliar subjects (Chan & Yung, 2018). Teaching experience has been identified as an essential factor in PCK development (Chan & Yung, 2018; Van Driel et al., 1998). Hence, the question arises as to how the teaching experience of a novice teacher teaching a topic for the first time would influence their PCK development.

2.2.4 CAPTURING PCK

Capturing the PCK of an educator can be rather challenging (Rollnick & Mavhunga, 2014). Despite acknowledging PCK as an academic construct (Loughran et al., 2004), both teachers and researchers encounter difficulties in articulating and recognising it, respectively (Loughran et al., 2000). To make matters more complex, the boundaries of PCK are blurry (Loughran et al., 2000). It is imperative to recognise that PCK is not a standardised concept

but a personalised expertise with distinct attributes and significant variations. These variations are influenced by factors such as the teaching environment, subject content, and the educator's experience (Loughran et al., 2012). As asserted by Kind (2009), PCK is tacit or hidden knowledge. She further elaborates that teachers are not consciously employing their PCK, rendering this phenomenon both intriguing and elusive. Teachers typically do not express their PCK in their routine conversations due to the absence of a necessity or expectation for them to explain their teaching approach. Additionally, teachers are frequently unaware of this knowledge they inherently possess (Loughran et al., 2004). Moreover, even among experienced teachers, there is no uniformity in their PCK regarding a particular topic they teach.

In 2004, Loughran et al. introduced a method for effectively capturing and presenting Pedagogical Content Knowledge (PCK). This method consists of two crucial components: the first one, called Content Representation (CoRe), focuses on the specific science content, while the second one, known as Professional and Pedagogical experience Repertoire (PaP-eR), is related to teaching practice. These tools were created to assist researchers in capturing and presenting the Pedagogical Content Knowledge (PCK) of science teachers.

The CoRe tool helped the researcher uncover science teachers' understanding of particular components of PCK (Loughran et al., 2004). Figure 2.2 below illustrates the original CoRe tool created by Loughran et al. (2004).

IMPORTANT SCIENCE IDEAS/CONCEPTS			
	Big Idea 1	Big Idea 2	Etc.
1. What you intend the students to learn about this idea.			
2. Why it is important for students to know this.			
3. What else you know about this idea (that you do not intend students to know yet).			
4. Difficulties/limitations connected with teaching this idea.			
5. Knowledge about students thinking which influences your teaching of this idea.			
6. Other factors that influence your teaching of this idea.			
7. Teaching procedures (and particular reasons for using these to engage with this idea).			
8. Specific ways of ascertaining students understanding or confusion around this idea (include likely range of responses).			

Figure 2.2: Original CoRe tool developed by Loughran et al.

Kind (2009) states:

“Loughran et al.’s (2006) CoRes offers, in my opinion, the most useful technique devised to date for eliciting and recording PCK directly from teachers. The method is clearly centred in teachers’ skills and knowledge, so a completed CoRe provides a powerful means of recording the work of an experienced teacher, available for sharing and exemplifying good practice.” (p. 195)

While Kind (2009) discusses the context of seasoned teachers, Williams and Lockley (2012) highlight that CoRes have been effectively utilised in pre-service science teachers’ education. Furthermore, this tool aids novice teachers in comprehending the components of PCK and formulating their understanding of teaching within specific topics (Williams & Lockley, 2012). Despite its age, the CoRe tool continues to be a valuable resource for researchers and is frequently employed in various studies, as evidenced by its usage in research conducted by Buldu and Buldu (2021), Coetzee (2018), Mazibe (2017), and Vollebregt (2020), among others. The enduring relevance of the CoRe tool in current research underscores its effectiveness and versatility in exploring pedagogical content knowledge.

The CoRe tool prompts teachers to articulate what are known as “big ideas” related to their subject area and how they would teach these concepts to their learners (Loughran et al., 2004). The PCK of individual teachers is revealed through the completion of several prompts associated with the big ideas (Loughran et al., 2004). Coetzee (2018) asserted that these prompts are crucial for pre-service teachers to reflect upon while planning a lesson. Utilising an adapted version of the CoRe tool enabled the researcher to access the teachers’ thought processes and reasoning when planning to teach specific content and identify the corresponding pedagogy (Bertram & Loughran, 2012).

2.2.5 MEASURING PCK

Over the years, the assessment of PCK has transformed as researchers have strategically employed diverse methods to discern the intricate interplay between teachers’ content knowledge and pedagogical skills. This transformation is marked by a continuous effort to measure and evaluate teachers’ proficiency by seamlessly integrating their content knowledge into effective pedagogical practices.

The assessment of PCK has undergone a chronological evolution, reflecting the growing recognition of its pivotal role in effective teaching. In its early stages during the 1980s, Lee Shulman introduced the concept of PCK, prompting educators and researchers to explore the dynamic interplay between teachers’ content expertise and their ability to convey that

knowledge to learners. Observations and reflections were primary tools during this period, aiming to measure the nuanced nature of teaching, as demonstrated by Shulman (1987).

Researchers placed increasing emphasis on various methods, including interviews (Clermont et al., 1994), surveys (Howitt, 2007), rubrics (Park et al., 2008), observations (Falk, 2012), and tests (Jüttner & Neuhaus, 2012). These methods aimed to comprehend teachers' reflections on their teaching practices, decision-making processes, and the challenges associated with integrating content and pedagogy. The rubric developed by Park et al. (2008), mentioned earlier, is particularly pertinent to this study. They designed a PCK rubric that underwent validation to assess teachers' PCK, specifically measuring two key parameters: Knowledge of students' understanding of specific subject matter (KSU) and knowledge of instructional strategies and representations of the subject matter (KISR).

Content knowledge assessments became integral to PCK evaluation. Teachers were not only assessed on their pedagogical strategies but also on their depth of understanding of specific subject matter (Coetzee, 2018; Mavhunga, 2014). Lesson planning and instructional artefacts gained prominence as researchers examined the alignment between teachers' plans, instructional materials, and content objectives (Mazibe et al., 2020; Vollebregt, 2020).

Due to the undeniable correlation between CK and PCK (Shulman, 1986), scholars have increasingly come to appreciate the significance of evaluating CK whenever tools for assessing PCK are employed or introduced. Consequently, they devised instruments to gauge the CK and PCK of educators in a precise and dependable manner for specific topics (Jüttner et al., 2013; Mavhunga & Rollnick, 2011). However, Park and Suh (2015) contended that creating distinct measures for every conceivable topic, while appearing ideal, would be impractical and lack meaningful comparability with other assessments.

Subsequently, at a PCK summit, a subgroup of participants formed a discussion group to investigate the possibility of a grand rubric (Chan et al., 2019). Such a rubric is generic and can be customised by researchers to measure different content topics and allow for the measurement of specific variants of PCK situated in the RCM, which includes pPCK, ePCK and cPCK. The Grand Rubric employs a four-point rating scale (Chan et al., 2019) and is designed to evaluate PCK through observations and interviews. Importantly, this rubric can be adapted for diverse topics, serving as a quantitative tool for appraising teachers' PCK in both practical applications and written formats.

Figure 2.3 below illustrates the structure and components of the Grand PCK Rubric template. This template consists of five PCK components suggested by Chan et al. (2019),

of which a teacher should have sound knowledge when teaching a specific topic: “a) Knowledge and skills related to curricular salience, ... b) Knowledge and skills related to conceptual teaching strategies, ... c) Knowledge and skills related to student understanding of science, ... d) Integration between PCK components, ... and e) Pedagogical reasoning”(Chan et al., 2019, p. 262).

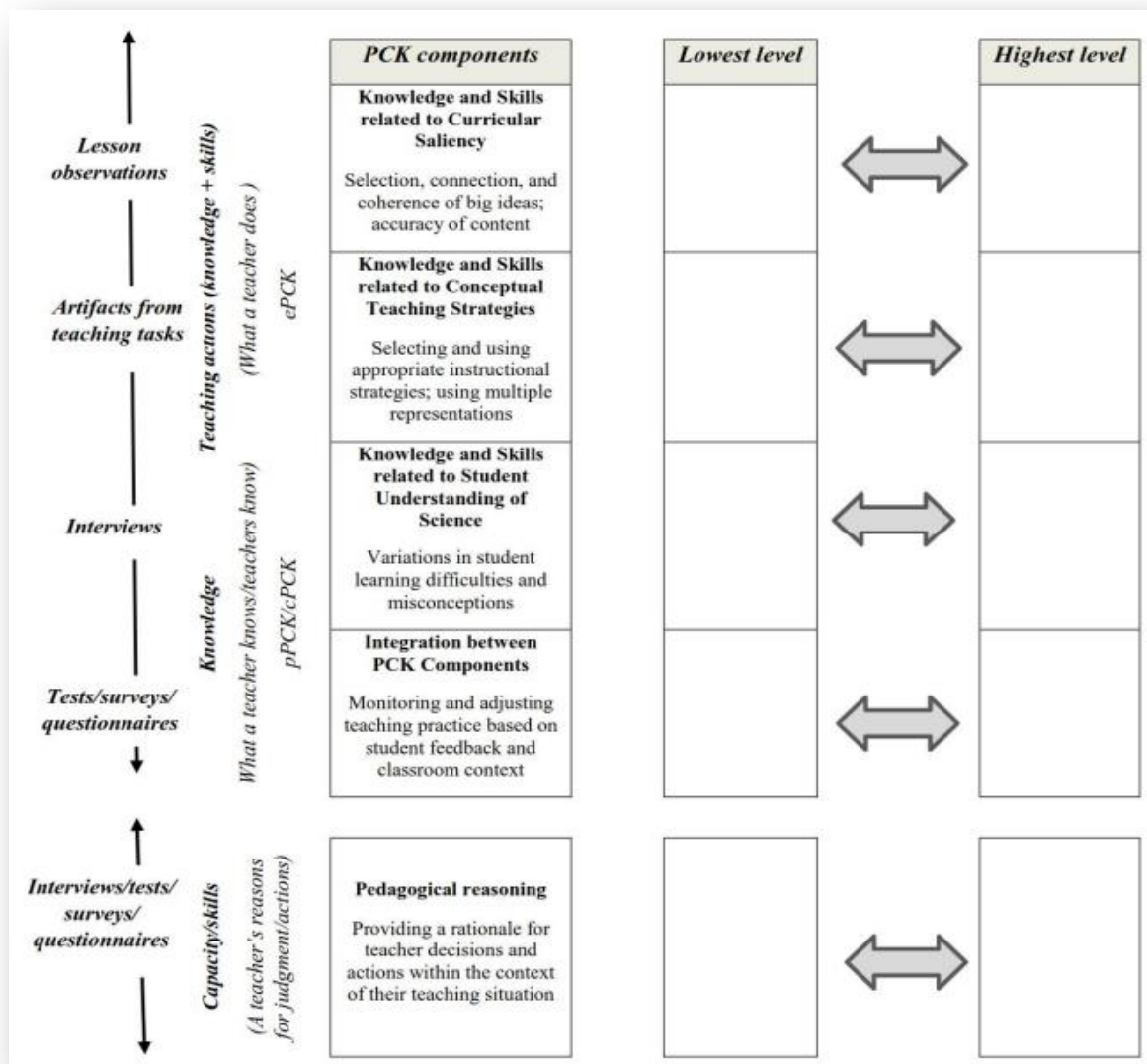


Figure 2.3: The Grand PCK Rubric template

Next to each PCK component is an evaluation criterion that ranges from the lowest to the highest level. The number of levels to be included can be determined based on the specific study's requirements. Coetzee (2018) suggested which CoRe prompts could be placed under each of the five Grand Rubric components. Using the suggested rubric structure by Chan et al. (2019) and aligning the prompts recommended by Coetzee (2018) with the PCK components in the Grand Rubric, this approach is an appropriate tool for comparing PCK

scores. It enables the assessment of PCK development in individuals, as captured in the CoRe, and will be elaborated upon in Chapter 3 of this study.

The PCK components situated in the Grand Rubric template can be described as follows: *Curricular saliency* described by (Mavhunga & Rollnick, 2013) pertains to a teacher's comprehension of where a particular topic fits into the curriculum. It involves the ability to discern the big ideas that underpin a topic (Rollnick & Mavhunga, 2017). In essence, it is about recognising the most significant and pertinent aspects of a topic within the context of the overall curriculum, as Mavhunga and Rollnick (2016) emphasised.

The component of *knowledge and skills related to student (or "learners" in the context of FET schooling in South Africa)* encompasses a teacher's awareness of common misconceptions (Mavhunga & Rollnick, 2013), an understanding of what learners already know that can either facilitate or hinder their learning (Mavhunga et al., 2016) and the accurate knowledge held by learners regarding the topic at hand (Mavhunga, 2019).

Pedagogical reasoning is indispensable in enacting PCK and reflecting upon teaching experiences, as pointed out by Mientus et al. (2022). The component *knowledge and skills related to conceptual teaching strategies* entails selecting appropriate teaching methods that align with learning objectives and the needs of the learners (Chan et al., 2019). This component includes presenting information in various forms, such as words, diagrams, notations, graphs or other representations to enhance learners' understanding of a concept (Chan et al., 2019). Furthermore, Chan et al. (2019) describe strategies to identify areas where learners may struggle and assess their understanding through questions and discussions. As aptly summarised by Mavhunga (2014), this component underscores a teacher's ability to explain a topic or concept in multiple ways and determine the most effective means of representing it.

2.3 TEACHING VERTICAL PROJECTILE MOTION

2.3.1 VERTICAL PROJECTILE MOTION AS A CURRICULUM TOPIC

In the South African Grade 12 curriculum, vertical projectile motion holds substantial importance as a physics topic. This concept is a crucial component of the broader study of mechanics and kinematics. Vertical projectile motion involves understanding the motion of an object launched vertically into the air and influenced by the gravitational force. It plays a pivotal role in developing learners' comprehension of fundamental physics principles and their application.

Time	Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
5 HOURS	<u>Vertical projectile motion in one dimension (1D)</u>				
5 HOURS	Vertical projectile motion* (1D) represented in words, diagrams, equations and graphs * Near the surface of the Earth and in the absence of air friction	• Explain that projectiles fall freely with gravitational acceleration 'g' accelerate downwards with a constant acceleration irrespective of whether the projectile is moving upward or downward or is at maximum height. • Know that projectiles take the same time to reach their greatest height from the point of upward launch as the time they take to fall back to the point of launch. This is known as time symmetry. • Know that projectiles can have their motion described by a single set of equations for the upward and downward motion • Use equations of motion to determine the position, velocity and displacement of a projectile at any given time. • Draw position vs. time (x vs. t), velocity vs. time (v vs. t) and acceleration vs. time (a vs. t) graphs for 1D projectile motion. • Give equations for position versus time and velocity versus time for the graphs of 1D projectile motion. • Given x vs. t, v vs. t or a vs. t graphs determine position, displacement, velocity or acceleration at any time t. • Given x vs. t, v vs. t or a vs. t graphs describe the motion of the object e.g. graphs showing a ball, bouncing, thrown vertically upwards, thrown vertically downward, and so on.	<u>Recommended experiment for informal assessment:</u> Draw a graph of position vs. time and velocity vs. time for a free falling object. AND Use the data to determine the acceleration due to gravity.	Materials: Ticker tape apparatus, ticker-timer, mass, platform.	

Figure 2.4: A snippet from the Grade 10-12 Physical Sciences CAPS document on the content of vertical projectile motion to be taught in Grade 12

The CAPS document provides guidelines for what should be taught in each grade and subject in the South African curriculum. It outlines the specific content teachers must impart in their instruction concerning all relevant topics. Figure 2.4, a page extracted from the CAPS document, illustrates the content related to the topic of vertical projectile motion and the recommended time allocation for covering this content (DBE, 2011).

Vertical projectile motion helps learners understand basic concepts of kinematics and apply the knowledge attained in Grade 10 about kinematics, such as displacement, velocity, acceleration and time (Mudau, 2014). It also develops their skills in solving problems involving motion in one dimension (Mudau, 2014). As I indicated in Chapter 1, the DBE (2022a) identified projectile motion as one of the topics in which learners performed the worst during past exams. This indicates a serious lack of problem-solving skills, which learners are displaying (Mudau, 2014). Therefore, teaching vertical projectile motion is crucial to enhance these problem-solving skills.

Focussing on the topic of vertical projectile motion, the diagnostic report of 2021 released by DBE suggested that teachers should make sure:

- That learners use sign conventions and keep to this convention throughout the question.
- To reinstate the concept of gravitational acceleration with learners and ensure that they understand that it does not change but remains constant.
- That learners are taught the skills of interpreting and sketching graphs.

The Department of Basic Education released a study guide to assist learners in answering the question of vertical projectile motion. This guide notes that learners should have sound pre-knowledge, especially from the Grade 10 chapter on *motions in one dimension* (DBE, 2020). The shape of graphs is explained to learners at the Grade level where learners also acquire the ability to interpret graphs of motion.

The guide corresponds with the suggestion made in the diagnostic report stating that learners must choose a reference frame with a positive direction of motion and use the same sign convention throughout the question (DBE, 2020). It is also advisable for learners to break the motion up into stages. This will allow learners to keep track of reference points throughout the motion and will allow learners to write down all available information from respective reference points in order for them to select an appropriate formula of motion to calculate the unknown variable (DBE, 2020).

2.3.2 LEARNERS' DIFFICULTIES AND MISCONCEPTIONS IN VERTICAL PROJECTILE MOTION.

The Oxford Dictionary refers to misconceptions as *a view or opinion that is incorrect because it is based on faulty thinking or understanding*. Learners often have ideas about a particular aspect or aspects within a topic that is not correct.

Learner misconceptions on content related to vertical projectile motion are well documented (Mudau, 2014; Tao & Gunstone, 1999; Vosniadou, 1994; Whitaker, 1983). Some learner misconceptions about projectile motion include:

- Fast-moving objects are associated with high acceleration, and slow-moving objects with low acceleration (Lemmer, 2013).
- Falling objects have a greater gravitational force than stationary ones, which may have no gravitational force at all. (Vosniadou, 1994)
- Gravity is an inherent characteristic of an object (Vosniadou, 1994)
- Acceleration and velocity always have the same direction (Rosenquist & McDermott, 1987)
- At the highest point, an item hurled upward experiences zero acceleration (Whitaker, 1983)
- An item in motion needs an initial force to continue moving forward. As the force diminishes, gravity becomes the dominant force and causes the object to fall to the earth (Prescott & Mitchelmore, 2005a)
- Objects released from a moving carrier descend vertically (Millar & Kragh, 1994)

Graphs are an important aspect of vertical projectile motion and are mentioned in four of the eight guiding bullets in the CAPS document describing the content that learners need to learn. McDermott et al. (1987) noted the following learner difficulties in connecting graphs to physical concepts:

- Distinguishing between the inclination and elevation of a graph.
- Analysing variations in elevation and variations in incline.
- Establishing a connection between one kind of graph and another.
- Aligning narrative data with pertinent attributes of a graph.
- Analysing the integral of a graph.
- Distinguishing the form of a graph from the trajectory of the movement.
- Depicting a negative velocity on a graph that shows velocity with time.
- Analysing and differentiating between several kinds of motion graphs.

The mistakes and errors of learners who wrote the 2021 NSC examination are documented in the diagnostic report (DBE, 2022a). This report also reveals the lack of learner capabilities in answering questions on vertical projectile motion. The learner errors and misconceptions are listed below:

- Learners failed to realise that when an object moves with constant velocity, the acceleration is 0.
- Incorrect sign conventions are applied to vector quantities.
- Learners failed to realise that objects dropped from a moving object have the same initial velocity as the moving object.
- Learners could not interpret the object's motion and could not sketch the graphs correctly.

Evidently, the errors and misconceptions in the diagnostic report correspond to those recorded in research and still affect our learners today. Therefore, inspection is required to enhance effective teaching methods and promote a better understanding of vertical projectile motion among learners.

Studies have shown that it is crucial for teachers to take student misunderstandings into account to facilitate effective learning (Gil-Perez & Carrascosa, 1990). Teaching strategies are important in facilitating meaningful learning and averting learner misconceptions (Dilber et al., 2009). Teachers having misconceptions or misinterpretations can be barriers to conceptual understanding of science for both the teacher and the learner. If teachers have misconceptions about the subject or topic, it can affect their ability to convey scientific concepts to their learners effectively (Qian et al., 2019).

2.4 CONCEPTUAL FRAMEWORK

The nature of PCK is dynamic, with each teacher and teaching context generating a unique teaching approach and response to specific challenges (Carlson et al., 2019). Pedagogical Content Knowledge (PCK) refers to the specialised information that teachers use while teaching a specific topic to specific learners within a particular setting. This knowledge is developed when teachers encounter and address specific issues within their teaching environment (Berry et al., 2015).

This study's first sub-question aimed to assess novice teachers' reported PCK levels before introducing the topic of vertical projectile motion, specifically focussing on the first three PCK components mentioned in Section 2.2.5.

The second sub-question explored how novice teachers enacted their PCK when teaching this topic for the first time. This was achieved through classroom observations and video-recordings, with the data aligned with the three components of PCK.

Finally, the third sub-question aimed to evaluate the novice teachers' reported PCK after they had taught their initial lessons on vertical projectile motion, emphasising the same three PCK components.

A conceptual framework was established, primarily based on the RCM, which places teachers and classrooms at its core to address these sub-questions and the primary research question (Carlson et al., 2019). The RCM considers the intricate layers of knowledge and experience influencing teaching practices, and it identifies three distinct PCK realms: cPCK, pPCK, and ePCK (Carlson et al., 2019). Mavhunga (2019) explains that the development of PCK could be experienced at the topic level through the three realms. However, in this study, the investigation centres on two of these realms: pPCK and ePCK.

Specifically, the pPCK of teachers pertains to the personalised knowledge unique to each individual teacher (Carlson et al., 2019). It involves interpreting and transforming cPCK, subject matter knowledge, and other teacher knowledge bases into practical teaching tools (Behling et al., 2022). The knowledge teachers employ when teaching a specific topic to learners within a particular context, intending to facilitate learner understanding, is categorised as ePCK (Carlson et al., 2019). The pPCK informs the teacher's ePCK (Label A in Figure 2.5) when delivering a lesson, and reciprocally, ePCK influences the teacher's pPCK (label B in Figure 2.5), as detailed in the RCM (Carlson et al., 2019).

It is important to bear in mind that ePCK is a subset of pPCK. Consequently, it is reasonable to anticipate that teachers may not necessarily enact the complete range of knowledge disclosed when their pPCK is captured. As Mazibe et al. (2020) discovered, when utilising the constructs of reported PCK and enacted PCK, teachers frequently articulate a more comprehensive PCK than what they actually put into practice in the classroom.

The foundation of this research was built around the notion that the worth of Pedagogical Content Knowledge (PCK) resides in its specificity to certain topics. Although the model (Figure 2.5) refers to PCK, for this study, it is PCK at a topic level with the two realms (pPCK and ePCK) of PCK as indicated. These realms are grounded in three key PCK components delineated by Geddis (1993) and are also aligned with the Grand Rubric template developed by Chan et al. (2019). These components are: "a) Knowledge and skills related to curricular saliency ... b) Knowledge and skills related to conceptual teaching strategies ... c)

Knowledge and skills related to student understanding of science” (Chan et al., 2019, p. 262).

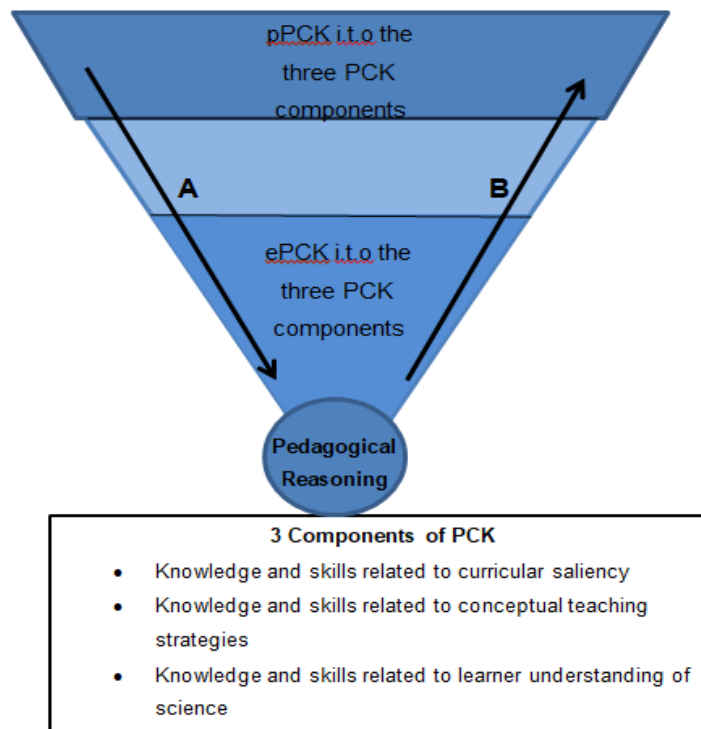


Figure 2.5: Summary of the conceptual framework

“Knowledge and skills related to curricular saliency” (p. 262): This refers to the teacher’s knowledge and ability to select appropriate concepts for a specific topic and connect the different concepts in a logical sequence.

“Knowledge and skills related to conceptual teaching strategies” (p. 262): This component entails knowledge and skills to select and use appropriate instructional strategies and topic-specific activities to achieve conceptual development and address learner difficulties and misconceptions. Using multiple representations is important, especially when explaining the concepts learners struggle to understand.

Knowledge of Representations play an essential role in the teaching and learning of science. A representation can take many forms, such as drawings, motion diagrams, simulations or experiments. The purpose of the representations is to help learners understand some aspects of nature.

“Knowledge and skills related to learners’ understanding of science” (p. 262): A teacher displays this knowledge when they can identify and acknowledge differences between individuals in learning and elicit and address learner difficulties and misconceptions.

Chan et al. (2019) state that teacher actions and knowledge can be measured using the first four components in the Grand Rubric. However, to assess and gauge PCK, this study only employed the first three components, as the integration of other PCK components (component 4) is intertwined with the knowledge and skills related to conceptual teaching strategies (component 2). This integration becomes evident in the teacher's approach to designing conceptual teaching strategies (Rollnick & Mavhunga, 2016).

In summary, the study's conceptual framework (see Figure 2.5), adapted from the RCM which was a product of the discussions during the PCK summit reported by Carlson et al. (2019), underscores PCK within a topic-specific context, focusing on pPCK and ePCK. This framework embraces the interactive relationship between these realms, as discussed earlier. Importantly, the model centres on the teacher (as initially depicted in the RCM), highlighting the teacher's pivotal role in teaching (Carlson et al., 2019).

2.5 CHAPTER SUMMARY

The study explores the development of PCK, particularly in the context of novice teachers teaching a specific topic for the first time. Through this investigation, I aim to shed light on the role of teaching experience on PCK development.

As we progressed through this chapter, valuable insights into the complexities of PCK was gained, its role in teaching, and how it can be measured and developed to enhance educational practices. This exploration sets the stage for the subsequent chapters of the study, where we will delve further into the topic-specific PCK required for teaching vertical projectile motion and its development through first-time teaching experience.

In Chapter 3, I will explain how the study's conceptual framework influenced the research technique used to investigate the development of Pedagogical Content Knowledge (PCK) in inexperienced teachers. Additionally, I will explore how these teachers applied their PCK during their first teaching encounters with vertical projectile motion.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter outlines and justifies the study's research design. The chapter explores the methodology employed to address the research questions in detail. The paradigm that underpins this study, along with a description of the sampling procedure and participant profiles are explained.

The chapter further elaborates on the research design, the instruments utilised, data analysis strategies, and discussions on steps followed to maintain the validity and credibility of the data and the findings. The processes undertaken for developing and adapting the respective instruments used for data collection and analysis are also discussed.

The chapter concludes with a summary of the research design and a discussion of ethical considerations. This approach ensures a robust and credible research design, contributing to the overall integrity of the study.

3.2 RESEARCH PARADIGM AND APPROACH

Weaver and Olson (2006) describe paradigms as “patterns of beliefs and practices that regulate inquiry within a discipline by providing lenses, frames and processes through which investigation is accomplished” (p. 460). This study adopts a qualitative interpretivist approach to explore the experiences and perceptions of the participants. Interpretivism is a philosophical viewpoint that posits reality as a subjective construct shaped by social interactions. It sees the researcher's role as deciphering and understanding the significance individuals assign to their actions and their interactions with others, as Bryman (2016) elucidates. The interpretivist approach allowed me to gain access to the perceptions and experiences of the participants (Thanh & Thanh, 2015). Pham (2018) stated that one of the advantages of interpretivist research is that in addition to describing human subjects or events, the researcher can also profoundly understand the participants in a social context. By following a qualitative interpretivist approach, this study aimed to provide a rich and nuanced understanding of the development of teachers' (participants') PCK (phenomena) through their classroom experience (social context) rather than seeking to generalise findings or test hypotheses.

One of the key endeavours in the interpretive paradigm, as stated by Cohen et al. (2002), is “efforts made to get inside the person and to understand from within”. Therefore, perceiving social reality from an interpretive perspective is a subjective process. That is, the personal

views and opinions of the researcher influenced the knowledge obtained through this study. The interpretation of the individual plays a crucial role in shaping the various understandings of social reality that exist (Tsang, 2014). This subjectivity can be a limitation in the study because it may lead to biased findings. Several strategies have been employed to mitigate this limitation, including triangulation, participant validation, expert reviews and transparency. These strategies are elaborated upon in Section 3.10.

3.3 RESEARCH METHODOLOGY

The research aims and objectives were accomplished by implementing a qualitative research methodology. Qualitative research is appropriate for delving into intricate and context-dependent phenomena that defy easy quantification or measurement, as per Creswell (2014). The qualitative design is an all-encompassing method of investigation that aims to comprehend a societal or personal issue. It was essential to employ a methodology in this research that allowed the teachers to express their methods. According to Savenye and Robinson (2005), qualitative research:

“Is typically conducted in natural settings without manipulation of the environment, therefore, allowing researchers not to predict or describe causality but to describe in detail what is happening. The goal is to yield insight into human activities and opinions from the perspectives of the participants.” (p. 68).

This study employed a multi-method qualitative design to delve into the experiences and viewpoints of the participants. Interviews and observations were used as data collection techniques. The study was structured into three distinct phases to facilitate a thorough exploration of the respective secondary research questions.

The teachers completed a pre-CoRe tool on vertical projectile motion in Phase 1 and participated in a semi-structured interview (SSI) to allow them to elaborate on their responses to the pre-CoRe prompts. This stage aimed to gauge the teachers’ proficiency in three components of PCK selected from the Grand Rubric (Chan et al., 2019):

- 1 “Knowledge and skills related to curricular salience ... ,
- 2 Knowledge and skills related to conceptual teaching strategies ... , and
- 3 Knowledge and skills related to learners’ understanding of science” (Chan et al., 2019, p. 262).

Phase 2 involved the teachers teaching two lessons on vertical projectile motion for the first time, thereby enacting their existing PCK and skills. Classroom observations were conducted during these lessons, and teaching and learning activities were recorded. These recordings were viewed a few times to identify instances in the lessons that were of interest

to the research questions. Focusing on these instances allowed me to formulate open-ended questions for the Video-Stimulated Recall (VSR) interview. After the lesson observations, a VSR interview was conducted to understand how teachers reasoned about their application of knowledge on the three components selected from the Grand Rubric. The data were analysed by identifying, coding, and interpreting emerging patterns and themes. The data analysis process is described in detail in Section 3.8.

In Phase 3, each teacher completed a post-CoRe tool on big ideas in the topic of vertical projectile motion, identical to the one completed prior to teaching the lessons. Responses to the post-CoRe prompts were further enhanced through the interview conducted with each participant a few days after their lesson presentations.

The data collection protocol and tools used were consistent with the interpretive paradigm. The combination of the design, multi-case study methodology, followed protocol, and utilised tools enabled the primary research question to be addressed effectively. This pertained to how the PCK of novice teachers about vertical projectile motion develop through teaching experience.

The goal of this study was not to generalise findings to all teachers in all contexts but to support existing theories about teacher knowledge and PCK development through an interpretative approach. Zainal (2007) highlighted that a case study often explores few subjects and does not provide a good enough foundation for scientific generalisation. Vasileiou et al. (2018) further elucidated this point by indicating that samples in qualitative research are typically small, which facilitates the depth of case-oriented analysis fundamental to this mode of inquiry. Therefore, while the findings may not be broadly generalisable, they contribute significantly to the depth and richness of understanding in the specific study area.

3.4 SELECTION OF PARTICIPANTS AND SAMPLING PROCEDURES

The population of this study comprises science teachers who teach the topic of vertical projectile motion for the first time. Participants were purposively selected through non-random methods based on the relevance of the information they possessed about the research questions (Lodico et al., 2010). Teachers located near the institution where the researcher was situated were considered for participation in this study. This method is known as convenience sampling and is described as a method used to select participants who are easily accessible (Emerson, 2015).

The participants in this study were three Grade 12, two males and one female, novice physical science teachers who had never taught the topic of vertical projectile motion before. All three participants were from the Waterberg district in the Limpopo province of South Africa. Each participant was given a pseudonym, which was used throughout this study. The first participant was known as Mr DN, the second as Ms NJ, and the last as Mr JP.

I was able to work with Grade 12 educators because lesson observation is part of my job description as the subject advisor for the Waterberg District. Moreover, teachers are used to having their lessons observed by the subject advisors for all subjects, and this would not be a new or intimidating experience for them. This process was entirely voluntary, and discontinuation or withdrawal at any time during the study was allowed without any consequences or repercussions. This was ensured by the forms given to participants explicitly stating that participation is voluntary and discontinuation is allowed without adverse effects. This possibility was observed when two participants decided to withdraw from the study due to personal reasons before the collection of data started. I assured the teachers that my interactions within the context of the research are separate from my professional role as subject advisor and that the study is designed to ensure anonymity and confidentiality.

The criteria used required physical science teachers who taught the topic of vertical projectile motion for the first time in Grade 12. The three teachers, each from different schools within the district, were included in the study without any discrimination based on gender, ethnicity, or language. The participants' biographical details are provided in Table 3.1.

Table 3.1: Participants' biographical information

	Mr DN	Ms NJ	Mr JP
Age range	18-25	26-35	18-25
Gender	Male	Female	Male
Qualification/s	B.Ed Degree in Science Education	B.Ed Degree in Science Education	B.Ed Degree in Science Education
Experience in teaching (in years as of the end of 2021)	0	4	0
Experience in teaching vertical projectile motion (in years as of the end of 2021)	0	0	0
Current studies (if any)	None	None	None
English as a first language?	No	No	No
Language of instruction	Afrikaans	English	English

As stated earlier, the study was conducted in three phases, with the same participants involved in Phase 1, 2, and 3. All necessary permissions were obtained to ensure the study was conducted in a practical, ethical, and legal manner in all administrative aspects (Cohen et al., 2017). The permissions obtained included approval from the school principal, the teachers participating in the study, and the learners of Grade 12 and their parents. The study was permitted to be carried out on the school premises, specifically in the Physical Sciences classroom. Consent was also obtained to audio record teacher interviews and to observe and video-record classroom activities as part of the study.

3.5 RESEARCH DESIGN

This research design was based on a multiple-case study approach that was consistent with the principles and beliefs of the interpretive paradigm. A case study refers to a research technique that entails a thorough and detailed analysis of a specific subject, also known as the case (Yin, 2018). The interpretive paradigm is a research philosophy that posits the existence of free will and a world constructed through cognition, where knowledge is acquired subjectively through the researcher's personal engagement (Schwandt, 1994). In this sense, a case study can be designed under an interpretive paradigm; this design enables researchers to engage closely with the participants and delve deeply into the issues at hand. (Yin, 2018). This approach enables the researcher to gain an understanding of the subject being studied and facilitates comprehensive and nuanced examinations of intricate matters within the real-world contexts of the participants. (Crowe et al., 2011). The case under investigation in this study is novice physical science teachers teaching *vertical projectile motion* for the first time. This study is a descriptive case study, which, according to Zainal (2007), is set to describe the natural phenomena that occur within the study's context. In this case, the natural phenomenon was the PCK of teachers. A limitation of case study research is that the results may not apply to a broader population (Simon & Goes, 2013). However, their findings can still contribute to the development of theories (George & Bennett, 2005).

Figure 3.1 illustrates the study design, depicting Phase 1, 2, and 3, the sequence of data collection, the number of encounters with each participant, and the chronological order of these interactions. Furthermore, Figure 3.1 visually represents the study questions that were addressed in each encounter.

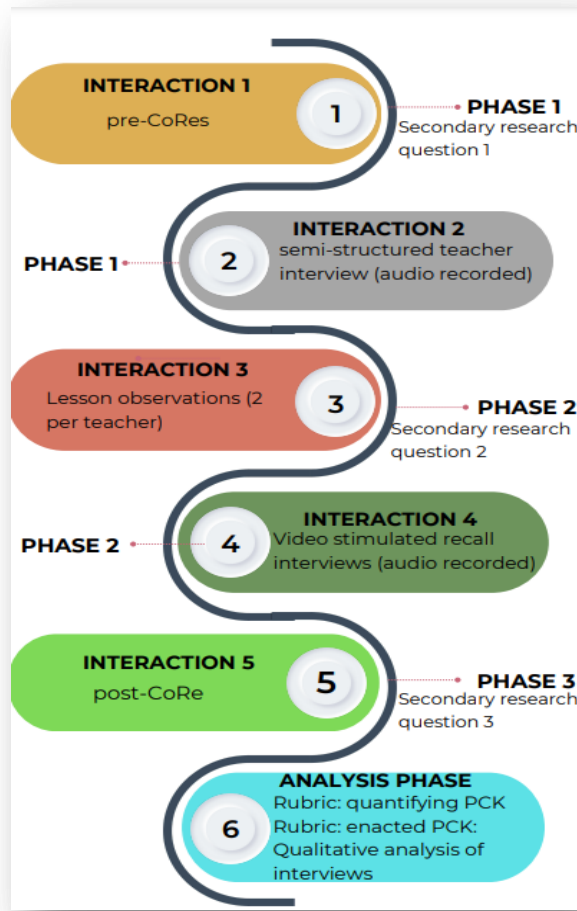


Figure 3.1: Visual presentation of the research design

Figure 3.2 illustrates an alignment of the research design with this study's conceptual framework. I investigated the development of pPCK through the teacher's first-time teaching experience (ePCK), focusing on the three PCK components mentioned in the conceptual framework. The CoRe tool accessed the teachers' PCK before (pre-CoRe) and after (post-CoRe) lesson presentations. The transfer of knowledge between pPCK and ePCK (see Figure 3.2, arrows A and B) was established through the interviews. Observations in the classroom gave us a deeper understanding of the teachers' pPCK and how they enacted PCK. Additionally, the insights gained from observing lessons and conducting VSR interviews were invaluable in understanding the teachers' ePCK and their pedagogical reasoning process.

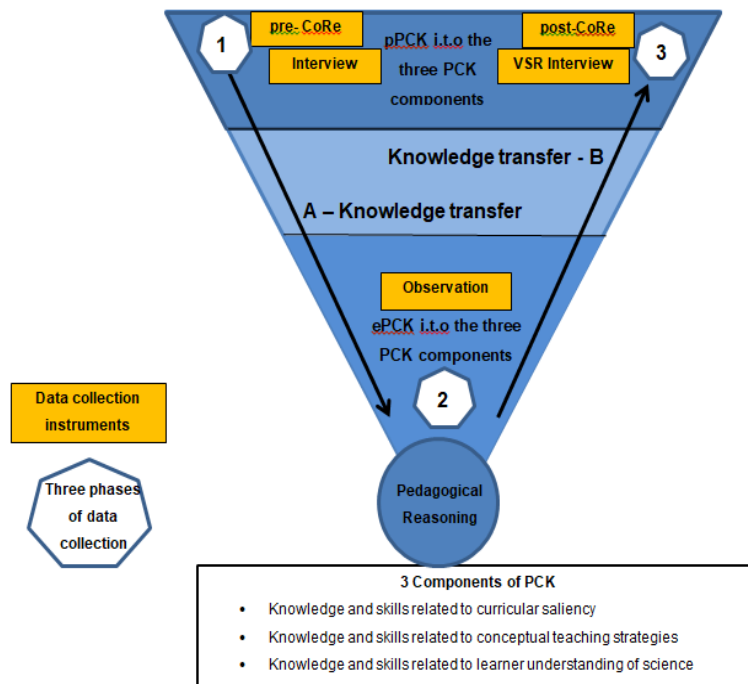


Figure 3.2: An overview of the conceptual framework, detailing the progression of events and the instruments employed throughout the research

As indicated (Figure 3.1 and Figure 3.2), data were collected in three distinct phases: a) when novice in-service teachers plan for their lessons on vertical projectile motion, b) during the teaching of the topic, and c) after teaching the topic. While data were collected in three distinct phases, the CoRe tool was utilised during two (Phase 1 and Phase 3) of these phases, before and after the topic was taught. The tool used before the lesson presentation (Phase 1) will be referred to as the "pre-CoRe," and the tool used after the lesson presentation (Phase 3) will be referred to as the "post-CoRe" to distinguish between the two CoRe tools.

Phase 1: In Interaction 1, the teachers were tasked to complete the pre-CoRe tool before teaching the topic of vertical projectile motion for the first time. The researcher already determined the two big ideas related to vertical projectile motion, namely, *the change in position of a projectile* and *the change in velocity of a projectile*. Eight prompts to elicit knowledge from the teachers pertaining to the three PCK components were selected and adapted from the CoRe tool developed by Loughran et al. (2004). The CoRe tool, provided to the three teachers for completion, can be seen in Figure 3.3 and is explained in detail in Section 3.6.1.

CoRe - Tool		
CoRe prompts	Big Idea 1	Big Idea 2
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i>?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?		
2. What concepts need to be taught before teaching this big idea?		
3. What representations would you use in your teaching strategy?		
4. Give particular reasons for the representations used to engage with this idea?		
5. Describe the strategy you will use to establish conceptual development of the key idea.		
6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?		
7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?		
8. How do you address the misconceptions and or learner difficulties?		

Figure 3.3: The pre-CoRe-tool that was provided to participants

The CoRe tool was distributed electronically to the three teachers in MS Word format, as shown in Figure 3.3. They were given the flexibility to complete it either online or manually. There were no time limitations to constrain the teachers, and they were encouraged to work on the CoRe until they were satisfied with the content. Furthermore, they were allowed to use any available resources, just as they would in the process of planning any other lesson. While teachers were not directly assisted in responding to the CoRes, the prompts' were explained and clarified. They were also informed that they could contact the researcher at any time if they required further clarification or guidance regarding the completion of the CoRes.

Interaction 2 strengthened the data obtained through the pre-CoRes by means of a semi-structured interview, which was recorded using a conventional tape recorder and conducted one-on-one with the teachers a few days after they submitted their pre-CoRe. This interview was used to corroborate the data collected using the pre-CoRe, which is particularly important in cases where teachers found it daunting to complete the CoRes, as has been seen in other studies, e.g. Mazibe et al. (2020). The interview questions were taken and derived from the CoRe prompts, intending to clarify prompts and supplement the information provided in the pre-CoRe. These questions were open-ended, indicating that they did not come with predefined answer choices, and teachers had to articulate their responses using

their own words (Züll, 2016). The transcribed and coded interviews of all three novice teachers can be found in Appendix G – Appendix I.

Phase 2, Interaction 3: The novice teachers were observed in their classrooms while teaching the topic of vertical projectile motion for the first time. These observations aimed to identify teaching events that aided in the development of their PCK through the teaching experience and also to assess the degree to which they enacted their pPCK, as revealed in their written pre-CoRes into practice when they taught the topic.

The researcher requested permission from the three participating teachers and their principals to video record the lessons conducted by each teacher. If the teacher did not cover the graphs of the motion component in the first lesson, a second lesson was to be recorded, specifically focusing on this content. Consequently, all three teachers had two lessons recorded, with the duration of each lesson varying between 45 to 60 minutes based on the particular school's timetable.

During these sessions, I acted as a non-participating observer, whereby I was not part of the group and did not take part in any activities taking place during teaching (Lodico et al., 2010). My primary role was documenting field notes while observing and recording the lessons.

The data analysis process during lesson observations was guided by a rubric that I adapted from Coetzee (2018), Mavhunga and Rollnick (2013) and Mazibe (2017). This rubric was tailored to align with the components of teachers' ePCK about vertical projectile motion. The rubric assisted me in looking for events that revealed the teacher's knowledge about teaching vertical projectile motion regarding the three components of PCK. The coded lesson narratives for all three teachers can be found in Appendix M – Appendix R.

Moreover, in Phase 2, Interaction 4, VSR interviews were conducted with the teachers to encourage thoughtful assessment and consideration of their lessons. During these interviews, teachers were presented with sections from their lessons that could potentially reveal insightful aspects of their PCK. They were free to pause the video segment at any point to contemplate and express their thoughts. They were encouraged to share all relevant information without reservation, as suggested by O'Brien (1993). This approach enhances the reliability and comprehensiveness of the post-CoRe data for subsequent analysis. It is worth reiterating that the selected questions were specifically designed to be open-ended in nature. The goal was to encourage the teachers to reflect and think about their teaching experiences when reminded of the teaching event while watching the video recording. The

coded and transcribed VSR interviews for all three teachers can be found in Appendix J – Appendix L.

In Phase 3, Interaction 5, following their lesson presentations, teachers were tasked with completing the post-CoRe tool. This phase provided them with another opportunity to articulate their responses to the eight prompts about the big ideas. Each teacher completed a post-CoRe tool on vertical projectile motion, identical to the pre-CoRe tool they had completed prior to teaching the lessons. Teachers had access to their pre-CoRes submissions while completing their post-CoRes.

3.6 DATA COLLECTION INSTRUMENTS

This study used pre- and post-CoRes, interviews and classroom observations to collect data.

3.6.1 CONTENT REPRESENTATIONS (CORES) TOOL

As discussed in Chapter Two, Loughran et al. (2004) designed a way to capture and portray teachers' PCK. This method assists teachers in articulating their PCK within a specific topic, which is *vertical projectile motion* in this study. I adapted and modified the CoRe- tool (Figure 2.2) used by Loughran et al. (2004) to align with the revised consensus framework and the three components of PCK under investigation.

The CoRe tool Loughran et al. (2004) developed required teachers to identify big ideas within the topic first. Padilla et al. (2008) explained these big ideas best when they said the conceptualisation of the content is based on the major concepts identified. Therefore, the researcher decided to provide the big ideas since the conceptualisation of the content is covered through the following two big ideas. (1) Change in position of a projectile and (2) Change in velocity of a projectile.

Teachers were expected to complete eight prompts specifically chosen to elicit their PCK about the two big ideas within the topic of vertical projectile motion. Bertram and Loughran (2012) claimed that the prompts would assist the researcher in accessing the teacher's thinking and reasoning when planning to teach specific content and identifying the pedagogy thereof. Coetzee (2018) believed these prompts are important for pre-service teachers to reflect on when they plan to teach a lesson and also suggested which CoRe prompts could be allocated to each of the PCK components used in the Grand Rubric (Chan et al., 2019) (see Figure 3.4).

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

Figure 3.4: The proposed application of CoRe prompts in conjunction with the Grand Rubric at the topic level, as recommended by Coetzee (2018)

I explain in Section 3.7 why only the first three components were used. Table 3.2 below displays the link between the CoRe prompts and the study's chosen framework. The information about teachers' PCK on the specific components was obtained when teachers answer the prompts in the CoRe tool. However, the knowledge teachers possess about the components can be deduced from their answers to any of the prompts.

Table 3.2: The link between CoRes and the PCK components from the Grand Rubric

PCK components from the Grand Rubric	CoRe prompts
1. "Knowledge and skills related to curricular salience"	1. "What do you intend the learners to learn about each of the ideas?" 2. "What concepts need to be taught before teaching this big idea?"
2. "Knowledge and skills related to conceptual teaching strategies"	3. "What representations would you use in your teaching strategy" (Coetzee et al., 2020, p. 364)? 4. Give particular reasons for the representations used to engage with this idea. 5. "Describe the strategy you will use to establish conceptual development of the main idea" (Coetzee et al., 2020, p. 364). 6. What questions would you consider important to ask when teaching this topic to ascertain learner understanding?
3. "Knowledge and skills related to learner's understanding of science" (Chan et al., 2019, p. 262).	7. What are the typical learner misconceptions and or learner difficulties that affect the teaching of this big idea? 8. How do you address the misconceptions and or learner difficulties?

3.6.2 INTERVIEWS

Two types of interviews were used to collect data (Phase 1 and Phase 2). The first was a semi-structured interview (SSI), which is described by Kallio et al. (2016) as:

“Conducted conversationally with one respondent at a time, the SSI employs a blend of closed- and open-ended questions, often accompanied by follow-up why or how questions.” (p. 493).

The disadvantages and advantages of semi-structured interviews were considered. One drawback, as outlined by Kallio et al. (2016), is that the process of getting ready for, organising, executing, and assessing interviews is more time-consuming and labour-intensive than one might anticipate. A substantial investment of time and effort is necessary to do it properly. Semi-structured interviews typically entail the challenging process of dissecting notes and, sometimes, sifting through extensive transcript hours. The advantages of employing semi-structured interviews are that they permit asking in-depth, open-ended questions on the topic (vertical projectile motion) during one-on-one interactions with the participants (teachers). These interviews also delved into the unique perspectives and individual insights of each participant in the study (Kallio et al., 2016).

The second interview conducted was a VSR interview, described by Nguyen et al. (2013) as:

“A research technique in which subjects view a video sequence of their behaviour and are then invited to reflect on their decision-making processes during the videoed event.” (p.1).

VSR interviews expect participants to make sense of their own behaviour (Sherin & Han, 2004). The process of making sense of things, while firmly rooted in a particular context, goes beyond the exact actions captured in the recording. The specific actions simply serve as a catalyst, prompting participants to attribute meaning to their conduct (Van Braak et al., 2018). One drawback of employing the VSR interview, as pointed out by Van Braak et al. (2018), is that the remembered cognitive processes may not always align directly with the more broadly held tacit knowledge that underpins the actual behaviour. As an illustration, what an individual thinks during teaching may not necessarily mirror their thoughts about the act of teaching itself. It is important to emphasise that the objective here is not to prompt the recall of the teaching event itself or the precise thoughts and reasoning that occurred during the teaching event. Instead, the aim is to trigger the teacher's contemplation and reflection on their teaching when the event is brought to their attention (Denley & Bishop, 2010). This approach may give the research access to possible development in the PCK of the teacher that were stimulated by the teaching event.

The questions in both interviews were open-ended in nature, which is described by Züll (2016) as questions that do not have a predetermined set of responses. Instead, these questions necessitate that the participants articulate their answers in their own words, either verbally or in written form. This approach ensures that the participants are not influenced or guided towards a specific response by any predefined categories.

In this study, the participants responded verbally and were recorded using a conventional voice recorder so the researcher could listen to it again when the data were analysed.

3.6.3 OBSERVATIONS

Observation entails a systematic process of collecting information, wherein researchers observe a given phenomenon in their natural environment (Queirós et al., 2017). Furthermore, Queirós et al. (2017) stated:

“This method is especially indicated when a given topic is relatively unexplored, and it becomes important to understand in detail a given phenomenon while maintaining the environmental conditions in which it occurs (p. 376).”

Observations allow data to be gathered in real-time without interfering with the event itself (Queirós et al., 2017). I have video-recorded at least an hour of instruction by novice teachers teaching the subject of vertical projectile motion for the first time. Video recordings provide the advantage of allowing numerous viewings for precise coding, as well as capturing unexpected behaviours and activities that may not have been anticipated when employing an observation schedule (Gall et al., 1996). Video recordings can also record non-verbal data (Cohen et al., 2013), which can be useful when teachers use body language and movements to convey specific concepts. The camera operator attempted to film as much of the participants’s activities as possible while remaining in one place in the classroom to ensure that the video recording did not disrupt the lesson.

3.7 DATA ANALYSIS TOOLS

A well-designed PCK rubric can help ensure that a valid and quality assessment of PCK is obtained (Chan et al., 2019). The data gathered during this research were examined using two rubrics: one for documented pedagogical content knowledge (PCK) before and after course presentations, and one for observed PCK during the act of teaching.

A rubric based on the Grand Rubric format (see Figure 2.3), suggested by a subgroup of the people at the second PCK summit (Chan et al., 2019), was used to assess the data captured by the CoRe tools (before and after lesson presentation). Chan et al. (2019) state that teacher actions and knowledge can be measured using the first four components in the Grand Rubric. However, I have opted only to use the first three (Table 3.2) because the

integration between PCK components (Component 4 in the Grand rubric) was combined with knowledge and skills related to conceptual teaching strategies (Component 2) when the lesson is observed and reflection is done with the teacher. I argued that the integration of the other components is visible in the teaching strategy of a teacher.

The components of PCK utilised for analysis are: “a) Knowledge and skills related to curricular salience, ... b) Knowledge and skills related to conceptual teaching strategies, ... c) Knowledge and skills related to student understanding of science, ...” (Chan et al., 2019, p. 262). It is important to note that the original third component refers to “students”, but in this study, it has been consistently replaced with “learners”. This change was made because we use the term “learners” for secondary school attendees and “students” for those in tertiary institutions in the South African context.

For this study, I integrated elements from three distinct rubrics that had already been validated in their respective studies, namely those developed by Mazibe (2017), Coetzee (2018), and Mavhunga (2012), to create a suitable rubric. While each of these existing rubrics featured four distinct competence levels for assessing teachers, the sample size for this study led me to opt for a streamlined three-level rubric employing a point scale of 1 = ‘Limited’, 2 = ‘Developing’ and 3 = ‘Exemplary’. Using only three levels enabled me to employ descriptors that clearly differentiated between the three levels of competency. Adjustments were made to these descriptors to align the rubric more closely with my specific research objectives, focusing on evaluating teachers’ competence in the three PCK components related to vertical projectile motion.

Once the rubric was created, it was shared with two experts in the field for validation to ensure it accurately described the information used to classify teachers within the three levels of competence. Changes to the initial rubric were recommended to ensure a fair and valid scoring system. For instance, one of the experts noted that the first prompt under curricular saliency in the expert CoRe asked, “What do you intend the learners to learn about each of the ideas?” rather than “Why”. Consequently, the descriptor “no reasons provided for the importance of concepts” was removed.

The modified rubric I employed sufficed for analysing the data collected through pre- and post-CoRes, as it allowed for distinguishing between the competencies of the three participants concerning the three PCK components. It was used alongside the expert CoRe to ensure the allocation of reliable and fair scores to the participants. After the initial scoring of each participant, a discussion between the researcher and the experts in the field took place, with the final score only being assigned once a consensus was reached.

An instance of this occurred when Mr DN made a statement in his pre-CoRe (discussed in Chapter 4) that could be interpreted in multiple ways. Initially, the researcher scored Mr DN as “limited” for the component curricular saliency in his pre-CoRe. However, after discussions with the field experts, a consensus was reached to score Mr DN as “developing” instead. One aspect that led to this decision was the experts’ different interpretation of the statement. To clarify, member checking was conducted with the participant, leading to the consensus decision to score Mr DN as “developing”.

The researcher used field notes during lesson presentations. Lodico et al. (2010) suggested that the researcher use descriptive and reflective field notes to control observer bias reflections. The researcher and experts in the field viewed the recorded lesson presentations to ensure that the correct conclusions were drawn from the lesson observations. The lesson recordings were scrutinised for events that revealed aspects of enacted PCK and afforded PCK development opportunities.

The second modified rubric (see Appendix C) enabled me to analyse data gathered through lesson observations, field notes, and recordings (revealed PCK). This rubric bears similarities to the first one, but it features adjustments in the information describing the three levels of competence to align better with the teaching context of the study. Coetzee (2018) and Mazibe (2017) successfully used a similar rubric. Like the first rubric, this one also used a point scale of 1 = ‘Limited’, 2 = ‘Developing’, and 3 = ‘Exemplary’ to facilitate comparisons between teachers’ pPCK and ePCK scores. Additionally, this rubric underwent validation by the same experts who validated the first rubric to ensure its accuracy in classifying educators within the three levels of competence. After a thorough discussion of each participant’s results regarding the three PCK components, a consensus was reached between the researcher and the field experts before the final scores were assigned.

An expert CoRe, called an exemplar of the PCK measurement in the rubric, was constructed and used as a measure against which the participants’ CoRes were evaluated (see Appendix A). This expert CoRe was informed by the content of the curriculum document on vertical projectile motion (DBE, 2011) and the knowledge and teaching experience of the researcher and two experts in the field of study.

The initial draft of the expert CoRe was reviewed by two field experts who proposed several modifications and additions. For example, they recommended removing the graphs depicting constant and negative acceleration from prompt 3, as these are not concepts themselves but rather consequences of the concepts. It is important to note that the expert CoRe was

designed specifically for the South African FET science curriculum. Thus, it does not necessarily provide a comprehensive overview of teaching vertical projectile motion.

The suitability and pertinence of the data set out in the CoRe of the participants were evaluated by using the expert CoRe (see Appendix A) and the rubrics employed for scoring teachers' pPCK and ePCK. Each of the three PCK components was assigned a score indicating the level of teachers' PCK. The scores for each PCK component were compared in the pre- and post-CoRes. Any differences between these two scores were used to determine whether there was evident development in the teachers' PCK.

3.8 DATA ANALYSIS STRATEGIES

An inductive approach was used to analyse the data. This method facilitated identifying connections between the research objectives and the findings derived from the collected data (Thomas, 2006). Consequently, this allowed themes and theories to emerge from the raw data.

The interviews and classroom observations were transcribed, and narrative accounts were given (see Appendix G – Appendix R). Both sets of data were analysed using a colour-coded system to highlight the three PCK components: “a) Knowledge and skills related to curricular salience”, (Yellow), “b) Knowledge and skills related to learner’s understanding of science” (Blue), and “c) Knowledge and skills related to conceptual teaching strategies” (Chan et al., 2019, p. 262) (Purple and Green), where green represented representations and analogies within the component. This system helped in relating the information from the interviews and teaching events from the observations to the relevant PCK components.

Data analysis occurred in three stages. The first stage involved an interpretative and qualitative analysis of the pre-CoRe and interview before lesson presentations (Chapter 4). The second stage focused on an interpretative and qualitative analysis of the lesson observation recordings and VSR interviews (Chapter 5). The third stage entailed an interpretative and qualitative analysis of the post-CoRe and VSR interviews (Chapter 6).

The pre-CoRe (Figure 3.3) was utilised to gather data on the teachers' initial comprehension and knowledge of the three PCK components of vertical projectile motion. An interview (Appendix G – Appendix I) was conducted to delve into the teachers' unfiltered perspectives on teaching the topic of vertical projectile motion prior to their first time teaching the topic. The pre-teaching interview was analysed, and comments pertinent to the teachers' PCK, as uncovered through the pre-CoRe, were examined.

The post-CoRe (Appendix D – Appendix F) was implemented to gather insights into the teachers' new understanding and knowledge of the three PCK components after they taught their lessons on vertical projectile motion for the first time. The responses to the post-CoRe prompts were strengthened through an interview (Appendix J – Appendix L) that was done a few days after the teachers presented their final lesson. The post-CoRes and interviews were reviewed and scored before a qualitative analysis of the CoRes.

Analysing and comparing the pre- and post-CoRe scores obtained from the rubric using a three-point scale, I aimed to determine whether the first-time teaching experience developed the teachers' PCK about vertical projectile motion. This determination was based on the relevant three components of PCK. The expert CoRe (see Appendix A) and the rubric for scoring pPCK (see Appendix B) were used concurrently to analyse the CoRes.

Narrative accounts (see Appendix M – Appendix R) were given for each classroom observation. These accounts were subsequently analysed by coding them with pre-determined codes corresponding to the three relevant PCK components discussed in Chapter 5. Specific video segments, rich in data that illuminated information regarding the three PCK components and two big ideas of this study, were selected to discuss during the VSR interview. Relevant comments made by each participant throughout their VSR interview indicated that their pedagogical reasoning abilities were connected to the three components of pedagogical content knowledge (PCK). The VSR interview included further comments on the acquisition of new pPCK knowledge after training. Every incident was carefully recorded as it happened in its original environment.

3.9 SUMMARY OF THE RESEARCH DESIGN AND INSTRUMENTS

Figure 3.5 depicts the research design.

Progress	Action	Instrument	Reason
Interaction 1 pre-CoRe: no time constraint	Meet to explain and clarify the CoRe prompts (after school). Teachers completed the pre-CoRe tool and submitted when satisfied.	CoRe template	Establish planned PCK and obtain untainted thoughts Secondary research question (1): What is the level of novice teacher's PCK revealed before teaching vertical projectile motion for the first time?
Interaction 2 Interview: ± 45 min	Meet for interview after the pre-Core was submitted (after school)	Semi-structured interview	Establish planned PCK and obtain untainted thoughts. To strengthen the information obtained through the pre-CoRe Secondary research question (1): What is the level of novice teacher's PCK revealed before teaching vertical projectile motion for the first time?
Interaction 3 Lesson observations: 45 min – 60 min	Each teacher presented two lessons (during school)		Access enacted PCK about the teaching of vertical projectile motion Secondary research question (2): What is the level of novice teacher's enacted PCK when teaching vertical projectile motion for the first time?
Interaction 4 VSR Interview: ± 45 min	Meet to carry out VSR interview (after school)	Review of selected video clips and sections	Access teachers' pedagogical reasoning Secondary research question (2): What is the level of novice teacher's enacted PCK when teaching vertical projectile motion for the first time?
Interaction 5 post-CoRe: no time constraint	Teachers completed the same CoRe-tool initially used and submitted it when satisfied with the content.	Core template	Establish new understanding and knowledge of teachers regarding the three selected PCK components. Secondary research question (3): What is the level of novice teacher's PCK revealed after teaching a lesson on vertical projectile motion?

Analysis Phase	1. Qualitative analysis of the pre-CoRe 2. Qualitative analysis of the audio recorded interview (before teaching) 3. Re-view classroom observation video recordings 4. Qualitative analysis of the audio recorded VSR interview 5. Qualitative analysis of the post-CoRe	1. Rubric for pPCK and expert CoRe 2. Rubric for pPCK and expert CoRe 3. Rubric for ePCK 4. Rubric for ePCK / Rubric for pPCK and expert CoRe 5. Rubric for pPCK and expert CoRe	1 & 2: Determine the level of teacher's PCK before teaching vertical projectile motion 3 & 4: Determine the level of teacher's PCK in the act of teaching vertical projectile motion 4 & 5: Determine the level of teacher's PCK after teaching vertical projectile motion Primary research question: Comparing the totals for pPCK before teaching (1 & 2) and pPCK after teaching (4 & 5) will indicate the development of teacher's PCK through first time teaching experience.

Figure 3.5: Summary of the research design showing progression relative to the teacher interactions and the sequence of data collection

3.10 CREDIBILITY AND TRUSTWORTHINESS

This research encompassed the utilisation of multiple sources, enabling the data to be triangulated for the purpose of seeking convergence (Creswell, 2014). In qualitative research, triangulation is used to ensure credibility. It involves the use of different data collection methods (Shenton, 2004). Coetzee (2018) states that data collected this way may lead to information that narrows down one clearly-defined theme. The methods used in this study to achieve triangulation consist of the following:

- Capturing the teachers' PCK about vertical projectile motion by completing the CoRe tool at two stages during the study.
- CoRe tools were validated using interviews to strengthen the data collected both before and after the teachers taught the topic.
- The teachers were observed while teaching the lesson, and the lesson was recorded for viewing and analysis.

An identical design, approach, and procedure were applied to all three participants, ensuring a consistent methodology during the study. Because the data were collected using different methods and instruments, I could cross-check the data for consistency or deviations (Mazibe, 2017). The rubrics used to analyse data were validated by two other experts in the field. The rubrics are derived from versions of Coetzee (2018) and Mazibe (2017), which they successfully used in their studies assessing teachers' reported and enacted PCK.

The fact that I am, in my role as subject advisor, monitoring and supporting teachers participating in this study may be a threat to the validity of the study. Since the halo effect

could play a role, I interpreted the CoRes of each teacher and the observations at “face value”. This means the accuracy or validity of the data were not doubted based on the participant. I also adhered strictly to the criteria described in the rubric. The opinion I have formed about these teachers did not influence my interpretations and analysis. Moreover, I have not observed these teachers in my role as subject advisor. I only observed the work done by learners in their scripts. I gave meticulous attention to the levels of competence in the rubric to avoid and reduce these observer effects.

Member checking or validation can also improve credibility. This process entails returning the researcher’s interpretation of their CoRes and interviews to the participants. The participants are then asked to evaluate whether these findings accurately represent their understanding and interpretation of the social construct under investigation (Neuman, 2007).

The CoRe tools, video recordings, and all data analyses were sent to the same experts who validated the assessment tools to ensure inter-rater reliability, eliminate bias and ensure the credibility of the interpretations,. This means that at least two independent experts assessed the same data (Mazibe, 2017). The experts in the field interpreted the data independently, and we then compared and discussed the interpretations.

3.11 ETHICAL CONSIDERATIONS

The study’s sensitivity was minimal, as it was improbable that any private or sensitive personal details about the participants would be revealed during the research. I applied for ethical clearance from the University of Pretoria and approached the participants only after the clearance was granted. In writing, I also obtained permission from the District office to conduct research in the selected schools. All stakeholders involved in the research were asked for permission before any data were collected. This was done using consent and assent forms given to principals (Appendix T), teachers (Appendix U), parents and learners (Appendix V) and completed before data were collected. Each participant in the study made this voluntary and informed decision. The forms clearly indicated that involvement is optional, participants are free to discontinue at any time, and the identities of individuals and schools participating would be maintained as confidential. Choosing not to participate or deciding to withdraw would not affect the manner in which participants are regarded or treated.

Efforts were consciously made to avoid recording the learners’ faces in the videos by filming from such an angle that only the front of the classroom was visible. If a teacher moved around, the camera was adjusted to focus solely on the teacher, not the learners. Consent and assent were obtained from all parents and learners, so no learner had to be positioned

behind the camera during lesson observations. The data collected and the results obtained will be kept confidential. Pseudonyms were assigned to each participant to ensure this confidentiality.

Ethical principles are adhered to when storing data and relevant information. Data were stored electronically and were shared with supervisors electronically. The study will comply with The Protection of Personal Information Act 4 of 2013 as well as Section 32 of the Constitution of South Africa, regarding that access to certain information is prohibited, especially when a person's privacy should be protected, as in the case of the research participants. Only the researcher and supervisors will have access to the raw data, which will be kept in a safe place for ten years before destruction.

CHAPTER FOUR

PERSONAL PCK: RESULTS AND ANALYSIS

In this chapter, I present the data and the analysis of the pPCK of the three teachers. Each teacher had to complete an adapted CoRe tool (Loughran et al., 2004) on the topic of *vertical projectile motion* before they taught the topic to a class for the first time. Responses to the prompts in the CoRe tool were strengthened by an interview with each participant before the lesson presentation.

The data from each teacher, consisting of the CoRe responses and the interviews, are presented case by case. An expert CoRe that served as a gauge of teachers' pPCK was developed in collaboration with other experts in the field. The information in this CoRe is seen as exemplary, although it is acknowledged that there may be other ways to present content in an exemplary manner in the CoRe tool. The responses given in the expert CoRe are thus extensive but not exhaustive. Therefore, other inclusions and interpretations by the participants were considered.

The teachers' responses to the prompts in the CoRe tool were scored using a rubric for pPCK, focusing on the first three components in the grand PCK rubric (Chan et al., 2019), namely (1) Knowledge and skills related to curricular saliency, (2) Knowledge and skills related to conceptual teaching strategies, (3) Knowledge and skills related to student's understanding of science. As explained in Chapter 3, I opted to use only the first three components of the grand rubric since I believe the other two components are visible in a teacher's teaching strategy. The first three components were discussed in more detail in Chapter 2, Section 2.4.

Eight prompts were used in the CoRe tool to elicit responses from the three educators about each big idea. Table 3.2 shows how these prompts align with the first three components of PCK from the grand rubric.

Scoring of the responses aided in answering the first sub-question of the study: What is the level of novice teacher's PCK revealed before teaching vertical projectile motion for the first time?

4.1 CASE STUDY 1 – MR DN

Mr DN is a physical sciences teacher with a B.Ed degree in Science education. Throughout his years at university, Mr DN attended classes in Afrikaans and completed his formal assessments in Afrikaans. At the time of the study, it was his first year teaching the subject, and he had no prior experience teaching the topic of vertical projectile motion. Mr DN was responsible for teaching physical sciences in Afrikaans throughout the entire FET phase at his school, Grades 10 – 12. The data collected through the CoRe tool and interview was in English, Mr DN's second language. The teacher is not very proficient in English and struggles to express himself. This shortcoming made it necessary to go back to the teacher to clarify certain things he said.

4.1.1 DATA FROM THE CORES AND INTERVIEW

Mr DN completed the pre-CoRe tool before formally teaching the topic of vertical projectile motion for the first time. He responded elaborately to the first prompt: What do you intend the learners to learn about each of the ideas? His responses then became less elaborate, and it was also observed that much of the information articulated in the first prompt was repeated for the other prompts. Most of the information obtained in the interview corresponds to the responses in CoRe. Mr DN completed the CoRe tool online. His submitted version is included below as Figure 4.1. His full interview transcript is available in Appendix H.

Mr DN: pre-CoRe		
CoRe prompts	Big Idea 1	Big Idea 2
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i> ?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?	How the displacement is affected by the other variables and how it affects them. That displacement can be 0, for example when you throw a ball in the air and catch it at its release point the total displacement = 0 m. It can be + and -. If a projectile is thrown upwards and comes down the maximum displacement is at the amplitude. When a projectile is let go while moving up wards like in a hot air balloon it will first move initially upwards and then fall down so the displacement is the total from the highest point to the lowest point. If a projectile bounces down from one level to a next like a ball falling down stairs the displacement is the total of the vertical downward movement and not the total of each bounce. At the displacement time graphs it is important to teach the students the shape of each graph according to what direction the ball is being thrown in which causes a either positive constant acceleration or a negative constant acceleration and that the gradient is the velocity.	How the velocity is impacted by the direction in which it moves like when it is moving upwards the change in velocity will go to 0 and when it falls downward the velocity changes from 0. The sign + and – on velocity and the relation that it will have with the other variables in projectile movement. The velocity is always 0 at the amplitude when it moves up and down. If a projectile is thrown upwards from a building and it falls down to the ground, when it passes the point from which it was thrown the velocity will be of the same size in the opposite direction. Once again the direction of the movement is important. They must also know if the is hard or soft so as to sketch the correct graph. At the velocity time graph we can see that if a ball bounces or changes direction each movement is plotted on the graph “independently”. The surface area is equal to the displacement.
2. What concepts need to be taught before teaching this big idea?	The relationship of displacement to acceleration time and velocity. In short all the movement equations and how to use them. As well as the concept of Newton 1 at the hot air balloon examples. Simple graph skills	The relationship of velocity to time acceleration, time and displacement. In short all the movement equations and how to use them. The learners need to know Impulse so they can understand why a soft ball's graph will look different to that of a hard ball's
3. What representations would you use in your teaching strategy?	For displacement I will use the following representations an object being falling downward. An object being thrown upward then falling past the point it was thrown from. I will	I will use the same representations as that for displacement since the two concepts will be explained together. I will also use a soft ball and hard ball at the graphs.

	use all the relevant graphs (positive and negative constant acceleration) A hot air balloon since it is asked a lot and it is with this	
4. Give particular reasons for the representations used to engage with this idea?	These representations are where the most misconceptions are formed and it usually the most difficult type of questions and is the easiest way to explain difficult concepts and address certain misconceptions. These representations will be able to address not only difficult misconceptions but also misconceptions at the introductory level	
5. Describe the strategy you will use to establish conceptual development of the big idea.	By using as SMART board I will use audio (by speaking) and visual (drawing and doing examples) to better their understanding while also asking pertinent questions about displacement and how they align with other variables throughout to further establish their understanding an knowledge.	By using as SMART board I will use audio (by speaking) and visual (drawing and doing examples) to better their understanding while also asking pertinent questions. Also by relating velocity the whole time to the other variables.
6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	What is the difference between displacement and distance? Is displacement a vector or scalar? Can displacement be + and -?	Is velocity a Vector or scalar? Does velocity have a sign (+ or -)? What is the difference between acceleration and velocity? How does velocity relate to acceleration
7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	That displacement should be handled like distance and they take the whole road length and not just the movement from a certain point. That if I throw a ball upward from a building and let it fall to the ground the displacement is all the downward movement from the amplitude. That a ball with in a hot air balloon's displacement is from where it has been dropped	That velocity is in the same direction as acceleration. That the velocity is always positive. At a hot air balloon the starting velocity is zero. Velocity is zero when you throw the ball in the air.
8. How do you address the misconceptions and or learner difficulties?	I believe you address them head on by using examples in the class that are formulated in a way so that the misconceptions are almost visible to me in the question. The learners must see for themselves where they have gone wrong. Firstly we must identify the misconceptions so a good class discussion on the topic after the first home work exercise will identify what type of questions the next exercise should have.	I believe you address them head on by using examples in the class that are formulated in a way so that the misconceptions are almost visible to me in the question. The learners must see for themselves where they have gone wrong. Firstly we must identify the misconceptions so a good class discussion on the topic after the first home work exercise will identify what type of questions the next exercise should have

Figure 4.1: Mr DN's pre-CoRe

4.1.2 ANALYSIS OF THE CORES AND THE INTERVIEW

The sections below reflect the analysis of Mr DN's CoRe and his interview. The data are compared to the expert CoRe and graded in terms of the levels described in the rubric.

4.1.2.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

The physical sciences CAPS document describes vertical projectile motion as motion in one dimension. At the same time, Mr DN used an example in Prompt 1, Big Idea 1, that may contradict this statement. The example used by Mr DN of a ball falling down stairs can be interpreted in more than one way. Therefore the data were validated by asking the participant to submit a drawing (Figure 4.2) to illustrate what he meant when he said:

“If a projectile bounces down from one level to a next like a ball falling down stairs, the displacement is the total of the vertical downward movement and not the total of each bounce.”

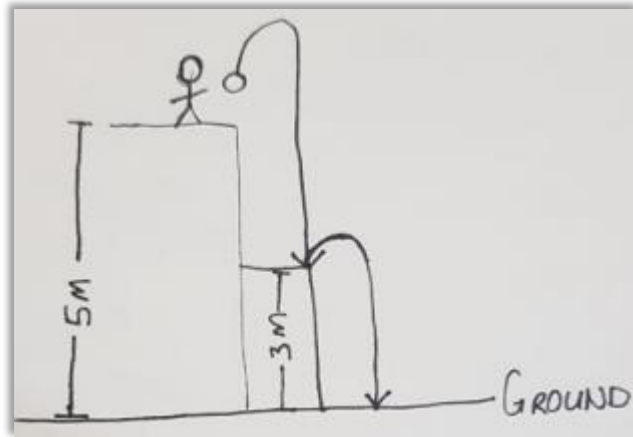


Figure 4.2: Mr DN's drawing to support his explanation of a bouncing projectile

The example illustrated in Figure 4.2 applies to vertical projectile motion. From the statement made by the educator, we can see his main focus is on the displacement of the projectile. He wants to emphasise the difference between distance and displacement for learners. Looking at the diagram in Figure 4.2, he will successfully demonstrate the difference to learners. He explained that the displacement of the projectile in the example is equal to five metres, while the distance covered by the projectile is more than five metres.

When the teacher talked about the projectile falling downstairs, I concluded that he meant from a higher to a lower story of a building and not from one step to the following along a staircase, which would be in two dimensions.

When asked about aspects of Big Idea 2 that he intended to teach (Prompt 1), he mentions: “The velocity is always 0 at the amplitude when it moves up and down.” I believe he meant altitude instead of amplitude. This language error can be ascribed to the fact that the

teacher's first language is not English. The velocity of an object at the highest altitude is indeed 0 m.s^{-1} . This concept is important for learners to understand since it is often not explicitly indicated or mentioned in problems related to projectile motion.

As a concept to be taught, Mr DN also included that the velocity of an object, when passing the starting point again, is equal in magnitude to the initial velocity but in opposite directions. Most of the other responses submitted by Mr DN for both big ideas at Prompt 1 consist of pre-concepts that the teacher links with new knowledge. These pre-concepts consist of the direction of movement (Grade 10), displacement and distance (Grade 10), Newton's first law (Grade 11), displacement-time graphs (Grade 10), velocity-time graphs (Grade 10) and contact time during a collision (Grade 12).

The following discussion elaborates on how the teacher intends to use these pre-concepts to develop new ideas in vertical projectile motion. In Grade 10, learners are always taught to have a frame of reference when answering questions. They are also taught that the horizontal displacement of an object would be zero when the starting and end positions of the object are the same. Mr DN describes how he intends to use an example (Prompt 1) that illustrates the frame of reference and vertical displacement of a ball when he said: "When you throw a ball in the air and catch it at its release point, the total displacement = 0 m". In his interview, at Question 6, he also emphasised the need to remind learners of the difference between displacement and distance. He stated:

"If I throw a ball into the air and it comes back down they [learners] might think I'm working with the entire distance rather than just the displacement."

This statement reveals some of his knowledge about curricular saliency. He selected an appropriate concept, namely displacement, for learners to know before starting with calculations on vertical projectile questions. This principle is important because the unknown variable Δx in the movement equations represents displacement, not distance.

Newton's first law is another application of a pre-concept that Mr DN correctly describes. He provided the example of a hot-air balloon, and to elaborate further, he states:

"When a projectile is let go while moving up wards like in a hot air balloon it will first move initially upwards."

This is correctly articulated, and the concept of inertia taught in Grade 11 is incorporated within this typical hot-air balloon problem learners may encounter in Grade 12.

He specified the concept of impulse (CoRe, Prompt 2) as part of the topic momentum. His main focus here is to assist learners in distinguishing between the differences in a velocity-time graph of a hard and soft ball (CoRe, Prompt 1 and Prompt 2). I believe he refers to the contact times of the balls with the surface on which they will bounce. A harder ball will have a shorter contact time with the surface compared to a softer ball. The teacher displays a shortcoming in his knowledge when he does not mention elastic and inelastic collisions, especially since it was just discussed in the previous topic, momentum and impulse.

The teacher displayed knowledge of curricular saliency when he referred to the interrelatedness of the big ideas when he responded to Prompt 3 in his CoRe, he said:

“I will use the same representations as that for displacement since the two concepts will be explained together.”

The significance of the above statement is that Mr DN realised it will be very difficult to teach the big ideas separately. From the quotation above, it is safe to say Mr DN will use the same representation for both big ideas but with the intention of linking the concepts of each Big Idea to the representation.

In an attempt to probe the teacher's knowledge about the sequencing of ideas in the topic, he was asked about the concepts that needed to be taught before teaching the big ideas (CoRe Prompt 2). The teacher correctly identified pre-concepts like displacement, acceleration, time and velocity. He also mentioned other relevant pre-concepts throughout his CoRe and interview, like Newton's laws (Interview Question 4), distance and displacement (Interview Question 5), vectors and scalars (Interview Question 5), different forces acting on an object (Interview Question 4), area and gradient of respective graphs (CoRe Prompt 1), velocity and acceleration (CoRe Prompt 7, Big Idea 2)

In his interview (Question 1), he stated that he considers the following pre-concepts: displacement, acceleration, velocity and the direction of movement as key concepts in the topic of vertical projectile motion. In Question 2 of the interview, he said:

“They all are integrated with each other and they depend on each other. So for instance, if the displacement is a certain height, the velocity will be a certain height [magnitude] according to the acceleration it will undergo.”

When the teacher was asked about the above quote, he indicated that he meant *magnitude* instead of *height* when he referred to velocity. The teacher clearly understands that there is a relationship between the variables and that they influence each other.

One concept Mr DN refers to often throughout his CoRe and interview is the direction of motion (CoRe Prompt 1, Big Ideas 1 and 2; Interview Question 2; Interview Question 5; Interview Question 8). One can see that he considers it as important. In Question 8 in the interview, Mr DN said:

“The biggest advice I’d give them is to make sure that your students understand the concept of the movement, in which direction.”

However, in his response to Prompt 1 of the CoRe, Mr DN indicates that the direction of a ball being thrown will determine either a positive or negative constant acceleration. This statement reflects a misinterpretation by the teacher. The sign of acceleration does not depend on which direction the ball is thrown in but on the chosen reference frame. The acceleration of a projectile in free fall will always be $9,8 \text{ ms}^{-2}$ downwards.

As seen above, Mr DN identified a considerable list of pre-concepts that are relevant to the big ideas. He indicated with examples how he intended to use these pre-concepts to develop new ideas in vertical projectile motion. These pre-concepts will assist learners in understanding the big ideas better. He could also identify pre-concepts from other topics and make logical links between them and the big ideas.

When referring to the expert CoRe (Prompt 1), the teacher omits to mention some key aspects of vertical projectile motion. These aspects include:

- Projectiles fall freely near the earth's surface, and the only force acting on the projectile is the gravitational force (air resistance is neglected).
- Projectiles in free fall will always experience a constant acceleration of $9,8 \text{ m.s}^{-2}$ downwards.
- Time symmetry.

Mr DN identified some relevant concepts and provided an extensive list of pre-concepts for each big idea. However, he omitted to mention some key aspects of the topic that were indispensable. It can be seen from the rubric that the second level of competence, *developing*, describes the curricular saliency the best.

4.1.2.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER’S UNDERSTANDING OF SCIENCE

Mr DN revealed awareness of learner difficulties and misconceptions throughout his CoRe. However, when specifically prompted at Prompt 7 about misconceptions and learner difficulties, he again did not mention all of them.

The information provided by the teacher at Prompt 7 in his CoRe only refers to learner difficulties. A closer look at the information provided for Big Idea 1 showed that his focus was mostly on one difficulty: confusion between distance and displacement. He also emphasised this difficulty in his interview (Question 5) when he said: “They [learners] already get confused with the difference between the displacement and distance.” He explains that learners consider the entire path length of the object (distance) and not the shortest straight-line distance between the initial and final position (displacement). Indeed, this is a learner difficulty listed in the expert CoRe (Prompt 7).

The last example used by Mr DN for Big Idea 1 in Question 7 is concerning the example of a hot-air balloon. He mentioned a typical misconception: “That [for] a ball within a hot air balloon’s displacement is from where it has been dropped.” This understanding is, in fact, correct and not a misconception. Earlier in the CoRe (prompt 1), Mr DN mentioned the example of the hot-air balloon, where he stated that an object dropped from a hot-air balloon will initially move upwards to a maximum height before falling to the ground. He goes further to say that the displacement of this object would be from the highest point to the lowest point, which is incorrect. The displacement would be from the point where the object was dropped to the ground. This statement clearly indicates that the teacher is unaware of his misconception regarding the displacement of an object dropped from a moving carrier.

Mr DN correctly identified another misconception associated with the hot-air balloon problem. In his CoRe (Prompt 7, Big Idea 2), he indicated that learners think the initial velocity of an object dropped from a moving carrier is zero, meaning the object will fall straight down. This misconception is listed in the expert CoRe at Prompt 7, and this scenario's representation can be found at Prompt 4 (Representation 3).

The teacher revealed more of his knowledge about learner understanding when he identified another misconception. He noted that learners think velocity and acceleration are always in the same direction. This corresponds to the misconception listed in the expert CoRe (Prompt 7, Big Idea 2) bullet number six. His statement in Question 6 of the interview regarding the initial velocity of an object being zero when thrown in the air is not mentioned in the expert CoRe since this difficulty is not normally documented in the literature.

The teacher revealed his lack of knowledge when he responded to Question 7 in the interview. He said:

“Give them physical examples and taking it to the real world experiences that they might have ... throwing a javelin into the air or throwing a shot put ball into the air or something like that.”

These movements are not vertical projectile motions since, in real life, these objects travel in two dimensions. Making use of these examples can create misconceptions.

Mr DN tried to explain the fact that learners are unable to distinguish between the shape of a position-time graph and the path of the motion (Expert CoRe, Prompt 7) when he said:

“At the displacement time graphs it is important to teach the students the shape of each graph according to what direction the ball is being thrown in.”

I believe he refers to the frame of reference and the effect it will have on the shape of the position-time graph.

From the information obtained in Prompt 1, it can be seen that Mr DN is aware of the physical quantities represented by the gradient of the position-time graph as well as the area underneath the velocity-time graph. He noted: “The gradient is the velocity.” (Prompt 1, Big Idea 1) and “The surface area is equal to the displacement.” (Prompt 1, Big Idea 2).

There is, however, no indication that he regards these concepts as learner difficulties, as listed in the expert CoRe. Also, he should not have used the term “surface area” but just “area” underneath the velocity-time graph. This, again, may be a consequence of his lack of proficiency in the English language.

Mr DN’s remarks corresponded to those in the expert CoRe (Prompt 8, Big Idea 1, Bullet 2) when he said that the misconceptions or difficulties should be discussed in class using representations, which are examples of scenarios that typically diagnose the existence of misconceptions. In his own words:

“Using examples in the class that are formulated in a way so that the misconceptions are almost visible to me in the question.”

He also explained that he designed questions based on learners’ responses to previous questions: “We must identify the misconceptions so a good class discussion on the topic after the first homework exercise will identify what type of questions the next exercise should have.”

Mr DN has identified some learner misconceptions and difficulties, and he has a workable strategy to address the misconceptions or difficulties. However, there is evidence that Mr DN himself has misconceptions or misinterpretations of certain scenarios.

When comparing Mr DN’s responses about knowledge and skills related to learner understanding of science to the rubric, it can be seen that the second level describes his

knowledge about learners' misconceptions. Hence, his competence in this grand rubric component was classified as *developing*.

4.1.2.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Although the teacher referred to many representations throughout his CoRe, he mainly focused on two types: drawings and the use of physical objects. He did not describe the use of videos or simulations.

When prompted in the CoRe tool about what representations he would use in his teaching strategy (Prompt 3), he mentioned using physical objects such as a hard and a soft ball. He specifically stated that he would use these balls when discussing graphs. As I explained earlier, I believe this is intended to explain the contact time between an object and the surface to learners. This is an excellent opportunity to demonstrate elastic and inelastic collisions and the different heights each ball will reach after a bounce. However, the teacher did not mention elastic or inelastic collisions throughout his CoRe and interview. This omission may indicate that he did not realise the possibilities of applying such balls.

Mr DN described the physical objects he intended to use when he answered Question 7 in the interview. As I explained earlier, when discussing misconceptions, Mr DN referred to using real-world examples and experiences to which learners can relate. This is a good idea and is also noted in the expert CoRe as Representation 5. However, the examples used by Mr DN (Interview Question 7), namely throwing a javelin or shot-put ball, are not considered exemplary (since they are not vertical projectiles) and will not be sufficient examples to enhance the conceptual development of learners.

Mr DN mentioned scenarios where objects would be used to demonstrate falling projectiles, objects initially thrown upwards and either caught at the point of launch or allowed to fall to the ground, and objects released from a moving carrier like a hot-air balloon. These examples suggested representations will support the development of concepts related to big ideas and will be discussed later in this chapter.

Mr DN did not give particular reasons for the representations he intended to use when prompted at Prompt 4 in the CoRe, but rather stated general reasons like:

- They represent scenarios where misconceptions originate.
- These representations represent the difficult questions.
- Representations make it easier to explain difficult concepts.
- Representations help to address misconceptions.

From the reasons above, it may seem that the teacher contradicts himself. He initially stated that the representations represent scenarios where misconceptions originate, whereas he later stated that representations help to address misconceptions. When he was asked to clarify the response, he explained that when representing challenging problems to learners in the form of a drawing (representation), he could show them difficult aspects of the topic and discuss challenges they might encounter. He used the example of the hot-air balloon saying:

“Most learners think when an object is dropped from a hot air balloon it will fall straight down, but it first goes up and then falls down. When I draw it on the board, learners can now see where the misconception is.”

From the last sentence, it can be concluded that he believes representations can be used to address misconceptions and assist the teacher in better explaining difficult concepts or scenarios.

The teacher revealed limited PCK when describing the velocity of an object moving upwards or downwards. He noted in his CoRe (Prompt 1, Big Idea 2) that:

“How the velocity is impacted by the direction in which it moves like when it is moving upwards the change in velocity will go to 0, and when it falls downwards, the velocity changes from 0.”

The teacher displayed his CK when he could identify how the velocity of an object would change depending on whether it is moving upwards or downwards. However, he erroneously said the change in velocity (Δv) for the upward movement would reach zero, but we know only the velocity (v) will reach 0 m.s^{-1} at maximum height. I believe this can again be attributed to the teacher's lack of English proficiency, especially considering that he did not make the same mistake when referring to the downward motion of the object. Nevertheless, it seems the teacher planned to convey the information to learners in the form of a statement or announcement instead of demonstrating it. He never linked this information to any of his representations.

Furthermore, this was the perfect opportunity for Mr DN to elaborate on the concept of acceleration and link it to the change in velocity of a moving projectile, which is a crucial aspect of vertical projectile motion, but Mr DN is unsuccessful in identifying the concept throughout his CoRe.

When Mr DN was asked to describe the strategy he would use to establish conceptual development of the main ideas, he indicated at Prompt 5 in his CoRe that he wanted to use

a SMART board. In Question 7 in the interview, he indicated he would like to teach this topic using diagrams in a talk and chalk strategy.

He elaborated on the use of diagrams in Question 8 in the interview saying: “Give them the diagram; as soon as they see a picture, they can see the movement.” Drawings will form an important part of his teaching strategy. Drawings are also included in the expert CoRe and can assist in teaching the topic effectively. However, Mr DN has not considered other representations like simulations or videos included in the expert CoRe. There is limited evidence of creative interaction occurring between the teacher and learners. This lack of interaction is unfortunate since the teacher has access to a SMART board.

Evidence indicates that his planned teaching strategy is very traditional, indicating a formal method of teaching. In Question 7 in the interview, he responded by saying:

“The strategies I will use are basically using the graphs [drawings] as well as the normal formulas that you use to put it together. Explaining using more of talk and chalk type things.”

Mr DN explained his strategy best when asked in the interview what advice he would give to teachers also teaching the topic for the first time (Interview Question 8). Here, he states that pre-knowledge from Grade 10 and Grade 11 is important and that learners should have mastered such concepts, revealing that he understands the importance of knowledge of pre-concepts. He then refers to new knowledge that can be linked to pre-concepts when talking about the concept of movement and that direction is an important factor. Reading the entire CoRe document and listening to the interview, I believe he refers to the frame of reference and the sign conventions of vector quantities. This is a good starting point and coincides with the first statement made in the expert CoRe following the revision of the learners’ prior knowledge.

He continued that once the pre-knowledge of learners is sound, the teacher should proceed to give learners a variety of problems and that these different problems should be practised in the form of repetition. This approach can create an environment where rote learning will take place, which is not necessarily the best way to master more complex concepts.

From the information gathered, it can be seen that Mr DN wanted to use a drawing to illustrate the problem to learners (Interview Question 8). He does not specify which drawing or problem he is referring to. From the drawing, he will explain the importance of direction and how the different variables influence each other (CoRe Prompt 5; interview Question 2). The diagram can be used to address learner misconceptions and difficulties (CoRe Prompt 4) that he mentions throughout his CoRe. When learners are equipped with all of these

skills, they can attempt the physical examples (Interview Question 7), being able to do the calculations using the formulas (equations of motion) when calculating unknown variables (Interview Question 7).

Mr DN displayed knowledge of curricular saliency of the big ideas in his teaching strategy when he responded to Prompt 3 in his CoRe, saying, “Since the two concepts will be explained together.” Sequencing is also considered by Mr DN when he listed his representations at Prompt 3 in his CoRe. He started with an easy representation of a falling object and expanded into more challenging scenarios.

Mr DN considers questioning an important aspect of his teaching strategy (CoRe, Prompt 5). In the expert-CoRe, it is also important to direct questions to learners throughout the discussion of examples to ensure conceptual understanding and development.

Most of the questions Mr DN planned to use (CoRe Prompt 6) addressed pre-concepts from Grade 10 and Grade 11.

Mr DN used good examples throughout his CoRe. These examples provide the opportunity to ask adequate questions to ensure conceptual development occurs when teaching the learners. It is, however, observed that Mr DN misses this opportunity to link questions to his examples, and I see no evidence that he knows which questions to ask beyond those related to pre-concepts. I do not believe that higher-order thinking skills will be required from the learners to answer the questions planned by Mr DN. The questions are basic, and rote learning questions are mostly posed.

The following example was used by Mr DN in his CoRe (Prompt 1, Big Idea 2):

“If a projectile is thrown upwards from a building and it falls down to the ground, when it passes the point from which it was thrown the velocity will be of the same size in the opposite direction.”

Utilising this example will provide the perfect opportunity for Mr DN to ask most of the questions that will assist in learner understanding and conceptual development. All questions listed in the expert CoRe (Prompt 6) can be applied to this example.

When asked about his teaching strategy, it is difficult to find a clear, structured strategy in the teacher's response in both the CoRe and interview. General strategies are provided with a limited explanation of application. This limited explanation gives rise to the idea that the teacher does not know exactly how he will address this topic or has not planned thoroughly enough.

From the preceding paragraphs, it is found that the level of responses obtained from the rubric that describes the knowledge and skills related to conceptual teaching strategies the best is *limited*.

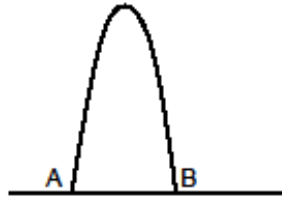
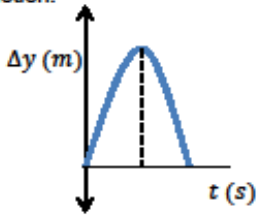
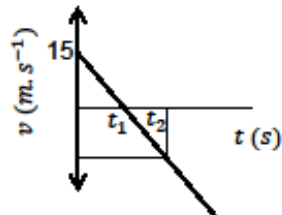
4.2 CASE STUDY 2 – Ms NJ

Ms NJ is a physical sciences teacher who holds a B.Ed degree in Science Education. At the time of the study, it was her fourth year teaching the subject. However, she is only responsible for teaching the chemistry part of the subject and has no prior experience in teaching the topic of vertical projectile motion. Ms NJ was given the responsibility at her school to teach chemistry to Grade 11 and Grade 12 learners. For district enrichment programmes, Ms NJ was tasked to teach both Paper 1 and Paper 2 topics, especially vertical projectile motion, since it was identified as one of the problematic topics in the district. These enrichment programmes are conducted in the afternoons, weekends and school holidays.

The data collected through the CoRe tool and interview was done in English, which is Ms NJ's second language. The teacher is not very proficient in English and struggles to express herself. This shortcoming made it necessary to go back to the teacher to clarify certain things she said.

4.2.1 DATA FROM THE CORES AND INTERVIEW

Ms NJ completed the pre-CoRe tool in her own handwriting and did not submit it electronically. I typed her CoRe using Microsoft Word but made no changes to the content. The CoRe shown below, as Figure 4.3, is an exact version of her submission. It should be emphasised that she had never taught the topic of vertical projectile motion before. Although Ms NJ did not elaborate much on most of the prompts in the CoRe, she responded in more detail in the interview, which was also conducted in her second language. Her full interview transcript is available in Appendix I.

CoRe		
CoRe prompts	Big Idea 1	Big Idea 2
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i> ?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?	➤ The difference between displacement and distance. ➤ The displacement vs time graph gives velocity. ➤ Direction of motion (upward and downward as positives), the effect of displacement of the object on signs.	➤ When an object is dropped its initial velocity (v_i) = 0 ➤ When an object reaches maximum height $v_f = 0$ ➤ The velocity vs time graph gives the acceleration The parabolic graph:  Time taken to reach max height = time taken to return to reference point.
2. What concepts need to be taught before teaching this big idea?	➤ In Grade 10 learners should have been taught motion in 1D. ➤ Learners should know about equations of motion.	➤ In Grade 10 learners should have been taught motion in 1D. ➤ Learners should know about equations of motion.
3. What representations would you use in your teaching strategy?	Graphs of motion: 	For a ball thrown upward 

4. Give particular reasons for the representations used to engage with this idea?	➤ Equations of motion are taken from the graphs. ➤ We use the graphs for learners to understand the motion of an object. ➤ We use the graphs to calculate the unknown variables ($v_f, v_i, \Delta y$) ...	➤ Equations of motion are taken from the graph. ➤ Learners can understand the motion of an object through the graph.
5. Describe the strategy you will use to establish conceptual development of the key idea.	➤ Use real life situations, ask learners questions that they can relate to. ➤ Use a ruler to show how to measure the distance in a straight line (measuring tape).	➤ Use parabola curve to explain time symmetry $v_i = -v_f$ $v = 0, \text{ at max height}$ $t = 2t$

6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	➤ Why is it that when an object is thrown up it always comes down?	➤ Why is it that when an object is thrown up its velocity decreases.
7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	➤ Learners confuse the difference between displacement and position. ➤ They cannot differentiate between vector and scalar quantity. ➤ They cannot draw the displacement vs time graph.	➤ Interpretation of the graphs. ➤ In time symmetry learners confuse $v_i = -v_f$ when ball is thrown vertically upward back to starting point with $h = 0$
8. How do you address the misconceptions and or learner difficulties?	➤ Explain to learners the difference between displacement and position. ➤ Explain vector → magnitude and direction. Scalar → magnitude only. ➤ Use more representations of graphs.	➤ More representations of velocity vs time graph. ➤ Explain the difference between the motion of a bouncing object and a dropped object.

Figure 4.3: Ms NJ's content representations

4.2.2 ANALYSIS OF THE CORES AND THE INTERVIEW

The sections below reflect the analysis of Ms NJ's CoRe and her interview. The data are compared to the expert CoRe and Graded in terms of the levels described in the rubric. This analysis provides evidence of the quality of Ms NJ's PCK in terms of projectile motion before she taught the topic.

4.2.2.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

It is mostly from Ms NJ's interview that information regarding her knowledge about curricular saliency can be deduced. When asked about key ideas for the topic in Question 1 of the interview, she said: "Firstly, the main key points are that the learners have to understand the definition or the difference between free fall and projectile."

Although the definitions of the two concepts mentioned are very similar, it is important for learners to be able to differentiate between them. When the DBE revised the examination guidelines for physical sciences Grade 12 in 2021, they included the definition of free fall, which was not present in the previous 2017 version. The teacher did not explain the difference because she might have thought it was given in the examination guidelines and that mentioning the terms was sufficient. The 2021 examination guidelines (DBE, 2021) defined the terms as follows:

- A projectile is an object that has been given an initial velocity and then moves under the influence of the gravitational force only.
- Free fall is defined as a motion during which the only force acting on an object is the gravitational force.

These explanations will enable Ms NJ to instil the understanding that projectiles fall freely and the only force acting on the projectile is the gravitational force.

When Ms NJ was prompted (Prompt 1) in her CoRe about what she intended learners to learn on each of the big ideas, she identified relevant concepts. Her response at Prompt 1, Big Idea 2, contains valuable information. She correctly identified two instances where the velocity of an object will always be $0 \text{ m} \cdot \text{s}^{-1}$. The first scenario explained that the initial velocity of a dropped object is $0 \text{ m} \cdot \text{s}^{-1}$ and the second example explained that an object reaching maximum height also has a velocity of $0 \text{ m} \cdot \text{s}^{-1}$ at the highest point (Prompt 1, Big Idea 2). The importance of these two examples is that this information (about the velocity) is not explicitly provided in the questions learners have to answer in assessments. When they (learners) see the words *dropped* and *maximum height*, they should be able to make the connection that it is an indication of the velocity being zero at that position.

The other relevant concept indicated by Ms NJ was the concept of time symmetry (Prompt 1, Big Idea 2); she also mentioned it in her interview in Question 1 when asked what she considered to be key concepts in vertical projectile motion. She said:

“The other thing they must understand is time symmetry, which gives us three things. It can give us the maximum height; we have to understand that if a ball is thrown vertically upwards the velocity decreases as the ball goes up. And also, when it reaches the maximum height our velocity is going to be zero. Once it comes back, it will have the same speed but in different directions.”

From her response above it seems like she divided the motion of the projectile into stages, the first stage being when the projectile is launched upwards, the second stage when it is at maximum height and the third stage when it returns back to the point of launch. Again, she mentioned that the velocity at maximum height is zero. She further indicated that a projectile passing the same position during the up and down motion will always have the same speed at that position; however, the directions of the velocities will be opposite.

There is a bit of confusion regarding the above quote made by Ms NJ, she claimed that time symmetry would provide three quantities, namely (1) maximum height, (2) velocity at maximum height and (3) equal magnitude in velocity at the same position but in different directions. However, the first two quantities mentioned cannot be deduced from time symmetry. Time symmetry actually only indicates that if you know how long (time) it will take an object to reach its maximum height, you will know how long (time) it takes the object to fall back from maximum height to its point of launch. The third quantity can be considered part of time symmetry because the same acceleration over the same time interval will lead to the same change in velocity. From the entry she made in her CoRe (Prompt 1, Big Idea 2), it is clear she understands the meaning of time symmetry, but as stated, she made confusing remarks about the information that can be deduced from time symmetry.

Regarding pre-concepts, Ms NJ is aware of pre-concepts that learners need to know. When specifically asked about pre-concepts in her interview and CoRe, she mentioned the following: motion in one dimension that is taught in Grade 10, as well as the equations of motion (CoRe, Prompt 2, Interview Question 2).

Other pre-concepts mentioned throughout her CoRe and interview includes those from Grade 10, namely: displacement and distance (CoRe, Prompt 1, Interview, Question 1), graphs (CoRe, Prompt 1), frame of reference (CoRe, Prompt 1, Interview Question 1) and vector and scalar quantities (CoRe, Prompt 7). The before-mentioned concepts are in line with those mentioned in the expert CoRe in Prompt 2.

When referring to graphs of motion (Grade 10 pre-concepts) mentioned above the teacher makes the following statements (CoRe, Prompt 1):

- “The displacement vs time graph gives velocity.”
- “The velocity vs time graph gives the acceleration.”

This Statement is not entirely correct and learners should be made aware that it is the gradient of these graphs that gives the information she mentioned. Also, she should rather refer to a position-time graph and not a displacement-time graph. As a case in point, she did not mention that the gradient of the velocity-time graph will provide the acceleration of the object during that time interval, which in the case of vertical projectile motion will always be a constant value of 9,8 in magnitude. Ms NJ did not mention that the area underneath a velocity-time graph will provide the displacement for the object during that time interval.

Ms NJ indicated how certain pre-concepts mentioned above are used in new knowledge obtained by the learners. She emphasised the importance of sign conventions and frame of reference when she answered Question 1 in her interview: “The first thing that the learner must know is that they must choose the direction that they are going to use throughout.” She indicated that the equations of motion play an important role in solving vertical projectile motion questions when she said in her interview (question 9):

“They should check what the unknown variable is. Using that information they can relate it to the four equations of motion that they have. They will now be able to see what it is that I have and what it is that I do not have.”

Despite identifying pre-concepts taught at Grade 10, she indicated that she does not believe there are any pre-concepts learners need to be aware of from Grade 11. This raises a concern since a force like gravity, done in Grade 11, can play an important role in conceptual understanding. She also does not mention the topic of momentum and impulse at the Grade 12 level, which includes concepts like contact time when an object bounces on the ground and elastic and inelastic collisions. This lack of knowledge can be attributed to the fact that Ms NJ has never taught physics in the FET phase before.

Ms NJ identified several relevant pre-concepts and concepts within each of the big ideas. However, there is no evidence of logical sequencing when referring to the pre-concepts and new concepts. We can refer to the example where Ms NJ mixed the concepts of time symmetry with maximum height and velocity at maximum height. Ms NJ did not provide logical links between the pre-concepts of Grade 11 and Grade 12 with the big ideas. It can be seen in the rubric that the second level, *developing*, describes Ms NJ the best.

4.2.2.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

In an attempt to probe the teacher's knowledge about learner difficulties and misconceptions in the topic, she was asked what she thought typical misconceptions or difficulties were that learners experienced (CoRe Prompt 7). One of the misconceptions Ms NJ identified is that learners interpret the shape of a position-time graph as a picture of the path of the motion.

She elaborated in her interview (Questions 4 and 6), when she said:

"The other thing [limitation] is with the graphs. I think it is a problem for both teachers and the learners, the interpretation of graphs."

"So the other misconception normally when we look at the graphs, it is the opposite, you find that a ball is thrown up but the graph is going down. So that causes the confusion because learners believe that if a ball is thrown up, that means my graph, maybe velocity-time graph, should also go up."

Ms NJ diagnosed the misconception well when she said learners think the direction in which the object is moving was the same as the direction in which the velocity-time graph is drawn. This misconception is also mentioned in the literature (Barclay, 1985; Clement, 1985; Lapp & Cyrus, 2000) and listed in the expert CoRe at Prompt 7. She also made a vague statement on Prompt 8 in her CoRe when she said the difference between a bouncing and dropped object should be explained to learners. When she was asked about this statement, she said: "learners confuse the two motions and is [sic] really struggling to draw their graphs."

An issue identified by Ms NJ as a misconception is that learners confuse the two physical quantities, velocity and height, with each other at the position of maximum height. She responded to Question 6 in her interview, by saying:

"The confusion at maximum height, learners know that if a ball is thrown up at maximum height velocity is zero, some confuse that with height. They say height is zero instead of the velocity being zero at maximum height."

This is not documented in the literature or diagnostic reports as a misconception. Her claim that learners know that the velocity is zero at maximum height is conflicting with the misconception identified in the expert CoRe (Prompt 7, Big Idea 1), where it is noted that learners do not know the velocity of an object at maximum height is zero. Perhaps only a lapse in concentration will cause learners to confuse the two physical quantities.

Other entries made at Prompt 7 in her CoRe revealed knowledge of learner difficulties. At Big Idea 1, she indicated that learners confuse displacement and position. When Ms NJ was

asked to elaborate on the entry, she indicated that she meant distance instead of position. She said she wanted to give an example of vector and scalar quantities that she mentioned in her next entry. This corresponds to the other difficulty she mentioned in Prompt 7 when she said learners cannot differentiate between vector and scalar quantities. She elaborated in response to Prompt 8 by saying that vectors and scalars should be explained to learners.

Ms NJ also showed awareness of learner difficulties when she mentioned the following in her interview: possible language barrier learners might have (Question 4), sign conventions and frame of reference (Question 6). Although language issues were not considered in the expert CoRe, I believe Ms NJ did well to mention this difficulty, as it is what she is currently experiencing in her teaching career. I do believe language can be a barrier to learning, especially if you are not taught or assessed in your home language. Rollnick (2000) acknowledged that expecting students to learn a new and difficult subject through the medium of a second language is challenging, giving them a double task of mastering both the science content and language.

Not using a frame of reference to interpret the questions or not remembering the physical significance of signs (plus or minus) for a set of quantities (vectors) is indeed considered a learner difficulty in the expert CoRe. Yet, Ms NJ did not mention the interpretation of graphs as an aspect her learners find challenging.

It can be concluded that Ms NJ identified misconceptions and learner difficulties, which only partially addressed documented misconceptions and learner difficulties. Her understanding of knowledge and skills related to learners' understanding of science was regarded as *developing*.

4.2.2.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Throughout her CoRe and interview, Ms NJ referred to the following representations that can support conceptual development when teaching the topic to learners. An object thrown upwards and returning to the point of launch (Prompt 1, Big Idea 2; Prompt 5, Big Idea 2; Question 1), real-life situations (prompt 5, Big Idea 1; Question 4), a ball thrown upwards (Prompt 3, Big Idea 2 ; Question 1; Question 4) and a bouncing object (Prompt 8, Big Idea 2).

When asked about representations suitable for vertical projectile motion (Prompt 3), Ms NJ responded:

“Normally, I use graphs on the board. I just draw graphs before explaining, before getting into the questions. I just draw the graphs and then just explain the important key points.”

It is only in the last part of her response to Question 7 that she elaborates on other representations she intends to use. She stated:

“We can use a normal ball or any object that could be in my hand at that moment, probably a duster or anything, just to show that if I’m throwing it up, it is going to come back down.”

From the first quote above it is clear that she intended to employ a sequence in which she evidently drew the graphs first and later demonstrated them with actual examples.

Figure 4.4 below is a diagram Ms NJ included as an example of a representation at Prompt 5 in her CoRe.

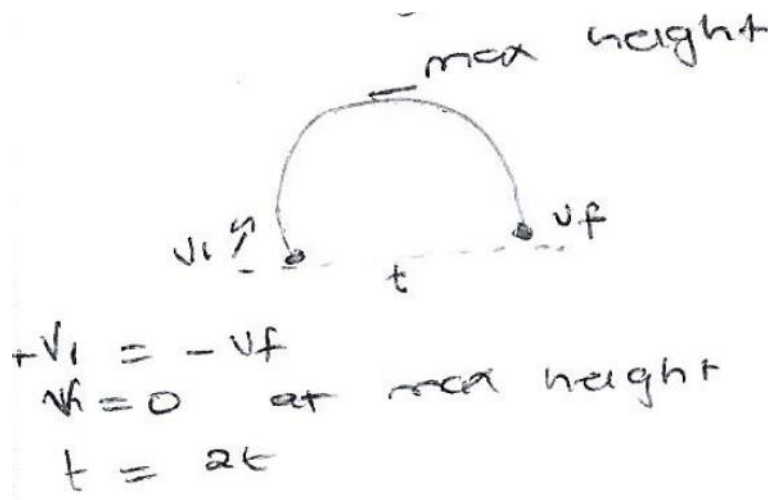


Figure 4.4: Representation used by Ms NJ

Ms NJ linked three concepts correctly to the representation (Figure 4.4). Firstly, she illustrated that the velocity of an object at maximum height is zero (Prompt 1, Big Idea 2). Secondly, she explained that $v_i = -v_f$ (Prompt 5, Big Idea 2). Lastly, she discussed the concept of time symmetry. She managed to explain time symmetry when she noted $t = 2t$ below her representation, which is illustrated above in Figure 4.4. It can be seen that she represented the time an object would need to reach the maximum height as “ t ”, therefore according to the definition of time symmetry, as explained earlier, we know that the object would need the same amount of time to return from maximum height to the point of launch. This means the total time for the object to reach its final position from the point of launch is: $t + t = 2t$ or $t \times 2 = 2t$. This was correctly noted by Ms NJ (Prompt 5, Big Idea 2). The

notation Ms NJ used can be confusing regarding the time. She used the same “ t ” to represent the total time and the time an object takes to reach maximum height. It would have been better if she had indicated total time = $2t$ instead of $t = 2t$.

Ms NJ mentioned the use of real-life examples when she responded to Prompt 5 in her CoRe; she elaborated when answering Question 4 in the interview when she said:

“Then the other thing I think teachers we normally do not use more real-life situations in class. We can just say a ball is thrown upward, but instead of bringing the ball to the class so that learners can experience that or can see that with their own eyes we just assume that they already know what we are talking about.”

From the quote above it can be seen that Ms NJ thought about the use of a real-life situation, that of a ball being thrown upwards. However, she did not explicitly link concepts to this representation; rather, she explained that representations should be demonstrated to learners in class and that learners should not be taken for granted that they understand what teachers are explaining. This is partly evidence of her knowledge of understanding how learners think.

As explained earlier in this section, Ms NJ planned to use the graphs of motion to explain to learners the motion of the object. This is an uncommon approach proposed by the teacher. This sequence suggested by the CAPS document is instead to analyse the motion and then draw the corresponding graphs. Explaining the motions of an object to learners using representations in the form of a drawing and learners’ intuitive understanding of the phenomenon can enable the teacher to link concepts to the different parts of the motion. This, in turn, can better assist them in drawing the graphs.

When the teacher was prompted (Prompt 5) to describe her teaching strategy, she provided very little information, and her response was ambiguous. However, the interview responses revealed more information about her reasoning.

Ms NJ described her teaching strategy the best when she answered Questions 1 and 9 in the interview. She referred to pre-concepts that learners should be aware of, although she only mentioned two pre-concepts, displacement and position. She then appropriately said:

“So the first thing that the learner must know is that they must choose the direction that they’re going to use throughout.”

Choosing the reference frame is important and is also noted in the expert CoRe (Prompt 5) after revision of pre-knowledge. Once the learners have determined their frame of reference,

the sign conventions allocated to vector quantities will be a lot easier to understand. Ms NJ displayed good knowledge about this when she said (Question 1):

“So that means if they have taken up as positive and the ball is going up, the initial velocity will take the positive sign and then when it goes down, then it [velocity] will take the negative sign.”

When she responded to Question 7, she indicated that it will be useful to use a ball or any object to show the physical movement of an object being thrown upwards and returning to the point of launch. This is a good representation, and the expert CoRe also suggests that the use of real-life examples can assist in conceptual development. It is, however, essential to support the representation used with a drawing on the board so that learners can refer to the diagram whenever needed.

This is indicated by Ms NJ when she described that learners should be able to draw a diagram on their own when attempting a question (Question 9). This is a good suggestion and will indeed assist the learners in interpreting the data. She further described her strategy when she said:

“Have a drawing to say, this is the motion of the ball, this is what is happening and then also have points to say, I will take this as my point A, then maybe maximum height as my B, the ground as point C.”

This corresponds to the suggestion in the expert CoRe (Prompt 5), which states that different stages of motion should be identified using alphabet letters. This approach will assist learners in linking the physical quantities to certain stages of the motion.

Ms NJ explained (Question 9) that learners should write down the information that is given and identify the unknown variable. Once they have this information, they are able to determine which one of the four equations of motion to use to solve for the unknown variable. This is a common teaching strategy for vertical projectile motion. This strategy is described by Gaigher et al. (2007) as a structured problem-solving strategy, which can be summarised in the following seven steps:

- 1 Draw a simple diagram to represent the system.
- 2 Indicate the data on the diagram.
- 3 Identify the unknown variable.
- 4 Analyse the problem in terms of physics principles.
- 5 Write down the relevant equation(s).
- 6 Substitute and solve.
- 7 Interpret the numerical answer.

Ms NJ planned to ask questions and responded with the following two questions in her CoRe (Prompt 6). (1) Why is it that when an object is thrown up, it always comes down? (2) Why is it that when an object is thrown up, its velocity decreases? Both of these questions will have the same answer: gravity. The question is considered good and is also noted in the expert CoRe at Prompt 6. However, these two questions alone are not enough to elicit knowledge from the learners and to enhance their conceptual understanding.

Ms NJ considered graphs of motion as a representation only and not as content to understand conceptually. However, she described other relevant representations and indicated how conceptual development can be supported. She linked this with a general teaching strategy that is overall workable. Questions asked by Ms NJ are very limited, and therefore, the sequencing for conceptual development is ambiguous. The second level, in the rubric, developing, describes her knowledge and skills related to conceptual teaching strategies the best.

4.3 CASE STUDY 3 – Mr JP

Mr JP is a physical sciences teacher with a B.Ed degree in Science education. At the time of the study, it was his first year teaching, and he never taught the subject or topic before. Mr JP was responsible at his school for teaching physical sciences to the whole FET phase. The data collection through the CoRe tool and interview was done in English, which is Mr JP's second language. The teacher was not very proficient in English and struggled to express himself. This shortcoming made it necessary to go back to the teacher to clarify certain things he said.

4.3.1 DATA FROM THE CORES AND INTERVIEW

Mr JP completed the pre-CoRe tool electronically and submitted it online. I did not change the content and wording, and the CoRe is included below, as Figure 4.5 is an exact version of his submission. It should be emphasised that this was Mr JP's first year of teaching, and he had never taught the topic of vertical projectile motion before. Even though some of his responses in the CoRe did not have much substance, he responded well and in more detail in the interview, even though it was in his second language. His full interview transcript is available in Appendix G.

Mr JP: Pre-CoRe		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i> ?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?	Firstly, I want my learners to learn displacement is a vector and not a scalar. That it is the final position minus the initial position. I also intend for them to learn when we are working with the horizontal motion, displacement is represented by x and by y when we are working vertical motions.	I intend for learners to know that the change in velocity of the horizontal motion is the same as the change in velocity of the vertical motion. I also intend for them to learn to choose the positive direction before calculating the change in velocity.
2. What concepts need to be taught before teaching this big idea?	The concept of distance and its difference to displacement needs to be revised.	Learners must know that velocity is the rate of change of displacement.
3. What representations would you use in your teaching strategy?	I intend to use a video showing a vertical projectile motion so that learners build a conceptual understanding of the motions they are to expect.	I intend to use a video showing a vertical projectile motion so that learners build a conceptual understanding of the motions they are to expect.
4. Give particular reasons for the representations used to engage with this idea?	I want learners to build their conceptual understanding of vertical projectile motions. I also know that they are most likely to not forget the presentation which means there is a chance of them not forgetting the conceptual knowledge.	I want learners to build their conceptual understanding of vertical projectile motions. I also know that they are most likely to not forget the presentation which means there is a chance of them not forgetting the conceptual knowledge. With the presentation they will be able to tell that at its maximum height the velocity is zero.
5. Describe the strategy you will use to establish conceptual development of the key idea.	In addition to the presentation I will use, I am going to explain the difference between distance and displacement to the learners at the beginning of the lesson before diving into the content.	In addition to the presentations, I will show them how to calculate the change in velocity of horizontal and vertical motions.
6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	I would give them few scenarios to calculate the change in displacement, the first where they get a positive displacement, the second where they get a negative displacement and the last one where they get a zero displacement.	I will ask them to calculate a change in velocity for both horizontal and vertical motions.

7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	Learners often confuse displacement with the distance travelled.	They usually confuse speed and velocity. They also forget to designate a positive direction when dealing with a change in velocity.
8. How do you address the misconceptions and or learner difficulties?	I will address this by teaching the difference at the beginning of my lesson.	Before starting any calculations, I will be clearly choosing the positive and the negative direction. I will do this often so they can build the habit of doing so as well.

Figure 4.5: Mr JP's pre-CoRe

4.3.2 ANALYSIS OF THE CORES AND THE INTERVIEW

The sections below reflect the analysis of Mr JP's CoRe and his interview. The data were compared to the expert CoRe and graded in terms of the levels described in the rubric.

4.3.2.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

Mr JP's response to the first prompt in his CoRe revealed his intention to show learners that motion in the horizontal plane is represented by "x" and motion in the vertical plane is represented by "y". This distinction is essential because learners are aware of the horizontal displacement (Δx) they encountered in Grade 10 and do not always realise that the vertical motion encountered in Grade 12 is represented by vertical displacement (Δy). This misconception is also noted in the expert CoRe at Prompt 1, Big Idea 1.

The following entry (Prompt 1, Big Idea 2) made by Mr JP caused reason for concern:

"I intend for learners to know that the change in velocity of the horizontal motion is the same as the change in velocity of the vertical motion."

It is possible that Mr JP meant horizontal motion in general, as discussed in Grade 10. However, if the statement is delivered this way and the concepts (horizontal and vertical motion) are not quantified, it may lead to confusion. It is important to be reminded that in the South African Grade 12 curriculum, only vertical projectile motion is considered and explained, meaning motion in two dimensions is not addressed. The statement above made by Mr JP reveals his lack of knowledge regarding curricular saliency.

When Mr JP responded to Prompt 4 in his CoRe, he indicated that he would use a representation to demonstrate that the velocity of an object at maximum height is zero. As explained by the previous two participants, this is an important concept for learners to know and understand, and it is also indicated in the expert CoRe at Prompt 1, Big Idea 2.

Mr JP mentioned in his interview (Question 2) that a key concept to be explained is: "The gravitational acceleration is always downwards." However, he did not emphasise that this acceleration is constant, an important concept that learners should understand when dealing with vertical projectile motion.

Mr JP referred to the following pre-concepts in his CoRe as a response to concepts to be taught: displacement, vector and scalar quantities (Prompt 1, Big Idea 1), change in velocity, frame of reference (Prompt 1, Big Idea 2), distance (Prompt 2, Big Idea 1). Mr JP confirmed this in the interview and elaborated on what he considers to be key concepts in the topic of vertical projectile motion. He responded:

“I would say displacement, change in velocity and signs, choosing the right direction. Choosing the right direction for your motions like positive direction and negative direction and most importantly, the gravitational force and gravitational acceleration.”

It is clear that Mr JP is aware of the relevant pre-concepts. Furthermore, when he answered Question 3, he demonstrated the ability to sequence the pre-concepts logically. He said:

“In Grade 10, definitely motion in one dimension. They need to be used to the use of the four equations of motions. They need to understand velocity because if I remember correctly, it is introduced in Grade 10 and displacement. In Grade 11 they need to understand gravity. The gravitational force [is] the gravitational acceleration from Newton's law of universal gravitation.”

He mentioned relevant pre-concepts from Grades 10 and 11, but did not mention any pre-concepts from Grade 12. This omission can be due to his lack of experience.

The Grade 11 topic, Newton's law of universal gravitation, mentioned by Mr JP in the above quote, is a crucial pre-concept for learners to understand. It develops the conceptual underpinning for learners regarding the gravitational force and gravitational acceleration an object will experience on Earth or any other planet.

Although he sequenced the pre-concepts logically, it should be noted that he could not sequence the new concepts pertinent to teaching vertical projectile motion in a logical order. This omission, again, can be due to the fact that he never taught the topic before. There is thus evidence of the teacher's knowledge of curricular saliency, but he could not sequence and scaffold the main ideas within the topic of vertical projectile motion.

Mr JP was able to identify an extensive list of relevant pre-concepts within each of the big ideas. He identified relevant new concepts within each of the big ideas. However, the list of new concepts was not extensive, and some important concepts were omitted. It is, therefore, reasonable to score Mr JP as *developing* for this component.

4.3.2.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

When Mr JP was probed in his CoRe (Prompt 7) to elaborate on typical learner misconceptions and difficulties, he only mentioned one difficulty about Big Idea 1. He indicated that learners confuse displacement with distance. This was also observed in his interview (Question 2) when he said:

“I think it is because most of the motions in vertical projectiles include displacement, which most of the time they confuse it with distance.”

and Question 5:

“I think distance and displacement, they might confuse the two. This is the biggest one. I think they are used to changing velocity from momentum. So I don't think that'll be a problem. So I would say displacement.”

Mr JP referred to this difficulty quite a few times throughout his CoRe. At Prompt 1, Big Idea 1, he indicated that he intended for his learners to know that displacement is a vector, not a scalar. He alluded to the fact that distance differs from displacement (Prompt 2, Big Idea 1). At Prompt 5, he indicated that he would explain the difference between displacement and distance to learners before starting with new content on vertical projectile motion.

He indicated (Prompt 7) that learners confuse speed with velocity and tend to forget the sign conventions when dealing with velocity.

Most of the challenges Mr JP identified are part of prior knowledge, focusing on understanding the differences between variables. This may indicate his lack of experience since he seems to be unaware of challenges specific to projectile motion. When asked (Question 7) to elaborate on learner difficulties, he acknowledged his lack of knowledge: “I'm not completely sure because of my lack of experience in teaching this particular chapter.”

Mr JP has a workable strategy to address the one difficulty identified but did not manage to include any other difficulties or misconceptions. The one difficulty he identified is the most basic misunderstanding that should have been addressed in Grade 10 already. The first level of competence describes Mr JP's knowledge and skills related to learners' understanding of science the best, namely *limited*.

4.3.2.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

In his response to Prompt 3 about what representations he would use, Mr JP indicated using a video of vertical projectile motion. He gave the same response for Big Idea 2, Prompt 3. This suggests that Mr JP was unsure of which representations to use and how to use them. There is a lack of depth in his strategy to implement useful representations, and his representations were vague and superficial, as evidenced by the fact that he did not elaborate on the video he intended to use.

There is no indication in any other part of his completed CoRe on what representations he intended to use. This lack of information can be attributed to the fact that he has never taught the topic and has no practical teaching experience. He stated in his interview in Question 4:

“I don’t think I have any [experience] because when we were doing our practical in university it was during a time when vertical projectile was already done, or before it was done.”

When Mr JP was asked in the interview (Question 9) what representations he would use when teaching the topic, he mentioned two types of representations. Firstly, he referred to the Physics Education Technology simulation called PhET, and secondly, he referred to the method of drawing the object’s motion on the board.

When Mr JP was asked (Question 10) to elaborate on the PhET simulation he responded:

“They are simulations that show concepts, physics concepts. I don’t know how to explain it. Simulations to denote or show abstract concepts in a way that can be easily understood. Yeah, I think they help the learners to sort of like imagine or conceptualise our understanding of abstract concepts.”

Simulations are indicated as an effective representation in the expert CoRe (prompt 3). However, it has to be noted that Mr JP is vague, and there is no evidence that he has ever looked at the PhET simulation on the topic. When prompted, he said that the video he mentioned and the PhET simulation are actually the same thing. Again, this can be ascribed to his lack of experience.

When Mr JP was prompted (Prompt 4) in the CoRe to give particular reasons for the representations used, he provided only one reason. His responses were generally vague.

Mr JP’s one coherent example was that an object’s velocity would be zero at its maximum height (Prompt 4, Big Idea 2). He also stated that learners would remember the presentation he planned to use and, therefore, they would remember the conceptual knowledge better. This reason was repeated for Big Idea 1 and Big Idea 2.

He did not link concepts to his representations or provide specific explanations of the usefulness of the representations. There is insufficient evidence on how using his representations will lead to increased learner understanding of concepts.

Mr JP did not provide adequate questions to ascertain the learner’s understanding. When prompted at Prompt 6 in the CoRe tool on what questions he would ask, he only mentioned scenarios where learners have to calculate an object’s displacement and change in velocity. These two types of questions are based on the pre-concepts learners already studied in Grade 10. Although it is good to revise and reinforce important pre-concepts, they should not be the only focus of his questions.

Prompt 5 in the CoRe tool required Mr JP to describe the teaching strategy he planned to use to establish conceptual development of the main ideas. He indicated that he intended to explain the difference between distance and displacement at the beginning of his lesson before he dives into the content:

“I would give them [a] few scenarios to calculate the change in displacement, the first where they get a positive displacement, the second where they get a negative displacement and the last one where they get a zero displacement.”

He also indicated (Prompt 6, Big Idea 2) that learners need to calculate the change in velocity for both horizontal and vertical motions.

Looking at his responses in his CoRe and interview, it seems Mr JP planned to implement the following strategies: He firstly wanted to revise the pre-concepts of distance, displacement (Prompt 5, Big Idea 1) and velocity (Prompt 5, Big Idea 2) before starting new content. He then planned to proceed with his lesson with a presentation (Prompt 5, Big Idea 1), which we now know is a PhET simulation. He noted that using this representation will assist learners in building their conceptual knowledge of the topic (Prompt 4, Big Idea 2) and help learners remember the content better (Prompt 4, Big Idea 1). It has to be noted that his explanation of how the representation will be used lacks clarity and depth.

One of the strategies he keeps referring to is dividing or separating the motion into different parts. He said in Question 8:

“Separating the entire motion like breaking it down into different parts. Separating the beginning of the motion, the initial velocity to the maximum height and the final velocity, and from the maximum height to the ground. That’s a strategy that I’m going to be using a lot instead of focusing on the initial velocity and straight to the final velocity.”

This method corresponds to the suggestion in the expert CoRe (Prompt 5), stating that different stages of the motion should be identified using alphabet letters. This approach will assist learners in linking the physical quantities to specific stages of the motion.

Mr JP planned to introduce the reference frame before starting with calculations (Prompt 8, Big Idea 2). This is a good idea that can assist learners in allocating positive and negative signs to the vector quantities based on the chosen frame of reference. This suggestion can also be linked to the different stages of the motion explained in the previous paragraph.

Mr JP indicated that he would then move to calculations. When asked at Question 11 what he thinks works well in explaining the topic, he mentioned that it is important for learners to

have the equations of motion at hand when attempting to answer questions and solve the problems. Of course, he would guide them along the way when solving problems. His advice on teaching the topic was (Question 12): “Helping them and teaching them how to solve projectile problems.”

The teaching strategy Mr JP planned to use is vague and poorly articulated. There is little evidence of an effective planned strategy. There was no acknowledgement of learner misconceptions, and almost all of his attention was fixated on Big Idea 1. Mr JP did not provide adequate questions to ascertain the learner's understanding. Because of his lack of explanations and elaboration on his intended strategies, the sequencing for conceptual development is ambiguous. I believe Mr JP's inexperience is evident, and I would classify his knowledge and skills related to conceptual teaching strategies as *limited*.

CHAPTER FIVE ENACTED PCK

RESULTS AND ANALYSIS

In this chapter, I present the data and the analysis of the ePCK of the three teachers. During lesson observations, data were collected to identify instances where teachers' ePCK was reflected. Two lessons for each participant were recorded. This recording was to ensure that all possible data about the teaching of vertical projectile motion pertaining to problem-solving and motion graphs were obtained. The duration of lessons was between 40 minutes and 90 minutes, depending on the school setup. The analysis of the lesson observations was also based on the three components of the grand rubric and answered the second sub-question of the study: What is the level of novice teachers enacted PCK when teaching vertical projectile motion for the first time? Like the previous chapter, this chapter is organised into a discussion of three cases, one per teacher.

Analysis of the video-recorded lessons.

I took the following steps during the analysis of the video-recorded lessons.

- I watched the recording of each lesson at least two times to familiarise myself with the content.
- I wrote a narrative account of the recorded lesson for each participant and divided the lesson into teaching sections. These sections typically lasted between one and 23 minutes and were narrated chronologically.
- I identified teaching events in the teaching sections and studied them for evidence about the teachers' ePCK.
- I used a colour-coded system to relate the teaching events to the three components of the grand rubric, namely: (1) Knowledge and skills related to curricular saliency (Yellow), (2) Knowledge and skills related to learner's understanding of science (Blue) and (3) Knowledge and skills related to conceptual teaching strategies (Purple and Green) where green represented representations and analogies within the component.
- I used the rubric (Appendix C) to score the teacher's ePCK, and a level (limited, developing or exemplary) was assigned to each of the three components selected from the grand rubric depicting the quality of enactment.

5.1 CASE STUDY 1 – MR DN

Mr DN was confident about the content he was presenting to his learners. He presented the content in Afrikaans, which is his and the learners' home language. The classroom atmosphere was light-hearted and conducive to learning. It was noted that Mr DN did not move around the classroom much but stayed in the front area. Mr DN used a SMART board located in his classroom. A SMART board is an interactive whiteboard with touch recognition for user input. To allow learners to follow the teacher's progress through the textbook during the lesson, Mr DN loaded the textbook onto his laptop for his first lesson so that the textbook could be displayed on the SMART board. In the second lesson, he used the drawing function on the SMART board instead of displaying the textbook.

I observed and video recorded two of his lessons on vertical projectile movements. Eight sections were identified in his first lesson (Figure 5.1), as briefly described below. The full lesson narrative is included in Appendix N. Eight sections were identified in his second lesson (See Figure 5.2), which is briefly described below. The full lesson narrative is included in Appendix Q.

Section	Description	Time
1.1	He began his lesson with an overview of all the components (definition of a projectile, gravitational acceleration, terminal velocity, equations of motion and problem solving) he wanted to cover and explained the term projectile.	1 min 16 s
1.2	Introduced the concept of gravitational acceleration and linked it to relevant pre-concepts like mass and weight, velocity, change in velocity, Newton's law of universal gravitation and equations of motion.	3 min 16 s
1.3	Started with problem-solving questions related to the topic of vertical projectile motion	4 min 23 s
1.4	Introduced new concepts of bouncing objects	1 min 57 s
1.5	Conducted problem-solving examples where he explained the solutions to the problems.	19 min 23 s
1.6	Hot-air-balloon problem addressed	10 min 45 s
1.7	Interpreting the velocity-time graph.	3 min 36 s
1.8	Started with a exercise on solving projectile motion problems	2 min 47 s

Figure 5.1: Eight sections identified during Mr DN's first lesson

Section	Description	Time
2.1	Begins his lesson by explaining the acceleration-time graph	2 min
2.2	Explained the position-time graph of an object thrown upward and was caught again at the point of launch	6 min 06 s
2.3	Explained the velocity-time graph of an object thrown upward and was caught again at the point of launch	4 min 14 s
2.4	Examples consisting of bouncing objects, explained the position-time and velocity-time graph	3 min 44 s
2.5	Provided examples involving bouncing objects by representing their motion using a velocity-time graph	3 min 25 s
2.6	Examples used in the first lesson are used again to describe the graphs	12 min 36 s
2.7	Revision of pre-concepts related to the graphs of motion such as gradients of and areas under graphs	5 min 51 s
2.8	Exercise on interpreting a graph	6 min 52 s

Figure 5.2: Eight sections identified during Mr DN's second lesson

5.1.1 ANALYSIS OF MR DN'S LESSON

5.1.1.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

Mr DN began his first lesson displaying a layout of concepts he wanted to address (Lesson 1, Section 1.1). The concepts displayed have a logical sequence, but whether Mr DN did this consciously or merely followed the textbook sequence was unclear. The sequence observed in Lesson 2 is less logical than in Lesson 1. This sequence was observed when he only explained the relevant pre-concepts regarding the three graphs of motion and their interrelatedness at the end of his lesson (Lesson 2, Section 2.7).

Mr DN emphasised the importance of pre-concepts at the beginning of his first lesson. He referred to the following pre-concepts throughout his lessons: equations of motion (Lesson 1, Section 1.2), mass and weight (Lesson 1, Section 1.2), position (Lesson 1, Section 1.3), distance (Lesson 1, Section 1.3), displacement (Lesson 1, Section 1.3)(Lesson 2, Section 2.2), velocity (Lesson 1, Section 1.2), change in velocity (Lesson 1, Section 1.2), acceleration (Lesson 1, Section 1.2; 1.3)(Lesson 2, Section 2.6), frame of reference (Lesson 1, Section 1.3)(Lesson 2, Section 2.2; 2.3; 2.4), graphs of motion (Lesson 2, Section 2.7), Newton's first law (inertia) (Lesson 1, Section 1.6), Newton's law of universal gravitation (Lesson 1, Section 1.2), energy (Lesson 1, Section 1.4)(Lesson 2, Section 2.4), and

momentum and impulse (Lesson 1, Section 1.3 And Lesson 2, Section 2.4). Most of the pre-concepts mentioned were discussed with learners in a manner of revision as they did in Grade 10 and Grade 11. After that, Mr DN attempted to link the pre-concepts to the new concepts regarding vertical projectile motion.

Mr DN started with two relevant examples (Lesson 1, Section 1.3) to demonstrate vertical projectile motion, namely (a) an object thrown upwards and caught again at the launching point and (b) a ball dropped from a certain height. These two examples were also described in the expert CoRe at Prompt 3. Mr DN used the same examples when explaining the graphs of motion in his second lesson (Section 2.2). Figure 5.3 shows the diagrams on the board illustrating the abovementioned examples.

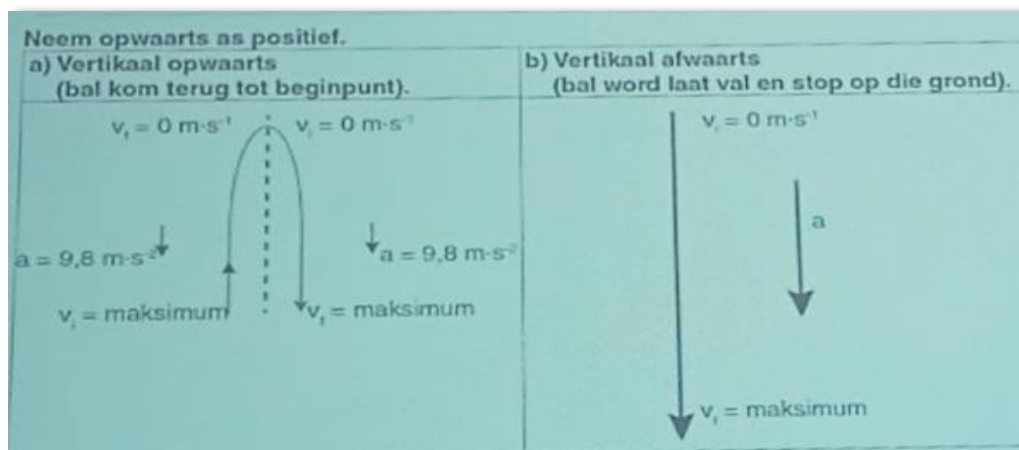


Figure 5.3: Illustrations of example (A) and example (B) used by Mr DN in Lesson 1

Using the examples in Figure 5.3, Mr DN explained the pre-concepts of distance, displacement and frame of reference as related to projectile motion. When he discussed the difference between distance and displacement, which are vector quantities and depend on direction, he said:

"We know the difference between distance and displacement. Distance is the total path length followed. Displacement is from where it moved its position."

This is an acceptable explanation by Mr DN and an important pre-concept that learners should know and understand. Mr DN clearly used standardised definitions to explain the pre-concepts. Here was an opportunity where he could have expanded his explanation and discussed with the learners what it means when the displacement of an object is negative, which is often required in vertical projectile motion problems. Such a discussion would require learners to apply their knowledge of vector quantities.

Another instance where Mr DN revealed his knowledge of curricular saliency is in Lesson 2 Section 2.7, where he explained the pre-concepts and interrelatedness between the three graphs of motion. As previously mentioned, it would have been better if Mr DN introduced this section earlier in his lesson. While his idea is commendable, the order in which he explained the concepts is restrictive. He has made a drawing on the SMART board revealing with arrows what the gradient and area of each graph represent. Figure 5.4 below illustrates the relationships between the graphs.

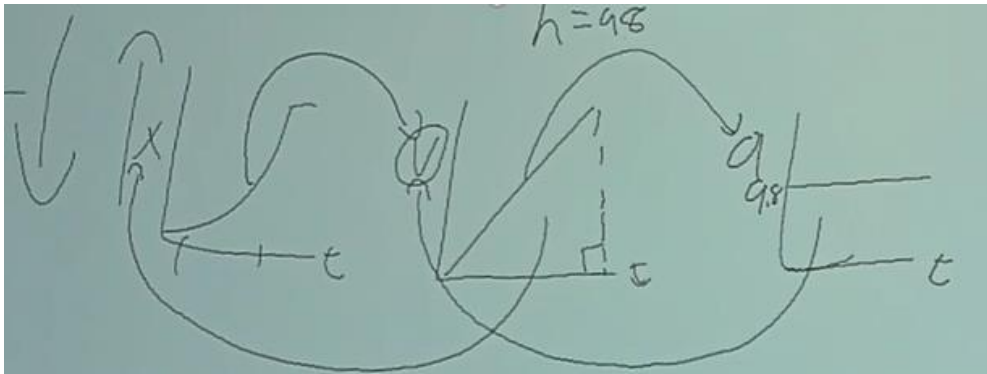


Figure 5.4: Mr DN explained the area and gradients of Graphs of Motion

This method used by Mr DN allowed learners to see the interrelatedness between concepts. All arrows pointing to the right in Figure 5.4 indicate which physical quantity is represented by the gradient of the graph where the arrow started. All arrows pointing to the left indicate what the area under the initial graph will represent. Mr DN made an important statement: "The velocity-time graph consists of straight lines because the acceleration is constant." He further explained that the gradient would be 9,8, the gravitational acceleration.

To further illustrate knowledge of curricular saliency, Mr DN explained most of the new concepts regarding vertical projectile motion. Using the examples in Figure 5.3, Mr DN was able to explain the following relevant concepts: (i) initial velocity of an object thrown into the air, (ii) final velocity of the object, (iii) gravitational acceleration, (iv) displacement (v) distance (vi) maximum height (vii) the equal magnitude of velocity at the same position (viii) initial velocity of an object dropped from a certain height. Mr DN used the examples illustrated in Figure 5.3 in his second lesson (Section 2.2) and linked the new concepts to specific points in the graph.

Mr DN discussed example (a) in Figure 5.3 but did not explain the concept of time symmetry. Although he split the movement into two halves, similar to the textbook's approach, and noted that the time for one half could be multiplied by two to obtain the total time of the movement, he omitted to mention that this phenomenon is called time symmetry.

Using example (b) in Figure 5.3, Mr DN showed that a dropped object's initial velocity (v_i) will always be 0 m.s^{-1} . He repeatedly referred to this concept in his lessons (lesson 1, Section 1.3; 1.4; Lesson 2, Section 2.3; 2.4). This repetition helped him to emphasise the concept, clarify it, and make learners aware.

Two examples (Lesson 1, Section 1.4) used by Mr DN portrayed a ball that was dropped and then bounced once off the ground. He emphasised the newly learned concepts from the previous examples, such as initial velocity, final velocity, acceleration and the velocity of a dropped object. In his examples, a distinction was made between a soft and a hard ball. Mr DN explained the contact time between an object and the ground and why the ball did not reach the same position from which it was dropped. These examples were also used in the second lesson (Section 2.4 and Section 2.5), where he drew the position-time and velocity-time graphs. He linked the new concepts to the graphs in question and also explained how contact time affects the shape of the graphs.

While explaining two concepts, Mr DN referred to scenarios that can confuse learners. When defining a projectile (Lesson 1, Section 1.1), he said:

"An object that is projected or launched into the air by shooting, kicking, hitting or throwing it."

Although this explanation is acceptable, it is imperative to emphasise that the only force acting on the object after it is launched is gravity since learners do not instinctively understand that. Although Mr DN did not explicitly say this, it was indicated on the board. It was concerning that after using the example of a fired gun (Lesson 1, Section 1.1), he did not address the direction of motion and thus did not narrow the example down to vertical projectile motion. In Grade 12, only vertical (up and down) movements are considered. It was observed during his second lesson (Section 2) that he expressly indicated that we only consider upward and downward movements in projectile motion and not movements in two dimensions. The second concept that can confuse learners was when Mr DN revised weight and mass (lesson 1, Section 1.2). He correctly pointed out that gravitational acceleration is a constant value of $9,8 \text{ ms}^{-2}$ downwards. He then draws the learners' attention to the fact that the moon's acceleration is $1,6 \text{ m.s}^{-2}$. According to the CAPS document, vertical projectile motion is only considered in one dimension near the earth's surface and without air resistance. Although examples for other planets are not required, he broadened learners' views.

Although Mr DN covered an extensive amount of pre-concepts relevant to the new content being taught to learners, he only elaborated or briefly explained them without interacting

adequately with his learners. An extensive amount of the essential concepts on the topic were explained, and the main ideas were sequenced logically. This can be ascribed to the fact that Mr DN worked from the textbook (projected on the SMART board) and followed the order suggested in the textbook. The sequencing in his second lesson needed to be more structured, which could limit the effectiveness of the content taught. He pointed out the interconnections between the concepts, but this could have been handled more effectively mainly because he needed to invite discussions from the learners. As can be seen from the analysis, Mr DN actively tried to illustrate his knowledge of curricular saliency. The third category in the rubric best describes Mr DN's knowledge of curricular saliency, namely *exemplary*.

5.1.1.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

As discussed earlier, Mr DN referred to an extensive amount of pre-concepts. However, it was noticed that learners were spoon-fed, and the teacher provided very few opportunities for discussion.

There was little interaction or discussion with learners regarding their understanding of the pre-concepts. Learners seldom responded or interacted with the teacher, and when they did, it was with one-word answers. A typical discussion (Lesson 1, Section 1.2) between Mr DN and the learners is reflected below:

Mr DN: "What is a change in velocity?"

Learners: "Acceleration."

Mr DN: "Acceleration."

He agreed with the learner's answer when he repeated it. This answer needs to be corrected. It should be noted that acceleration is the change in velocity per unit time ($\frac{\Delta v}{\Delta t}$) or the rate of change in velocity.

In Lesson 1, Section 1.1, Mr DN introduced the concept of terminal velocity. Although terminal velocity is not a pre-concept discussed in Grades 10 or 11, it has related pre-concepts like velocity and acceleration. During the section, a learner asked, "What is terminal velocity?" Mr DN explained that it is when an object reaches maximum velocity when falling due to gravitational acceleration ($9,8 \text{ ms}^{-2}$). He mistakenly stated that the acceleration remains constant after the object reaches terminal velocity when, in fact, it becomes zero.

Mr DN explained terminal velocity again when he was directed to it through the textbook (Lesson 1, Section 1.2). He indicated that an object reaches a maximum (constant) velocity when falling because air resistance is present. The upward force created by air friction equals the force of gravity pulling the object downwards. On this occasion, Mr DN could have referred to Newton's second law of motion ($F_{net} = ma$) and pointed out that the net force is zero, the acceleration is zero, and the velocity of the object does not increase. This was an opportunity to have a class discussion about scenarios where there is friction (external force) and scenarios without friction.

It was also observed in the second lesson that he explained new concepts without incorporating the pre-concepts in the development of new concepts. Learners know the three motion graphs because they are taught in Grade 10. Mr DN only referred to this pre-knowledge and their interrelatedness with the new content at the end of his lesson (Lesson 2, Section 2.7). This may be one reason a learner asked him when to use straight lines and curved lines when drawing a graph earlier in his lesson (lesson 2, Section 2.2). Mr DN responded well and said that because the object is accelerating, the velocity of the object is not constant; hence, we cannot use straight lines when drawing the position-time graph. If he incorporated this explanation at the beginning of his lesson, learner understanding of the concepts could be enhanced.

The following concepts can be regarded as learner difficulties as noted in the expert CoRe (Prompt 7) and already discussed in the previous section: Frame of reference (Lesson 1, Sections 1.2; 1.3), displacement (Lesson 1, Section 1.3), distance (Lesson 1, Section 1.3), velocity (Lesson 1, Sections 1.2; 1.3).

Mr DN attempted to address the following difficulties identified in the expert CoRe (Prompt 7): Solving problems involving equations of motion (Lesson 1, Sections 1.2; 1.5; 1.6) and interpreting the area and gradient of graphs (Lesson 2, Section 2.7). Mr DN showed his lack of knowledge of learner understanding when he displayed the answers to all his examples on the SMART board before learners could solve them. The expert CoRe noted at Prompt 7 that learners struggle to solve problems involving equations of motion, especially when manipulating the formula. When Mr DN displayed the solution to problems on the board, he deprived learners of the opportunity to have fruitful discussions, thus exposing learner difficulties. Figure 5.5 indicates what was displayed on the SMART board when he attempted to solve the first problem-solving question using the equations of motion. The problem is about a cricket ball projected upward with an initial velocity of $20 \text{ m} \cdot \text{s}^{-1}$.

Voorbeeld:
 Morné gooi 'n krieketbal vertikaal in die lug op met 'n snelheid van $20 \text{ m}\cdot\text{s}^{-1}$.
 Bereken:
 1. die maksimum hoogte wat die bal bereik.
 2. die tyd wat dit neem totdat die bal terug is in sy hand.
 Die probleem het opwaartse sowel as afwaartse beweging. In die eerste deel van die probleem gaan slegs met die opwaartse beweging gewerk word.

1. Kies opwaarts as + en afwaarts as -.
 By die hoogste punt is die snelheid vir 'n oomblik 0, dus is $v_f = 0 \text{ m}\cdot\text{s}^{-1}$.
 Die versnelling is $9,8 \text{ m}\cdot\text{s}^{-2}$ afwaarts.
 Die beginsnelheid is $20 \text{ m}\cdot\text{s}^{-1}$ opwaarts.
 $v_f^2 = v_i^2 + 2a\Delta y$
 $0 = (+20)^2 + 2(-9,8)\Delta y$
 $\therefore \Delta y = +20,41 \text{ m}$ Die maksimum hoogte is dus $20,41 \text{ m}$.

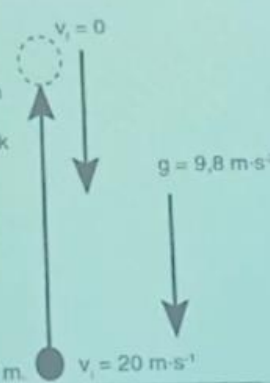


Figure 5.5: First problem-solving question displayed on the SMART board

Figure 5.5 shows the diagram, the explanation and the solution to the question. Therefore, learners are not required to discuss the concepts. They merely follow the information and steps to the solution on the board. These events were observed in Lesson 1.

Mr DN paid attention to some known misconceptions. When he introduced his first two examples (Lesson 1, Section 1.3) (Figure 5.3), he explained that gravity is the only force acting on an object during free fall. Using example (a), he was able to explain to the learners that the velocity at maximum height is $0 \text{ m}\cdot\text{s}^{-1}$. The diagram showed that velocity and acceleration are sometimes in different directions.

Mr DN also explained the scenario of a hot-air balloon (Lesson 1, Section 1.6), where an object was released from a moving carrier. In this case, the hot-air balloon was moving upward, and an object was released from the rising balloon. Mr DN took the opportunity to address the misconception that the released object falls straight down from a moving carrier. He reminded the learners of Newton's first law of motion (inertia) and explained that the object first moved upward when released from the moving carrier before it falls to the ground.

Another common misconception documented in the expert CoRe is that learners consider the shape of a position-time graph as the object's trajectory. Mr DN said in Lesson 1 (Section 1.3): "Position-time graphs observed are the same as the motion of the object." This remark may strengthen the misconception instead of addressing it. He attempted to address this in Lesson 2 (Section 2.6) by explaining different motion graphs: position-time, velocity-time, and acceleration-time. Using the SMART board, he illustrated scenarios to help learners understand the relationship between an object's motion and graphs. However, in

Lesson 2 (Section 2.2), he reiterated that graphs represent the object's motion path, missing an opportunity to clarify that a graph's shape can differ from an object's motion.

When Mr DN explained the graphs of motion in terms of bouncing objects (Lesson 2, Section 2.4), he made a misinterpretation that could confuse learners. He used a drawing on the board indicating a soft ball falling to the ground and bouncing back up. He then drew a position-time graph displayed in Figure 5.6, but never indicated the frame of reference to learners. This is essential information for learners to interpret and understand the graph drawn. It was also observed that Mr DN continuously referred to the textbook while drawing the graph. It is evident that he is simply copying the graphs that are already available in the textbook. Mr DN mistakenly used Δy and Δt on the vertical and horizontal axes of his graph (Figure 5.6) when only "y" and "t" were needed to indicate position and time, not the change in position and change in time.

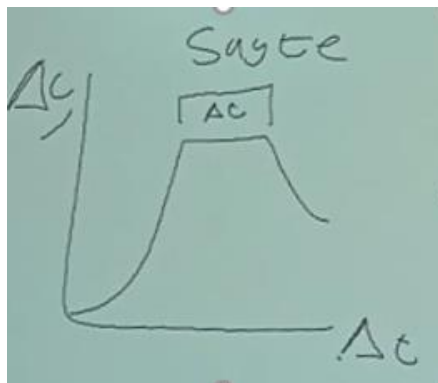


Figure 5.6: Position-time graph for bouncing ball

Mr DN did not make an effort to identify possible gaps in the learners' knowledge of the pre-concepts, and he never determined whether his learners had mastered them, which meant he could not address them if there were any. Because he did not facilitate discussions with the learners, he could not expose difficulties that the learners may have had. Although Mr DN addressed complex concepts such as the hot-air balloon problem, which often gives rise to a known misconception, he did so in a way that passed all the information to the learners and thus did not encourage any of the learners' own thinking. His lack of the ability to foster discussion with learners was evident throughout his lessons, potentially hindering critical thinking and conceptual reasoning. The first category in the rubric, *limited*, best describes Mr DN's knowledge of learner understanding.

5.1.1.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Mr DN used representations, but they were mainly limited to one type: diagrams displayed on his SMART board. Some diagrams were illustrations from the textbook, and he drew others. In Lesson 1, he mostly displayed diagrams from the textbook that were uploaded on the SMART board. In Lesson 2, he did not upload the textbook on the SMART board again. He made drawings using the drawing function of the SMART board of the same scenarios mainly used in Lesson 1.

Some of Mr DN's explanations required basic representations (which could have been his own drawings with labels) that he should have incorporated into his lesson. However, most of the ideas he referred to, which were not in the textbook, were conveyed to learners through verbal explanations and hand gestures without using representations to reinforce his explanation. For example, he used his hand when he first explained the difference between the pre-concepts of distance and displacement (Lesson 1, Section 1.3). He showed the path of motion in the air rather than drawing a diagram indicating the physical quantities at different stages of the motion. This behaviour was observed throughout Lesson 1 (Sections 1.4, 1.5, and 1.6).

It should be noted that during lesson 1, Mr DN could not use the SMART board's drawing function. He indicated that the required program was not yet installed on his laptop, and his laptop was also not calibrated. This issue was settled in Lesson 2. It could be because of this situation that Mr DN dealt differently with representations in Lesson 2 than in Lesson 1. There was, however, an ordinary whiteboard available in the classroom that Mr DN could have used to explain concepts to learners.

Figure 5.7 shows a problem example explained by Mr DN: A ball is thrown into the air and caught at the point of launch (Lesson 1, Section 1.3). While he explained the solutions, there was no representation (diagram) to which he could refer. Again, there was a whiteboard available in the classroom that could have assisted Mr DN in displaying the representation of the problem in question. Since not all learners can imagine the motion and know at what stage the information is obtained, it can be assumed that it was difficult to understand and interpret the solutions to the given problem.

2. Aanvaar dat die tyd op = tyd af, dan hoef daar slegs met die opwaartse beweging gewerk te word.

Kies op as + en af as -.

$$v_f = v_i + a\Delta t \quad 1+$$

$$0 = +20 + (-9,8)\Delta t$$

$$\Delta t = 2,04 \text{ s en die totale tyd} = 2 \times 2,04 = 4,08 \text{ s}$$

Vog 'n metode: As die bal terug is in sy hand, is die verplasing 0 m. (Waar het dit begin en waar het dit geëindig?)

Kies op as + en af as -.

$$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2 \quad 1+$$

$$0 = (+20)t + \frac{1}{2}(-9,8)\Delta t^2$$

$$\therefore 4,9\Delta t^2 - 20\Delta t = 0$$

$$\therefore \Delta t(4,9\Delta t - 20) = 0$$

$$\therefore \Delta t = 0 \text{ of } \Delta t = 4,08 \text{ s}$$

Die verplasing is 0 m by tyd 0 s en by tyd 4,08 s.

Figure 5.7: Solutions to a problem discussed by Mr DN without Representation

Figure 5.8 shows Mr DN's diagram from the textbook regarding the hot-air balloon problem (Lesson 1, Section 1.6). The problem in question is well explained in the illustration, and labels are added to indicate the physical quantities. Once again, it is observed that Mr DN relied on narration and explanation to solve the stated problem when the representation on the board was no longer visible for him as a reference.

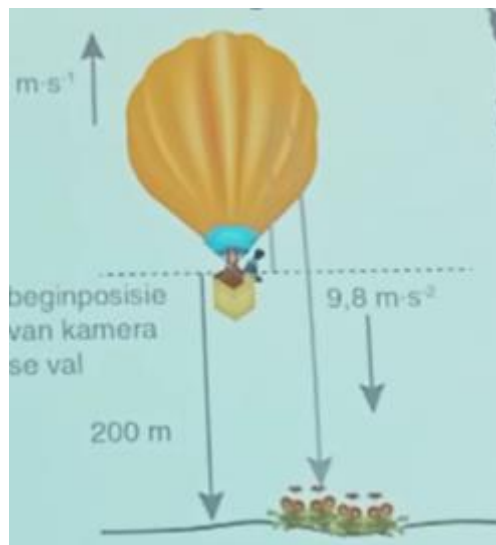


Figure 5.8: Representation of the hot-air balloon

The representations Mr DN used were related to the concepts he intended to explain, as seen in Figures 5.5, 5.6 and 5.8. The representations were clear, and learner understanding can be achieved if they are used and demonstrated correctly.

In the second lesson (Sections 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6), when Mr DN had the drawing function of the SMART board available, it enabled him to link certain concepts to his representation. This strategy allowed learners to follow the different stages of the movement and link concepts to the different stages of the movement. Figure 5.9 illustrates how Mr DN

added information to his representation (Lesson 2, Section 2.2) while explaining. On the left is the initial representation used by Mr DN, and on the right is where he added information (0 m and 10 m) after explaining and investigating the scenario.

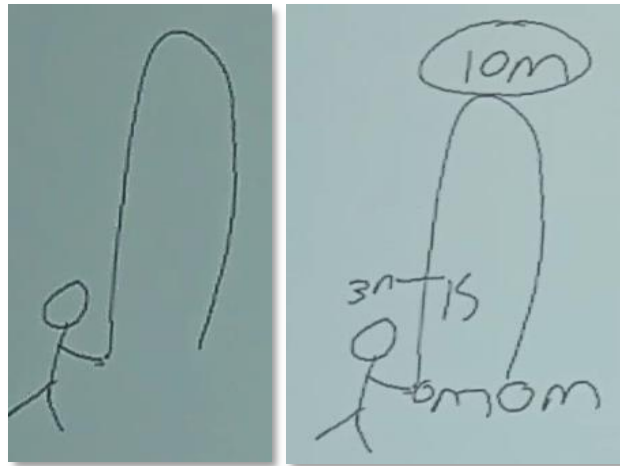


Figure 5.9: Development of the representation used by Mr DN

Mr DN explained the main ideas of the topic satisfactorily. There were instances when he linked pre-concepts to the main ideas, for example, when he indicated that gravitational acceleration is constant. He also linked Newton's first law of motion to the question of the hot-air balloon (Lesson 1, Section 1.6) and explained the importance of this pre-concept for understanding the new content. He explained pre-concepts such as acceleration, velocity, distance and displacement in the context of new examples of projectile motion, emphasising the difference between the stages of motion, as shown in Figure 5.3.

Mr DN referred to the interrelatedness of concepts during his lesson. Such an example can be found in Figure 5.3 (Lesson 1, Section 1.3) when he explained critical concepts such as initial velocity, final velocity, gravitational acceleration, displacement and distance. He explained, for example, that the velocity of an object travelling upwards decreases due to the gravitational force acting downward (in the opposite direction) on the object.

However, as I indicated earlier, one of the significant areas for improvement in Mr DN's strategy was to involve learners in discussions. His teaching required little learner participation and was highly teacher-centred. Most of the questions asked by Mr DN required yes/no or one-word answers. In the first lesson, not one section was observed where Mr DN engaged with the learners regarding any concept. This restricted opportunities for him to identify learner's difficulties or misconceptions.

The textbook used by Mr DN scaffolds examples from easy to difficult, it also includes typical problems that cause challenges for learners. Relying on the textbook, he addressed the learners' difficulties and misconceptions through procedural teaching, explaining the problem and solutions to the learners, such as the example used of the hot-air balloon (Lesson 1, Section 1.6). Instead of asking the learners what path the object will follow when it is dropped from the moving carrier, he told them it would move upwards.

A discussion took place in the second lesson (Section 2.6). Mr DN drew an object projected upwards from the top of a building, reaching its maximum height and falling past its starting point to the ground. When he explained the acceleration-time graph, he indicated constant acceleration. Because they chose the upwards motion to be positive, the graph was drawn at $-9,8 \text{ ms}^{-2}$ on the acceleration-time graph. One learner was confused and asked why the acceleration-time graph did not change like the other graphs. Mr DN explained that it is because the gravitational acceleration is constant, and the gravitational force acts down on an object. The learner struggled to understand, and Mr DN used force diagrams in different instances to strengthen his explanation, indicating that the acceleration is downward. He explained that if they chose downwards as positive, the graph would have been drawn at $+9,8 \text{ ms}^{-2}$. He also said: "Make use of the same sign throughout the question." This is a good example of the teacher's knowledge of the learner's understanding of science.

Mr DN had a workable teaching strategy, but due to his lack of experience, he presented highly teacher-centred lessons. He was able to explain the main ideas and the interrelatedness between concepts. However, he could have managed to engage learners in discussions, but most of his questions required one-word answers. The representations were relevant to the examples and concepts explained but used ineffectively to engage with the learners and specific concepts. Especially when he initially discussed relevant concepts and explained calculations, there were no concrete representations and the representations he later used did not support conceptual development. Therefore, Mr DN's knowledge and skills related to conceptual teaching strategies is best described by the rubric's first tier: *limited*.

5.2 CASE STUDY 2 – Ms NJ

Ms NJ was confident about the content she presented to her learners. She prepared well for the lesson; she had two posters ready in the classroom specifically designed for this lesson. The posters contained important ideas Ms NJ wanted to emphasise. She presented the whole lesson mostly standing by the board and hardly moving around. She used a chalkboard for all her representations, which were chalkboard drawings and calculations.

After her explanations, she expected learners to complete exercises handed to them on a separate sheet. It should be remembered that Ms NJ never taught physics in Grade 10 or Grade 11 before.

I observed and video-recorded two of her lessons on vertical projectile motion. Four sections were identified in her first lesson (Figure 5.10), briefly described below. The complete lesson narrative can be found in Appendix O.

Section	Description	Time
1.1	Ms NJ started her lesson by defining a projectile and free-fall. She introduced the concept of the gravitational force.	6 min 15 s
1.2	She introduced new concepts such as free-fall, the velocity of an object at maximum height, time symmetry, equal magnitude of velocity at the same position and the initial velocity of a dropped object from a moving carrier.	14 min 40 s
1.3	She explained the variables found in the equations of motion and how to select a suitable equation.	5 min 37 s
1.4	She discussed an example with the class on determining the displacement of an object thrown upward from the top of a building and falling to the ground.	22 min 24 s

Figure 5.10: Four sections identified during Ms NJ's first Lesson

Lesson 2 has been divided into six sections, which are briefly described below (Figure 5.11). The complete lesson narrative can be found in Appendix R.

Section	Description	Time
2.1	She introduced the graphs of motion (velocity-time graph) using a scenario where an object was dropped from the top of a high building.	9 min
2.2	She explained gravitational acceleration using the scenario mentioned in 2.1.	3 min
2.3	She explained the position-time graph using the scenario described in 2.1.	6 min 50 s
2.4	She explained the velocity-time graph to learners in terms of an object thrown upward from the top of a building and falling to the ground.	15 min 45 s
2.5	She explained the position-time graph using the scenario described in 2.4.	4 min 43 s
2.6	She explained the acceleration-time graph using the scenario described in 2.4.	1 min 59 s

Figure 5.11: Six sections identified during Ms NJ's second lesson

5.2.1 ANALYSIS OF MS NJ'S LESSON

5.2.1.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

Ms NJ spent little time explaining or revising pre-concepts during her lessons but referred to the following pre-concepts throughout her lessons: gravitational force (Lesson 1, Section 1.1), the normal force (Lesson 1, Section 1.1), frictional force (Lesson 1, Section 1.1), tension (Lesson 1, Section 1.1), velocity (Lesson 1, Section 1.1; 1.2) (Lesson 2, Section 2.1), frame of reference (Lesson 1, Section 1.1; 1.2; 1.4 and Lesson 2, Section 2.1; 2.3; 2.4), equations of motion (Lesson 1, Section 1.3), Cartesian plane (Lesson 1, Section 1.3), gravitational acceleration (Lesson 2, Section 2.2), gradient (Lesson 2, Section 2.1), area (Lesson 2, Section 2.4).

In some cases, Ms NJ only mentioned the pre-concepts and never elaborated or explained them, e.g. normal force (Lesson 1, Section 1.1), frictional force (Lesson 1, Section 1.1), tension (Lesson 1, Section 1.1). The expert CoRe mentioned pre-concepts that Ms NJ neglected in her lessons. For instance, she did not revise the difference between distance and displacement, which are critical concepts in vertical projectile motion. It may be because Ms NJ was yet to teach physics in Grade 10.

One of the pre-concepts Ms NJ devoted much time to was the frame of reference being used. Throughout her lessons (Lesson 1, Section 1.1, 1.2, 1.4 and Lesson 2, Section 2.1, 2.3, and 2.4), she emphasised the significance of selecting a positive direction of motion. Ms NJ made a poster containing the four equations of motion and explained the meaning of each variable and the units in which that variable is measured. She indicated to learners that the variable "x" represents the horizontal position and the variable "y" represents the vertical position of an object.

An instance where Ms NJ revealed her knowledge of curricular saliency was in Lesson 2, Section 2.2 and Section 2.4, where she explained the pre-concepts and interrelatedness between the three graphs of motion. She demonstrated the mathematical relationships between the graphs by explaining to learners that the gradient of the velocity-time graph represents the object's acceleration for that time interval and that the area between the velocity-time graph and the x-axis represents the object's displacement for that time interval. It should, however, be noted that Ms NJ did not indicate to learners what the gradient of the position-time graph and area of the acceleration-time graph represent.

Ms NJ's lessons focused on starting and explaining the new concepts related to the vertical projectile motion topic. It is common for teachers to first focus on the relevant pre-concepts before beginning with new concepts. This was observed in her introduction (Lesson 1,

Section 1.1) when she explained the difference between free fall and a projectile according to the examination guidelines released by DBE. She wrote two definitions on the board: (a) Projectile: An object given an initial velocity and then moved only under the influence of gravitational force. (b) Free fall: Motion during which the only force acting on an object is the gravitational force. This distinction between the two is superficial since her definition of a projectile describes a free-fall motion. Clearly, Ms NJ focused on these two definitions due to the examination guidelines and the probability of them being asked in the examination.

Ms NJ displayed good knowledge of the curricular saliency of the topic in developing a poster containing critical concepts regarding vertical projectile motion for her classroom. The poster can be seen below in Figure 5.12.

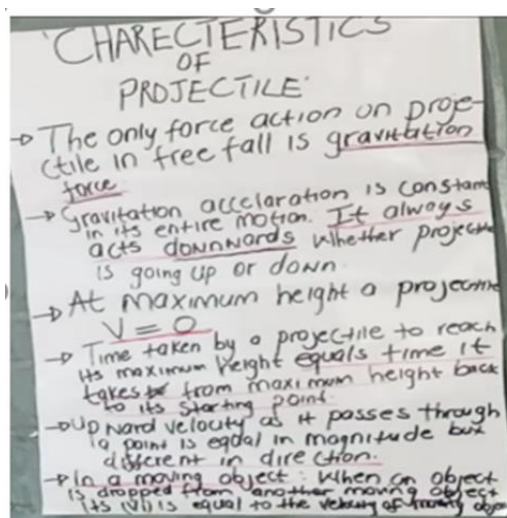


Figure 5.12: Important concepts Ms NJ included on her poster

Ms NJ included and explained six new and important concepts on her poster (Lesson 1, Section 1.1):

- 1 The only force acting on a projectile is the gravitational force.
- 2 Gravitational acceleration is constant in its entire motion. It always acts downwards whether the projectile is going up or down.
- 3 At maximum height, the velocity of a projectile is zero.
- 4 A projectile's time to reach its maximum height equals the time it takes from its maximum height back to its starting point.
- 5 The upward velocity of an object as it passes through a point is equal in magnitude but in different directions.
- 6 In a moving object (carrier): When an object is dropped from another moving object, its initial velocity is equal to the velocity of the moving object.

It is important to note that in Point (2) on her poster, she indicated that gravitational acceleration acts downward on an object, whereas gravitational acceleration is not a force and cannot act on an object; only the gravitational force can act on an object.

She explained points (3), (4), and (5) mentioned above using a diagram which can be seen below in Figure 5.13 (Lesson 1, Section 1.2)

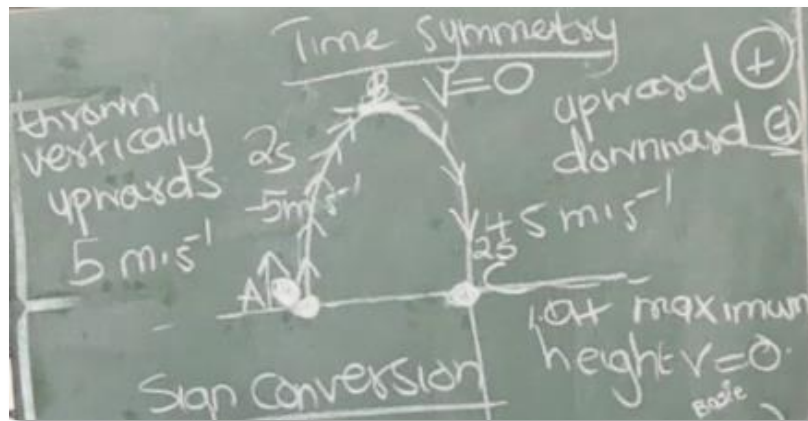


Figure 5.13: Diagram Ms NJ used to explain the concepts on her poster

She used the example of a ball thrown vertically upwards, reaching maximum height, and ending again at its starting point. She indicated point A as the starting point with an initial velocity of 5 m.s^{-1} . As she followed the diagram to maximum height (point B), she indicated that the object's velocity decreased until it reached its maximum height, where the velocity would be 0 m.s^{-1} . She indicated that the object accelerated back down, and the velocity was -5 m.s^{-1} when it reached the same position from where it was launched (point C).

At this point, she explained what she called “sign conversions” to learners and said: “The upward or downward direction should be selected as the positive direction, and we call this sign conversion”. It is clear from the above quote that she meant sign convention and not conversion. Ms NJ encouraged learners to use the same direction the object initially travels in as the positive direction. She also expanded her explanation, indicating to learners that they are working with vertical projectile motion (emphasising the word vertical), which means it is an up-and-down motion. Because they have chosen the upward movement to be positive, all motions in an upward direction are positive, and all motions in a downward direction are negative. Ms NJ then explained time symmetry and pointed out that if it takes the ball two seconds to reach its maximum height from the point of launch, it will take two seconds to fall from maximum height to the point of launch.

Other relevant concepts that Ms NJ referred to in her lesson that does not appear on the poster include: (a) the initial velocity of a dropped object is zero (Lesson 2, Section 2.1), (b)

projectile motion occurs in the absence of air resistance (Lesson 1, Section 1.4) (c) horizontal (Δx) and vertical (Δy) displacement (Lesson 1, Section 1.3) (d) projectile motion can be described by a single set of equations (Lesson 1, Section 1.3).

Ms NJ explained many relevant concepts regarding the topic of vertical projectile motion. Concepts are sequenced logically, and interrelatedness is explained. It is, however, noted that Ms NJ did not focus much on explaining pre-concepts and, in some cases, only mentioned them. Therefore, the second tier in the rubric describes Ms NJ's knowledge about curricular saliency the best, namely, *developing*.

5.2.1.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

Ms NJ referred to many pre-concepts, as seen in the previous section. However, she did not explore learners' knowledge and understanding of relevant pre-concepts and opportunities created for discussion were limited.

In her first lesson (Section 1), she asked learners: "Why, when we throw an object up, it always comes back down?" and the learners responded with: "Gravitational force" Ms NJ agreed with the answer. This was the only question posed by Ms NJ during Lesson 1.

The lack of interaction between Ms NJ and the learners limited the opportunities to discuss and expose learner difficulties. Ms NJ did, however, provide opportunities for learners to ask questions if they needed clarification on anything. This led to the following two instances where learners asked questions about difficulties they experienced.

The first was when a learner asked (Lesson 1, Section 1.4) for other options to solve projectile motion questions regarding the sequence in which the equations of motion are used and if it is possible to use more than one equation. Ms NJ responded that if the information was available, other equations could be used to solve the problems. She proceeded by solving the problem with more than one equation as described by the learner to show the class that other options will produce the same answer. This response will assist the learner's understanding.

The second instance was observed (Lesson 2, Section 2.5) after Ms NJ finished her position-time graph of an object thrown upward from the top of a building and falling back to the ground, using the upward motion as positive. A learner asked: "Will the graph be almost the same if we chose downward as positive?" Ms NJ responded, "If you choose downward as positive, your graph is going to be sort of a reflection of what is happening this side [pointing to the original graph]". Ms NJ then drew the mirror image of her first graph,

indicating how the position-time graph would look if the opposite direction (downward) was chosen as the positive direction. Although her response resolved the question, more is needed to assist the learner in understanding the specific concepts and skills required for drawing the graph. This was an opportunity for Ms NJ to relate the object's motion to the graph using the different sign conventions and expand and rephrase the solution.

Ms NJ made a mistake and reinforced a known misconception when she drew the position-time graph discussed earlier and illustrated in Figure 5.14. She drew the last part of her graph using a straight vertical line instead of a line following a parabolic function, creating the impression that the object falls to the ground in an instant. This graph also creates the impression that the shape of the position-time graph corresponds with the path of the object, which is a known misconception. This caused a learner to ask: "Why is there a straight line back to the ground?" Ms NJ was initially unsure in her response but then indicated that she should improve her drawing ability and that the line should not be straight down. She then corrected her mistake, using a curved line back to the horizontal axis.

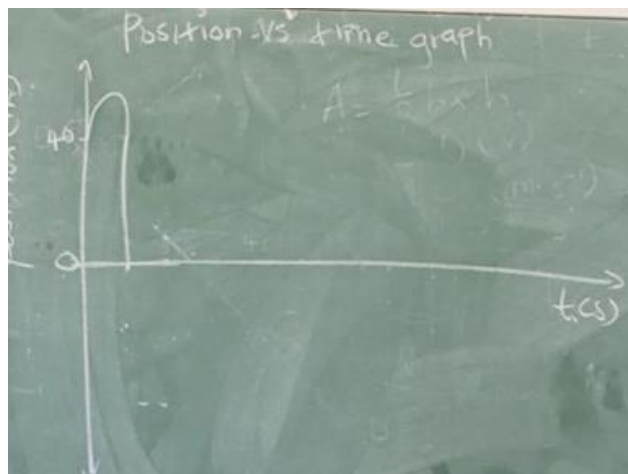


Figure 5.14: Ms NJ's first attempt drawing the position-time graph

Ms NJ paid attention to some misconceptions and learner difficulties. The first was when she explained that the gravitational force is the only force acting on a projectile (Lesson 1, Section 1.1). She also used the definitions of a projectile and free fall obtained from the examination guidelines to emphasise it. On numerous occasions, she illustrated that the velocity of an object at maximum height is zero (Lesson 1, Section 1.2; 1.4 and Lesson 2, Section 2.4), and this was also point number three on her poster (Figure 5.12). Furthermore, she explained that the gravitational acceleration of an object in free fall will always be $9,8 \text{ ms}^{-2}$ downward (Figure 5.12) (Lesson 2, Section 2.2; 2.6), and she showed learners that an object dropped from a carrier moving upward will not fall straight down immediately after release (Figure 5.12 and Figure 5.13) (Lesson 1, Section 1.2). She taught learners how to

interpret the area and gradient of the velocity-time graph but never referred to what the area of the acceleration-time graph and gradient of the position-time graph represent.

Discussions initiated by Ms NJ were minimal and needed to be more elaborate in dialogue with her learners. As discussed earlier, the learners, rather than the teacher, initiated the discussions. Ms NJ referred to many pre-concepts throughout her lessons but failed to explore learners' knowledge and understanding of those pre-concepts. Because she seldom facilitated discussions with learners, the opportunities were limited to uncover gaps and challenges in learners' prior knowledge and to establish if they were on track with the new content taught. Ms NJ paid attention to some general misconceptions and learner difficulties. She also addressed those using standard definitions and did not expand and rephrase the solutions to the difficulties or misconceptions. Therefore, the first tier in the rubric describes Ms NJ's knowledge and skills related to the learner's understanding of science the best, namely, *limited*.

5.2.1.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

The representations Ms NJ used throughout her lessons were restricted to mainly one type—diagrams drawn on the chalkboard. There were limited instances where she utilised any other types of representations. One such instance was at the beginning of Lesson 1 (Section 1.1) when she threw her pen into the air and indicated to learners that the pen was falling back down because the force of gravity is the only force acting on the object.

Ms NJ utilised a diagram (Figure 5.13) to clarify the concepts that were displayed on her poster (Figure 5.12). Her explanation of the connections between the concepts was clear and coherent. Additionally, she incorporated other diagrams (Lesson 1, Sections 1.2; 1.4 and Lesson 2, Section 2.1; 2.4) to illustrate the concepts further, which included initial velocity, final velocity, maximum height, sign conventions, gravitational acceleration, and change in time. Ms NJ linked the information from various questions and examples to her representations. However, her diagram (Figure 5.15) could have confused learners.

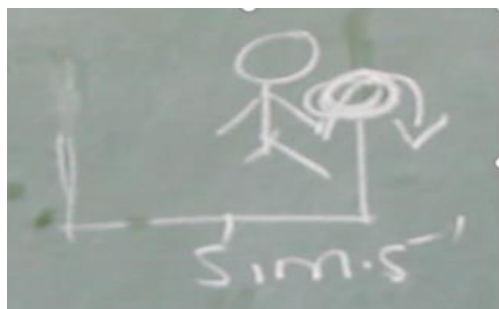


Figure 5.15: Diagram used to explain the concept of an object dropped from a moving Carrier

Ms NJ used the diagram in Figure 5.15 to explain the problem of the hot-air balloon. In this scenario, an object is dropped from a carrier moving upward at a constant velocity. Learners needed to know that the object will have the same initial velocity as the moving carrier and, therefore, will move upwards and then fall to the ground. From her diagram (Figure 5.15), it looks like the object was thrown overboard and not released from rest. Also, the diagram could be more neat and clear. The circled part represents the object, and the curved line from the person's hand represents the object's motion. Learners often find this concept difficult to understand, and where learner misconceptions are evident, it is vital to make sure the representations do not cause misconceptions.

The teacher can use questions to identify learner difficulties or misconceptions. During Lesson 2, she asked more questions and attempted to facilitate more discussions. During Section 2.1, when she introduced a class exercise, she asked an important question: "When an object is dropped, what is it that we know?" The learners responded and said: "The velocity is zero". Ms NJ agreed and added that it was because the object was at rest. Not long after, she asked another question, enquiring about what learners thought would happen to the velocity of an object after it is dropped. The learners responded with: "Increase".

During Lesson 2, Section 2.2, Ms NJ asked a question about the gravitational acceleration of a dropped object. She presented two options: 9.8 and -9.8. The class chose 9.8, which Ms NJ wrote on the graph in Section 2.1 without further explanation. This question was deemed less successful as learners were already familiar with the sign convention, which Ms NJ had indicated prior to asking the question. In Section 2.4, she asked a good question that was intended to assess learners' understanding of time-symmetry. However, she never allowed learners to respond and immediately answered the question herself.

She explained the main ideas of the topic satisfactorily. There were instances where she linked pre-concepts to the main ideas, which were also effectively linked to her representations (drawings). Such an example (Figure 5.16) is where she discussed the first class exercise (Lesson 1, Section 1.4). Ms NJ used Figure 5.16 to illustrate the relationship between initial velocity, final velocity, and height in projectile problems, using the key points ($A \rightarrow D$) along the motion path of the object.

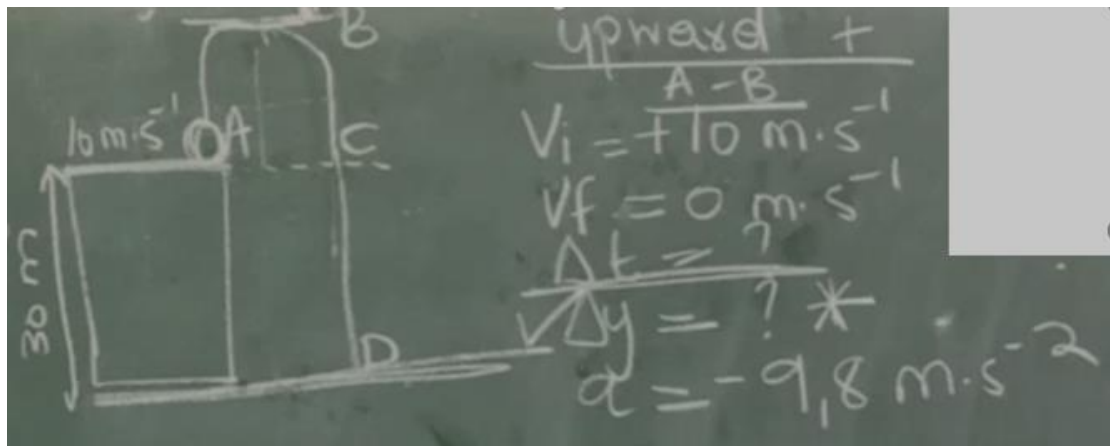


Figure 5.16: Ms NJ linking the different stages of motion to concepts

On more than one occasion (Lesson 1, Section 1.4) (Lesson 2, Section 2.1), Ms NJ emphasised that learners should read their questions carefully to ensure they understand and interpret the questions posed to them. Her examples were demonstrated using diagrams to help learners interpret the scenario. She also divided the object's motion into sections using alphabet letters. These alphabet letters were indicated on the diagrams and served as reference points, e.g. Figure 5.16.

She explained some of the examples using both directions as positive (Lesson 1, Section 1.2) (Lesson 2, Section 2.5). This strategy taught learners that more than one reference frame can be chosen in a given scenario. She indicated that learners must choose a direction of motion to be positive (Lesson 1, Section 1.2; 1.4) (Lesson 2, Section 2.1; 2.3; 2.4; 2.5). She advised them: "Choose the direction in which the object is moving as positive", meaning that learners should choose the initial direction of motion as positive (Lesson 1, Section 1.2). It was good to observe that Ms NJ did not enforce a certain reference frame on learners but encouraged them to choose any direction to be their positive direction as long as they kept to it throughout the question (Lesson 1, Section 1.4).

Ms NJ attempted to give learners a strategy (Lesson 1, Section 1.3) to follow so that they could solve vertical projectile motion problems successfully using the equations of motion. She displayed the four equations of motion on the board in front of the class and explained to learners that each equation had a missing variable. She used the example of $v_f = v_i + a\Delta t$ and said this equation does not have displacement (Δy). She then advised learners to look for the variable that is asked and keep in mind which variable is missing, which will assist them in choosing a suitable equation to solve the problem. Ms NJ worked through vertical projectile problems with learners (Lesson 1, Section 1.4) using the equations of motion; she implemented the strategy describing solving the problems step-by-step with learners.

Ms NJ explained the main ideas satisfactorily and referred to the interrelatedness between concepts. One area in which she needed improvement was the type of questions she asked learners. Her questions mainly focused on rote learning and lacked higher-order thinking questions. She addressed misconceptions and learner difficulties through procedural teaching, which required limited involvement of learners. One type of representation was mainly used in drawings to explain relevant concepts. Both lessons from Ms NJ were highly teacher-centred and could be described as a traditional chalk-and-talk teaching method. The category that best describes Ms NJ's teaching strategy is *developing*.

5.3 CASE STUDY 3 – Mr JP

During the lesson observation of Mr JP, he seemed ill at ease, which can be ascribed to either the presence of the researcher or the fact that it was the first time he presented this content or both. He presented the lessons in English, which is his second language. It was noticed that he was caught off guard by particular examples. He incorporated technology in the form of PhET simulations into his lesson and used the blackboard in front of the classroom. He presented the lessons mostly standing by the board and hardly moving around. In his second lesson, he offered treats as a reward to learners who tried to answer his questions. He gave learners homework after each lesson. This was the first time Mr JP taught vertical projectile motion and his first year teaching Grade 10 and 11 classes.

I observed and video-recorded two of his lessons on vertical projectile motion. He presented other lessons in between the two recorded lessons, and he presented lessons after his second lesson was recorded. All of the mentioned lessons were about vertical projectile motion. Six sections were identified in his first lesson, briefly described in Figure 5.17 below. The complete lesson narrative can be found in Appendix M.

Section	Description	Time
1.1	He introduced the vertical projectile motion concept and the importance of gravitational force.	4 min 05 s
1.2	He explained the difference between the pre-concepts displacement and distance.	10 min 15 s
1.3	He revised the pre-concepts of initial and final velocity.	1 min 20 s
1.4	Mr JP demonstrated projectile motion using a PhET simulation and attempted to solve projectile problems with the class using the equations of motion and pointing out critical concepts within the topic of vertical projectile motion.	11 min 08 s
1.5	He did an example from the textbook of a ball dropped from a high building.	9 min 44 s
1.6	He did another example from the textbook involving a ball projected upwards.	8 min 56 s

Figure 5.17: Six sections identified during Mr JP's first Lesson

Lesson 2 has been divided into five sections, briefly described in Figure 5.18 below. The complete lesson narrative can be found in Appendix P.

Section	Description	Time
2.1	He introduced the three graphs of motion. He started to explain the acceleration-time graph.	8 min 25 s
2.2	Mr JP explained the position-time graph of an object thrown upward and falling back to the point of launch.	15 min 10 s
2.3	He explained what the gradient of the position-time graph drawn in section 2.2 represents.	11 min 50 s
2.4	Mr JP interpreted a position-time graph already drawn. The graph was drawn for an object dropped from a certain height and bounced back to the same height it was dropped.	6 min 55 s
2.5	He explained how to draw the velocity-time graph of an object thrown upward and falling back to the point of launch.	5 min 21 s

Figure 5.18: Five sections identified during Ms JP's second lesson

5.3.1 ANALYSIS OF MR JP'S LESSON

5.3.1.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

Mr JP referred to the following relevant pre-concepts throughout his lessons: momentum (Lesson 1, Section 1.1; 1.4; 1.3; 1.5), gravitational force (Lesson 1, Section 1.1), gravitational acceleration (Lesson 1, Section 1.4 and Lesson 2, Section 2.1), Newton's law of universal gravitation (Lesson 1, Section 1.1), equations of motion (Lesson 1, Section 1.2) displacement (Lesson 1, Section 1.2 and Lesson 2, Section 2.2), velocity (Lesson 1, Section 1.2), vector and scalars (Lesson 1, Section 1.2; 1.4), distance (Lesson 1, Section 1.2), change in velocity (Lesson 1, Section 1.3), sign convention (Lesson 1, Section 1.4; 1.5; 1.6 and Lesson 2, Section 2.1; 2.2; 2.4), metric units (Lesson 1, Section 1.6), dependent and independent variables (Lesson 2, Section 2.1), gradient (Lesson 2, Section 2.3; 2.4) and tangent (Lesson 2, Section 2.3; 2.4).

He spent much of his time explaining the difference between displacement and distance (Lesson 1, Section 1.2), and displaying knowledge and skills related to curricular saliency. These concepts are also considered in the expert CoRe as pre-concepts that should be explained. He revised the definition of displacement, writing the following on the board: "It is the body's change in position". He then alluded to the critical fact that displacement is a vector quantity and is described by magnitude, direction and units of measurement. In contrast, distance is a scalar quantity and does not depend on direction.

Mr JP then wrote on the board:

"To know displacement, you must know the straight-line distance between the reference point, the new position, and the direction in which the body has moved."

This comment is a good description of displacement and the importance of the vector characteristics. To illustrate this statement, Mr JP used the following two examples he drew on the board (Figures 5.19 and 5.20).

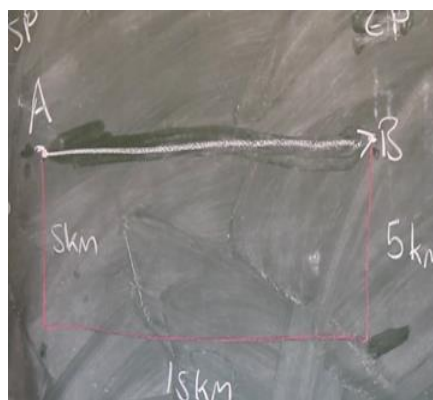


Figure 5.19: First diagram used by Mr JP to explain the difference between displacement and distance

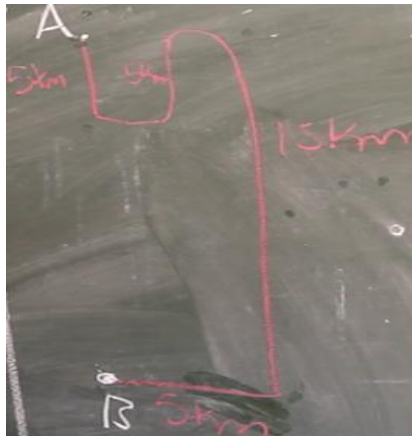


Figure 5.20: Second diagram used by Mr JP to explain the difference between displacement and distance

Using Figure 5.19, he explained that the distance is the total path length (25 km), and displacement is the straight-line distance between the two reference points A and B, which is 15 km. In an attempt to include vertical motion, he used Figure 5.20 (Lesson 1, Section 1.2), in which he demonstrated the use of both horizontal and vertical lines, potentially complicating the focus on vertical motion displacement within a single dimension.

Mr JP referred a few times during his first lesson to the concept of momentum (Lesson 1, Section 1.1; 1.3; 1.4; 1.5), which was the preceding Grade 12 topic. He discussed the pre-concepts in general, and momentum was merely mentioned as a topic where the pre-concept under discussion was last used. For example, Mr JP reminded learners about an object's velocity change. This change is calculated by subtracting an object's initial velocity from its final velocity, just as in momentum.

Another pre-concept Mr JP devoted much time to was sign conventions (Lesson 1, Section 1.4; 1.5; 1.6 and Lesson 2, Section 2.1; 2.2; 2.4). Throughout his lessons, he indicated the importance of choosing a direction of motion to be positive. When he did an example from the textbook (Lesson 1, Section 1.5), he told learners: "The first thing we need to do is select a direction of motion to be positive". He indicated this selection each time on the board next to his diagrams, which represented the motion of objects described in the examples.

During Lesson 2 (Section 2.3), Mr JP focused on interpreting the slope of the position-time graph, highlighting that the gradient of the position-time graph represents the object's velocity for that given instant. He demonstrated how to calculate the gradient mathematically and emphasised understanding curved lines by explaining the concept of tangents to the curved lines and how they will represent the object's instantaneous velocity. Though he didn't delve into numerical values, he focused on illustrating differences in tangent gradients

to convey changes in velocity. However, he omitted discussion on the area and gradient of the velocity-time graph and the area of the acceleration-time graph.

Mr JP displayed good knowledge of the topic's curricular saliency when he explained critical concepts regarding vertical projectile motion. He started his first lesson (Lesson 1, Section 1.1) by referring to the definition of a projectile. He read from the textbook: "The motion of an object that is straight upwards or straight downwards when the only force acting on the object is the gravitational force". In doing so, he highlighted that the gravitational force is the only force acting on a projectile and that it will only work with problems consisting of up and down movements. These comments correspond with the CAPS document, which stipulates that only motion in one dimension is considered in Grade 12 vertical projectile motion problems. He then explained the term free fall (Lesson 1, Section 1.1) and emphasised that objects in free fall have only the force of gravity acting on them.

He alerted learners that the velocity of an object would be zero when it reaches maximum height (Lesson 1, Section 1.4). He elaborated and indicated the importance of this concept when he said: "This is something you will encounter a lot in the topic of vertical projectile motion". This comment can be considered evidence of the teacher's understanding of the topic and related issues since this information is not explicitly provided in the questions. When dealing with his first problem-solving question (Lesson 1, Section 1.4), he indicated that the gravitational acceleration is always a constant value of $9,8 \text{ ms}^{-2}$ in a downward direction and does not change. He emphasised this during his second lesson (Section 2.1) when he revealed that the acceleration-time graph does not change and remains constant.

Other relevant concepts explained by Mr JP were time symmetry and its implication for the object's velocity (Lesson 1, Section 1.4). After calculating the time the ball took to reach its maximum height from the position it was launched, he indicated that the ball would take the same amount of time to fall from a maximum height back to its starting position. Using the same example, Mr JP also explained that the ball's velocity at the point of launch would be equal in magnitude to the ball's velocity when it reaches the same position upon its return but in the opposite direction. In Lesson 2 (Section 2.2), Mr JP indicated that the displacement of an object would be zero when it reached the same position again from where it was launched.

As explained, Mr JP referred to many new relevant concepts. However, he failed to mention one specific concept in his two lessons: the initial velocity of an object dropped from a moving carrier travelling in an upward direction. The object will initially move upward with the same initial velocity as the carrier before it falls to the ground. This concept is crucial to know

and understand since it influences learners' conceptual reasoning when dealing with such problems.

Other relevant new concepts that Mr JP referred to included:

- The initial velocity of an object at rest is zero (Lesson 1, Section 1.3)
- In the Grade 12 topic, projectile motion occurs in the absence of air resistance (Lesson 1, Section 1.1)
- Horizontal (Δx) and vertical (Δy) displacement (Lesson 1, Section 1.2)
- Projectile motion can be described by a single set of motion equations (Lesson 1, Section 1.2)

Mr JP referred to many pre-concepts during his lessons. However, he verified learners understanding and knowledge of only a few of these pre-concepts. Mr JP sequenced his concepts logically. He explained relevant pre-concepts and then moved on to new concepts, where he explained the interconnections between the pre-concepts and new concepts. As explained, he omitted some crucial concepts. The second category in the rubric describes his knowledge of curricular saliency the best, namely *developing*.

5.3.1.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

As discussed in the previous section, Mr JP mentioned many pre-concepts but emphasized displacement and distance (Lesson 1, Section 1.2). Mr JP seemed to lack knowledge about learners' understanding and how they learn because information regarding pre-concepts was spoon-fed to the learners. Such instances were observed in Lesson 1, Section 1.2 when he merely wrote the definition of displacement on the board without discussion. Another instance was observed in Section 1.5 when he explained what it meant if air resistance was ignored. He did not use the opportunity to discuss the pre-concept of air resistance and guide them to discover that the only force acting on a free falling object is the gravitational force.

Furthermore, his questions only required one-word answers, which learners were led to most of the time when he provided a possibility of two answers, as can be seen in Lesson 1, Sections 1.1, 1.2, 1.3, 1.4, and 1.6 and Lesson 2, Section 2.2 and 2.4. Such an example is Lesson 1, Section 1.3, when he asked:

“If an object travels at a certain velocity and should come to a stop in eight seconds, will the initial or final velocity be zero?”

Questions like these do not elicit critical thinking and deprive the learners of the opportunity to reason conceptually.

Mr JP addressed specific learner difficulties and misconceptions, which included:

- The inability to distinguish between the shape of a position-time graph and the object's path
- Not using a frame of reference to interpret the question
- Confusing displacement with distance
- Incorrect sign conventions used for vectors
- Not correctly interpreting the slope of the position-time graph
- Not realising that gravity is the only force acting on an object during free fall
- Not understanding that the velocity of an object at maximum height is zero

At the beginning of his second lesson (Section 2.1), Mr JP indicated the importance of interpreting the motion graphs. He explained that “it is important to choose a positive direction of motion” to be able to draw and interpret the graphs. He said they will always choose the upward direction as positive in class, but learners should remember that the opposite direction could also be positive. Mr JP indicated that the gravitational acceleration will always be $-9,8 \text{ ms}^{-2}$ when choosing upward as the positive direction. Doing all problems treated in class by choosing upward as positive is restrictive and does not allow learners to explore using a different reference frame.

Mr JP proceeded to the position-time graph and indicated it could also be called a displacement-time graph (Lesson 2, Section 2.2). This is scientifically incorrect because learners should be reminded that they are working with the position quantities on the graph's vertical axis and could only obtain the displacement if the change in position is considered. He successfully explained (Lesson 2, Section 2.2) that the position-time graph can have different shapes depending on the motion. However, when explaining an example (Lesson 2, Section 2.4) where the shape of the position-time graph is different from the object's motion path, he was less successful because he insisted on choosing the upward direction as positive. He drew a graph from the textbook, shown in Figure 5.21.

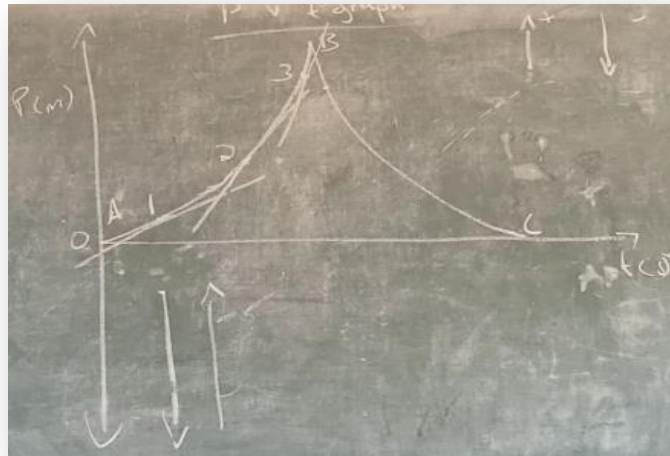


Figure 5.21: Position-time graph of a ball that is dropped and bounced back to the same height

The graph is drawn for a scenario where a ball was dropped from a certain height, allowed to bounce, and returned to its original position from where it was released. As shown in Figure 5.21, Mr JP used the gradient of the tangents in the graph, which he explained earlier in Section 2.3, to interpret the object's motion. He indicated that the ball's velocity is increasing from point A to B because the gradients of the tangents are increasing. He interpreted the motion from B to C in the same manner, saying the velocity of the ball is decreasing because the gradients of the tangent lines are decreasing. This interpretation allowed him to conclude that the ball was moving downward from A to B and upward from B to C.

Looking at the graph in Figure 5.21, the sign convention for the ball being dropped is that downward is positive. However, Mr JP made a mistake when he indicated that the upward direction is positive and the downward direction is negative because he always chooses the upward direction as positive (Lesson 1, Section 1.4): see the top right-hand corner of Figure 5.15. He also indicated this during Lesson 2 (Section 2.1) when he said: "Upward as positive direction is the notation we will use in the class". Because he indicated the upward direction as the positive direction and did not determine the positive direction from this particular graph, he became confused. Hence, he said: "There is something I am missing here; I will look at it and come back to you" (Lesson 2, Section 2.4). This comment caused confusion in the class, and learner difficulties were enhanced instead of addressed.

He made another mistake (Lesson 2, Section 2.2 and Figure 5.21) when he labelled the vertical axis of the position-time graph "p (m)" instead of "x" or "y". The letter p represents momentum, which may confuse learners when referring to the graph.

In Lesson 2, Mr DN tried to explain motion graphs, particularly the position-time graph, by starting with simple examples and gradually scaffolding to more complex ones in Sections 2.2, 2.3, and 2.4.

In summary, Mr JP mentioned many pre-concepts throughout his lessons (Lesson 1, Section 1.2), but in contrast with how he addressed distance and displacement, he merely reminded them of the other pre-concepts. Consequently, fruitful discussions that could expose learner difficulties or misconceptions were limited. As indicated earlier, he attempted to address complex concepts and some known misconceptions. Although he succeeded in some, there were times that he created opportunities where misconceptions or learner difficulties may have been created. Such an instance was when he tried to explain the position-time graph in Lesson 2, Section 2.4. In this section, his misinterpretations were evident. Therefore, from the rubric's first tier, Mr JP's knowledge of learner understanding is best described as *limited*.

5.3.1.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Mr JP made extensive use of representations. He introduced vertical projectile motion using a PhET simulation on a television screen connected to his laptop (Lesson 1, Section 1.1). He demonstrated a basic projectile movement when he threw the chalk in his hand in the air and caught it again at the point of launch. Lastly, he had drawings on the board to illustrate the examples he discussed.

Most of the representations used by Mr JP were relevant to the concepts he explained. Figure 5.22 shows the diagram Mr JP used to demonstrate the motion of a cannonball that was fired from a cannon four metres above the ground, reached the maximum height and fell to the ground.

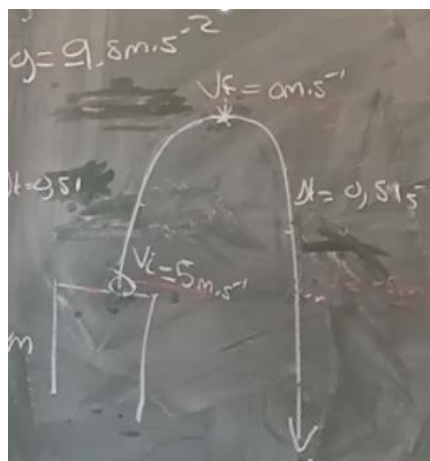


Figure 5.22: Diagram used by Mr JP to illustrate crucial concepts within the topic of vertical projectile motion

Mr JP used this diagram (Figure 5.22) to explain crucial concepts (initial velocity, displacement, gravitational acceleration, final velocity and maximum height) regarding vertical projectile motion. He indicated the different quantities on this diagram according to

the chosen reference frame. He would point at specific reference points and logically explain the interconnections between position, velocity and acceleration at those points.

However, there were instances where the representations used by Mr JP did not serve the intended purpose and could confuse learners or induce learner difficulties. Such an instance was at the beginning of Lesson 1 (Section 1.1) when he used a PhET simulation on a television screen connected to his laptop of a cannon shooting a ball into the air. The representation can be seen in Figure 5.23.



Figure 5.23: Representation used to illustrate the motion of a projectile fired from a cannon

It is clear from the CAPS document that only one dimension of motion is considered in Grade 12 vertical projectile motion problems. From Figure 5.23, it is clear that the object's motion is in two dimensions. Mr JP used the same simulation to explain and demonstrate to learners the vector properties of the velocity concept, which can be seen in Figure 5.24.



Figure 5.24: Representation used to demonstrate the velocity of an object fired from a cannon

He included the green vector arrow in this simulation, displaying the direction and magnitude of the object's velocity. In this manner, learners could see that the object's velocity decreases as it moves upward and increases as it moves downward. Once again, he used

two dimensions for this simulation instead of one. This meant the velocity would never reach zero, whereas, in one dimension, the velocity would reach zero at maximum height. This could confuse learners because they can see the green arrow never becoming zero when reaching maximum height. Mr JP also did not explain that the vertical component of velocity becomes zero but not the horizontal component.

He could have made the angle of the projection 90 degrees, and then it would have shown vertical projectile motion. Although PhET simulations, when used correctly, can help support the discussion on concepts, they were at times futile in Mr JP's lessons as they supported the discussion of motion in two dimensions.

He explained the main ideas of the topic satisfactorily. There were instances where he linked pre-concepts to the main ideas, which were also effectively linked to his representations (drawings). Such an example can be seen in Figure 5.22, where he discussed his first example (Lesson 1, Section 1.4). He used Figure 5.22 to illustrate the relationship between initial velocity, final velocity, and height in projectile problems, which learners must understand. During lesson one, he emphasised critical points along the object's motion path; in lesson two (Section 2.2), he used alphabet letters ($A \rightarrow C$) to emphasise these key points. This is an example of Mr JP's improved knowledge and skills related to his teaching strategies after his first lesson.

Mr JP seldom incorporated questions in his lessons to stimulate conceptual reasoning, mainly because his questions required one-word answers and rote learning. At one stage, he even ignored a wrong answer given by a learner (Lesson 1, Section 1.1). Ignoring wrong answers deprives the teacher of identifying possible learner difficulties or misconceptions, which can lead to more effective teaching outcomes when addressed. He guided learners to the answers by giving them options to choose from. For instance (Lesson 1, Section 1.3), he stated: "If an object starts from rest, it means the final or initial velocity would be zero" and then asked, "If an object travels at a certain velocity and should come to a stop in eight seconds, will the initial or final velocity be zero?" Similarly, in Lesson 2, Section 2.4, he asked, "Is the gradient of the line increasing or decreasing?" It is clear from the analysis that Mr JP still needs to acquire the ability to facilitate meaningful conceptual discussions through the questions he poses.

In Lesson 1, Section 1.5, Mr JP advised learners to read their questions multiple times to ensure they comprehend the situation. He implemented a teaching technique where he would have three learners read the question aloud before attempting to solve or interpret it. This strategy helped them to understand the problem better before attempting to solve it. Mr

JP would then draw a diagram on the board to visually represent the scenario and connect the given information to the diagram at the appropriate reference points. He did not use alphabet letters to distinguish between reference points during his first lesson. He only started using them in his second lesson. As discussed earlier, Mr JP indicated to learners that they will always choose the upward direction as positive when dealing with problems in class (Lesson 2, Section 2.1). This strategy could confuse learners and, in fact, the teacher himself, as was the case when he tried to interpret the position-time graph (Lesson 2, Section 2.4).

To solve vertical projectile problems using equations of motion, Mr JP employed the following strategy. He wrote the information available on the board and asked which equation they thought would work best to solve the problem. After identifying the equation, he would substitute the values and solve the problem, emphasising the importance of direction if the answer is a vector (Lesson 1, Sections 1.4, 1.5, and 1.6). This instance can be seen in Lesson 1, Section 1.6 when he calculated the final answer (maximum height) and only wrote the magnitude on the board. He asked: "Is this our final answer?" to which learners responded: "No, the final answer should include direction".

Mr JP explained the main ideas satisfactorily and referred to the interrelatedness between pre-concepts and new concepts. One area in which he needed improvement was the type of questions he asked learners. His questions mainly focused on rote learning. He also ignored a wrong answer and frequently gave learners possible answers to choose from when asking questions. I considered this as evidence that he could not formulate higher-order reasoning questions, and this caused his lesson to be highly teacher-centred. He tried to address misconceptions and learner difficulties through procedural teaching, which caused him to misinterpret a question. The category that best describes Mr JP's teaching strategy is *limited*.

CHAPTER SIX

PERSONAL PCK AFTER TEACHING THE TOPIC FOR THE FIRST TIME

In this chapter, I present the data and analysis of the pPCK of the three teachers after they have taught the topic of vertical projectile motion for the first time. Each teacher completed the CoRe tool on *vertical projectile motion*, the same as the one they completed before teaching the lessons. Henceforth, this CoRe will be referred to as the post-CoRe. Responses to the post-CoRe prompts were strengthened by a video-stimulated recall (VSR) interview with each participant a few days after presenting their lessons.

The data analysis focused on the differences in participants' responses between their pre-CoRe and post-CoRe. To construct their post-CoRes, the teachers used their pre-CoRes as bases and made changes where they saw fit. To evaluate their pPCK, I looked for differences between the pre- and post-CoRe responses, such as additions or removals of responses to the prompts in the pre-CoRes. The added responses in the post-CoRe are highlighted for easy identification (see appendices D to F). In the reported cases, teachers found it daunting to complete the CoRe tool, a challenge that has been reported in other PCK studies (Mazibe et al., 2020). Therefore, the VSR interviews (see appendices J to L) were used to clarify and supplement the information provided in the post-CoRe. This allowed teachers to reflect on their lessons and verbally articulate their pPCK. The VSR interviews also assisted in identifying aspects of the lessons that resulted in changes in the pPCK of the teachers, as revealed in the post-CoRe.

The data from each teacher, consisting of the post-CoRe responses and the VSR interviews, are presented case by case. As with the pre-CoRes, the expert CoRe served as a gauge for evaluating responses from the teachers. The responses given in the expert CoRe are extensive but not exhaustive, and therefore other inclusions and interpretations by the participants were considered. Figure 3.4 indicates how the CoRe prompts align with the PCK components from the grand rubric.

The teachers' responses to the prompts in the post-CoRe tool were scored using the same rubric for pPCK that was used when scoring the responses in the pre-CoRe, focusing on the first three components in the grand PCK rubric (Chan et al., 2019), namely (1) Knowledge and skills related to curricular saliency, (2) Knowledge and skills related to conceptual teaching strategies, (3) Knowledge and skills related to student's understanding of science.

Scoring of the responses contributed to answering the third sub-question of the study: What is the level of novice teacher's PCK revealed after teaching a lesson on vertical projectile motion for the first time?

6.1 CASE STUDY 1 – MR DN

Mr DN completed and submitted his post-CoRe electronically. He made minor adjustments to the pre-CoRe when he completed his post-CoRe and mostly added remarks about gravity. He did not remove any information from his pre-CoRe responses but included new information in Prompts 2, 6, 7, and 8, which are highlighted in his post-CoRe for easy reference (see Appendix E). He elaborated on some responses in his VSR interview, although many of his answers could be more specific. It is important to note that Mr DN completed the post-CoRe tool and his interview in his second language, English. He is not proficient in this language, and it was observed that he had difficulty expressing himself, particularly during the interview. His post-CoRe and full VSR interview transcript can be found in Appendix E and K, respectively.

6.1.1 ANALYSIS OF DATA FROM THE POST-CORE AND VSR INTERVIEW

The sections below reflect the analysis of Mr DN's post-CoRe and his VSR interview. The data are compared to the expert CoRe and graded in terms of the levels described in the rubric.

6.1.1.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

When Mr DN was asked during the VSR interview (Question 1) if there is anything he would change in his introduction of the first lesson, he answered:

"Yes, firstly, I would give them one example of Grade 10 movement in one dimension with the movement equations. To sharpen up that knowledge a bit ... I would have looked at a quick example. This is how we use these equations".

Mr DN recognised the importance of reviewing pre-concepts before delving into the new concepts on vertical projectile motion. This was also noted during the VSR interview (Question 15) when asked if he would change anything in his second lesson. Mr DN referred to the graphs of motion and said:

"For an introduction, go back to Grade 10, because you always have the movement graphs, which are almost the same as this [vertical projectile motion]"

Figure 6.1 is extracted from his post-CoRe (Prompt 2, Big Ideas 1 and 2), where he was prompted on which concepts had to be taught before teaching the big idea. The highlighted part is new information that he added, "The effects of gravity and the direction of gravity and how it reacts in the real world", displaying knowledge of curricular saliency. This insight may be ascribed to events in his lessons, where gravity played a crucial role in his explanations (Lesson 1, Sections 1.1 to 1.6 and Lesson 2, Sections 2.1, 2.2, 2.3, 2.6, 2.7, and 2.8). Such

an example can be seen in his first lesson (Section 1.3), where he referred to gravity in his description of the motion of a projectile that was thrown upwards, reached maximum height and fell to the ground. He explained that as the object moves upwards, gravitational acceleration slows the object down since the gravitational force acts downward on the object. He emphasised that upon the return of the object, the gravitational acceleration is still acting downwards, which causes the object to accelerate with an acceleration of $9,8 \text{ ms}^{-2}$ from a maximum height where the initial velocity was 0 ms^{-1} to the point of launch.

It is noted from the quote above that Mr DN used the terms gravitational force and gravitational acceleration interchangeably. Failing to distinguish between these terms can introduce ambiguity into scientific discussions. Moreover, teaching science involves conveying complex concepts to learners, and precise terminology is crucial for their understanding. This will be discussed in the next section.

2. What concepts need to be taught before teaching this big idea?	The relationship of displacement to acceleration time and velocity. In short all the movement equations and how to use them. As well as the concept of Newton 1 at the hot air balloon examples. Simple graph skills. The effects of gravity and the direction of gravity and how it reacts in the real world	The relationship of velocity to time acceleration, time and displacement. In short all the movement equations and how to use them. The learners need to know Impulse so they can understand why a soft ball's graph will look different to that of a hard ball's. How gravity effects the speed of an object over time

Figure 6.1: Extract from Mr DN's post-CoRe

Although his new additions at Prompt 2 were vague, evidence can be found in the VSR interview (Questions 8, 11 and 14) that he knew the essential characteristics of gravitational acceleration, which he did not mention in his pre-CoRe. Responding to Question 14 in the VSR interview, he said: "The only force working on it [a ball in free fall] is gravity", which is evidence of his knowledge about the concept. In Question 8, he said: "If you are on the Earth, the acceleration due to the gravitational force is always downwards ...acceleration is constant", and in Question 11: "We always work with a constant acceleration that is 9,8". These are crucial concepts to understand and were noted in the expert CoRe (Prompt 1, Big Idea 2).

Mr DN mentioned pre-concepts in his VSR interview that were not previously included in his pre-CoRe, namely Newton's second law (Question 6), vector diagrams (Question 4), and motion in one dimension (Question 6). Adding these to the list he accumulated in his pre-CoRe made his list of pre-concepts extensive. As mentioned earlier, he did not remove any information from his pre-CoRe. Consequently, the analysis of Chapter 4 remains valid, where it was found that pre-concepts were mixed with relevant new concepts (Prompt 1, Big Ideas 1 and 2). This suggested that Mr DN could not distinguish between the existing

knowledge of learners and new knowledge to be acquired regarding the topic of vertical projectile motion.

During his post-CoRe and VSR interview, Mr DN did not display knowledge about the important concept of time symmetry, which is vital in the component of curricular saliency of this topic. This lack of knowledge was further evident in his lessons, as the concept was neither explained nor mentioned. It is worth noting that the expert CoRe (Prompt 1, Big Idea 1) includes this important concept.

During the VSR interview, Mr DN demonstrated his knowledge of curricular saliency when he effectively integrated a pre-concept from a Grade 10 topic into the big ideas, which allowed him to scaffold his examples from easy to more complex problems. An illustrative instance of this occurred when he connected the pre-concept of motion in one dimension (taught in Grade 10) to the overarching ideas. His elaboration on Question 6 in the VSR interview revealed his strategic approach: he emphasised the pre-concept of motion in one dimension while he explained the intricacies of a challenging problem involving a hot-air balloon. Specifically, he recalled an example from a recent class activity involving a hot-air balloon scenario where a person running towards the hot-air balloon attempted to catch an object dropped from the carrier while in motion. This scenario necessitated combining two distinct one-dimensional motions – vertical and horizontal – within a single problem.

Another example of him linking concepts from other topics, such as Newton's Second Law, to vertical projectile motion is when he explained his reasoning process (Question 14) when teaching the acceleration-time graph (Lesson 2, Section 2.6). During this section, he also had to answer a question from a learner on why the acceleration-time graph does not change. He included the pre-concept of Newton's second law in his explanation and linked it to projectile movement using force diagrams, as discussed in Section 5.1.1.3. This can be considered a reason for his new entries in the post-CoRe, which are mainly about gravity and its importance. Once again, he was able to show improved knowledge about the curricular saliency of the concepts after he had taught the topic for the first time because he did not mention such examples in his pre-CoRe.

To summarise, Mr DN identified an extensive list of relevant pre-concepts in his pre-CoRe. He did not remove any of them from his post-CoRe, which could, therefore, still be considered extensive and relevant to the big ideas. He created logical links between pre-concepts from other topics within the big ideas, as explained. He identified relevant concepts within each big idea, only omitting the concept of time symmetry, which still makes his list of relevant new concepts extensive. Mr DN revealed sound knowledge of the pre-concepts

required and new concepts to be taught in this topic, which justifies ascribing the level *exemplary* for this component.

6.1.1.2 KNOWLEDGE AND SKILLS RELATED TO LEARNERS' UNDERSTANDING OF SCIENCE

In his VSR interview, Mr DN identified some misconceptions and learner difficulties in addition to his pre-CoRe. After he had taught the topic, he alluded to the following challenges during his VSR interview, and they are discussed in the coming paragraphs: vector arrows (Question 4), reading ability of learners (question 4) and interpreting the slope of the position-time graph (Question 12).

Mr DN considered understanding of vector arrows a difficulty when he referred to one of the examples he did in class, particularly concerning the representation (Figure 6.2) used in the textbook. This representation illustrated an object thrown upwards, reached its maximum height and fell to the ground.

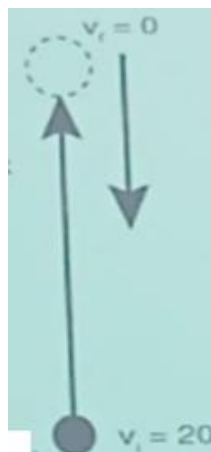


Figure 6.2: Representation in the textbook of an object reaching its maximum height and falling back

He explained it as follows (Question 4):

"I would have just taken the arrow and drawn it onto the ground so that they could see it going upwards, and then it came downwards, straight down onto the ground. There's something that can confuse them, which is the arrows are next to each other. They won't go back to the vector diagrams because when we draw vector diagrams in one dimension, we draw them underneath each other if they are in opposite directions. But sometimes, they forget that knowledge and might think the ball is being thrown forward."

This representation should be clear to Grade 12 learners since they are aware of the scenario where an object is thrown into the air and falls back to the ground. It should be noted that vector arrows are not considered learner difficulties in the expert CoRe, and there was no evidence in his lessons that learners experienced this as a challenge. It can be that

the teacher is having difficulty with the representation in question, and he thinks the diagram in the textbook (Figure 6.2) is meant to be a vector diagram. It should be noted that these arrows (Figure 6.2) are not meant to be vectors but merely arrows to indicate the direction of motion.

The learners' reading ability specified by Mr DN is not a topic-specific difficulty and, therefore, not considered in the expert CoRe as PCK specific to the topic. Mr DN regarded the interpretation of the slope of the position-time graph as a learner difficulty because of the following question posed to him during his second lesson (Section 2.2).

- "Why don't we use straight lines [when drawing the position-time graph] going straight up and down?"

To answer the question (Lesson 2, Section 2.2), Mr DN explained: "Then it means time does not move." His explanation was corroborated in the VSR interview (Question 12):

"I explained to him [learner] that [using straight up and down lines in the position-time graph] means his time is staying the same. He only took into consideration the displacement. He didn't consider the time for the graph."

His explanation indicates his knowledge that the time on the horizontal axis is indicated in time intervals, and if straight up and down lines are used to draw the graph, it means that there is no time-lapse.

Mr DN showed improved knowledge on learner difficulties when he reflected on the learner's earlier question, which was addressed in the preceding paragraphs. In the VSR interview, he said (Question 12):

"I think it was a good question from him [learner] because the learners might ask, but we working with a straight up and down movement; why can't it [position-time graph] move straight up and down?"

It is clear from his observation that he recognised the learner's misconception that the position-time graph resembles the projectile's actual path.

The earlier question asked by the learner: "Why don't we use straight lines [when drawing the position-time graph] going straight up and down?" triggered Mr DN to explain the difference in using straight and curved lines to draw the position-time graph as can be seen in Figure 6.3. Hence, he referred to questions learners might ask in the VSR interview (Question 12): "Why can't I [learner] use straight lines? Why is there a curved line?" referring to the position-time graph he had drawn in class (Figure 6.3).

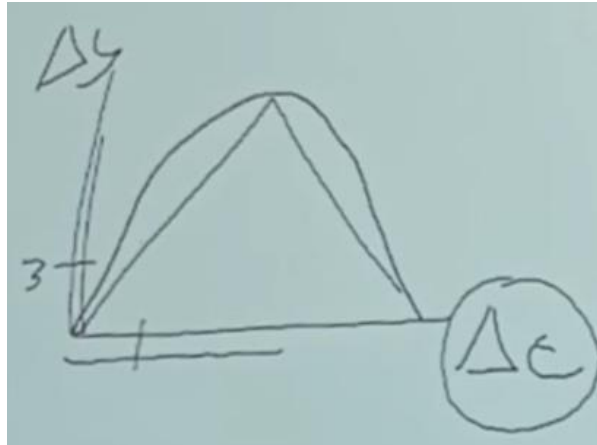


Figure 6.3: Position-time graph where Mr DN explained the use of straight and curved line

He used this opportunity in class (Lesson 2, Section 2.2), and explained to learners why the position-time graph is drawn using curved lines and not straight lines (Figure 6.3). He indicated (Lesson 2, Section 2.2) that straight lines cannot be used because there is acceleration. His explanation was corroborated in the VSR interview (Question 12) when he said: “the answer is quite simple. It is because there is acceleration.” He elaborated further in the VSR interview (Question 12) and said:

“If it was straight lines [diagonal lines in the position-time graph], it meant there was no acceleration. It was a constant velocity. So, it is not a constant velocity [referring to the curved position-time graph] because there was acceleration, so the slope [of the position-time graph with curved lines] indicates to us that there was a change in velocity. It [Object moving upward] moved over a certain amount of time, and it moved slower, slower, slower, and then when it fell [moving downward] over one second, it moved more metres in one second. That is why it can't have straight graphs [lines]”.

The quote provided above appears perplexing due to the participant's limited proficiency in English. It can still be concluded from the above explanation that Mr DN is familiar with the slope of the position-time graph representing the object's velocity for that time interval. He also knows that if the position-time graph consisted of straight (diagonal) lines (Figure 6.3), the velocity would be constant for that time interval, and the acceleration zero. Mr DN did well when he indicated that the velocity would not be constant (referring to his position-time graph having curved lines) (Figure 6.3). His analysis of the non-uniform motion of a projectile was insightful. He astutely observed that as the object ascends, its speed decreases, and conversely, its rate of displacement per second increases as it descends. Therefore, when graphing the position-time graph for a projectile, straight lines are not applicable due to the

varying velocity. This understanding of projectile motion is crucial in physics, especially when drawing graphs of motion.

However, he still displayed a lack of knowledge about learners' understanding in his preceding explanations. He could have alluded that examples with constant velocity are not considered in projectile motion since the focus is on objects in free fall, meaning the acceleration will always be a constant $9,8\text{ ms}^{-2}$ downward. He could have been more specific and explained that comparing the slope of the tangent lines to the curved position-time graph indicates that the object's velocity is changing.

There were instances in the post-CoRe that reflected some misinterpretations by Mr DN, but there were also instances where he identified misconceptions or difficulties from learners, possibly ascribed to his experience from his lesson presentations. Such instances can be seen in his post-CoRe (Prompts 1 and 7, Big Idea 1).

Figure 6.4 is an extract of Mr DN's response in the post-CoRe (Prompt 7). Comparing the responses to Prompt 7 in the pre- and post-CoRes revealed only one new entry about gravity, which was highlighted (yellow) for easy reference. It should be noted that the entries made by Mr DN in Prompt 7 described the misconception or difficulty he thinks learners might have. His new entry: "That since the direction of the movement changes the direction of gravity or the sign of gravity changes", correctly describes a possible misconception learners might have. This entry may have originated from his teaching experience during Lesson 2 (Section 2.6). He drew an acceleration-time graph of an object thrown from the top of a building, reaching its maximum height and falling to the ground. His graph correctly showed a horizontal line at -9.8 m.s^{-2} for the entire movement. A learner asked if his graph only represented the motion's first (upward) part. He correctly responded and said (Lesson 2, Section 2.6): "No, it is for the whole motion." He showed good knowledge of learner understanding and expanded his explanation by drawing force diagrams on different positions of the object's motion path to indicate that gravity is the only force (constant) acting on the object in a downward direction irrespective of the object's direction.

7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	That displacement should be handled like distance and they take the whole road length and not just the movement from a certain point. That if I throw a ball upward from a building and let it fall to the ground the displacement is all the downward movement from the amplitude. That a ball with in a hot air balloon's displacement is from where it has been dropped. That since the direction of the movement changes the direction of gravity or the sign of gravity changes	That velocity is in the same direction as acceleration. That the velocity is always positive. At a hot air balloon the starting velocity is zero. Velocity is zero when you throw the ball in the air.

Figure 6.4: Mr DN's response to Prompt 7 in his post-Core

Evidence of his pPCK emerged in his VSR interview (Question 5) when he said:

"In the real world, when we talk about somebody and say they are slowing down instead of they have a negative acceleration. But in physics and the science classroom, we talk about acceleration only. Acceleration can be positive or negative. It doesn't mean you drive in the opposite direction because it is not velocity."

It should be noted that the phrase Mr DN used in the quote can be misleading and create a misconception. He talked about an object slowing down having a negative acceleration; this is not always the case, and an object will only slow down if the velocity is positive and the acceleration negative or vice versa.

Mr DN exposed learners' misconceptions about velocity and acceleration always being in the same direction when he remarked in the quote above that in the "real world" (daily life), we would talk about slowing down instead of negative acceleration. He used velocity (vector) as an example and elaborated that the positive and negative sign indicates the direction of the motion when referring to the object's velocity. This is not the case with acceleration, as he stated: "It doesn't mean you drive in the opposite direction because it is not velocity".

In Chapter 4, after analysing the data in his pre-CoRe, it was discovered that he is unaware of his misconception about the total displacement of an object dropped from a moving carrier. This means he did not realise that his response (Figure 6.4) revealed his misunderstanding. Once again, it should be noted that his intention with the entries at prompt 7 (Big Idea 1) in his post-CoRe was to encapsulate potential learner misconceptions. However, his assertion (Figure 6.4), "That a ball within a hot-air balloon's displacement is from where it has been dropped," diverged from the misconceptions typical of learners. His entry does not identify a misconception but is indeed correct. This distinction is reiterated by his entry in his post-CoRe (Prompt 1, Big Idea 1), where he referred to the hot-air balloon example, wherein he stated that an object dropped from a hot-air balloon will initially move upwards to a maximum height before falling to the ground. He elaborated that the displacement of this object would be from the highest point to the lowest point, which is incorrect considering the typical hot-air balloon problem. The total displacement of an object dropped from a moving carrier is from the position where it was dropped to the ground.

Considering his ePCK during Lesson 1 (Section 1.6), contradicting evidence was found. He did a hot-air balloon example from the textbook of an object dropped from the moving carrier 200 metres above the ground, as displayed in Figure 6.5.

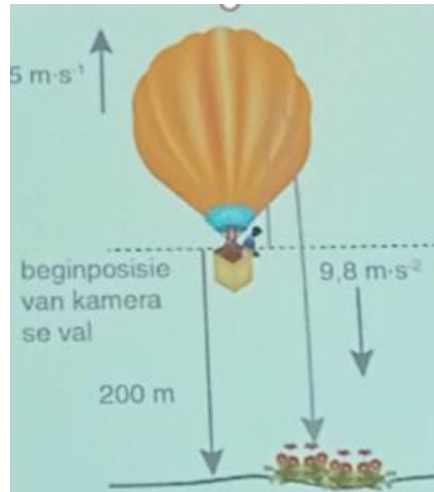


Figure 6.5: Hot-air balloon problem Mr DN did in class

When he explained (Lesson 2, Section 1.6) the hot-air balloon problem in Figure 6.5 above, he used gestures in the air to show how distance and displacement should be interpreted in this question. He indicated that the displacement of the object would be 200 m (the position from where it was dropped), but the distance would be the total path length followed by the object, hence more than 200 m. This was indeed explained correctly. A plausible explanation for his oversight in recognising the need for corrections within his post-CoRe entries might be attributed to his reliance on the textbook's explanations and calculations. It is noteworthy that the textbook explicitly denoted the displacement of the dropped object as 200 metres (Figure 6.5). Furthermore, when he explained the questions related to the hot-air balloon problem, the answers were promptly displayed on the SMART board. Hence, no reasoning was required when the textbook used 200 metres as the displacement.

Mr DN's lack of knowledge of learner understanding was evident in his response to Question 9 in the VSR interview. When asked whether he identified misconceptions from the learners, he described a specific discussion between him and a learner. He described the homework question they discussed of an object thrown upward from the top of a building, reaching its maximum height, and falling back to the ground. They needed to calculate the total time for the movement. The learner then calculated the time it took the object to reach its maximum height and the time it took to reach the ground from maximum height. The learner added these two times and obtained a final answer for the total time. Mr DN agreed that this was correct. The learner needed clarification on the method Mr DN used in class to obtain his answer, calculating the total time considering the entire motion and using the displacement from the top of the building to the ground. The learner needed help understanding how the answers were the same because he felt Mr DN's option did not include the entire movement.

Mr DN should have explained to the learner that they are considering displacement in the equations of motion. Hence, when the reference points are at the top of the building and the ground, they are indeed considering the entire movement. He said to the learner:

“If I throw the ball upwards there’s negative deceleration. Every second, it goes slower, and that’s why it takes longer for you to complete that first movement [from the top of the building to the maximum height] than it takes to complete the entire movement from its amplitude or the top point down to the ground”.

This is not a proper response to the learner’s question and reveals a misinterpretation on Mr DN’s side. The concept of time symmetry explains that the time an object takes to reach its maximum height will equal the time it takes from its maximum height back to its starting position, considering that the starting position and the final position are at the same height. Hence, there is no difference between the upward and downward movement times. Therefore, his statement above that it will take the object longer to reach its maximum height starting from the top of the building compared to the time from the maximum height to the ground is entirely wrong.

As explained in the previous section, Mr DN did not refer to the concept of time-symmetry in his pre- or post-CoRe, or any of his interviews. He is apparently unaware of the concept of time-symmetry.

Another important aspect regarding his knowledge of learner understanding that can be considered from the quote above is the term “*negative deceleration*” that he used to describe the acceleration of the ball thrown upward. Deceleration, although not a scientific term, refers to acceleration in the direction opposite to the direction of the velocity and always implies reducing speed. It would have been more precise to use the term “*acceleration*” with appropriate signs and directions to describe velocity changes rather than “*deceleration*”.

Even though Mr DN described many misconceptions and learner difficulties, the interpretation of his entries posed challenges, attributed in part to his lack of English language proficiency, which is his second language. Furthermore, his approach to copying the information from his pre-CoRe without substantial revision and only adding new information contributed to the complexity of his responses. He could have expanded and re-phrased his pre-CoRe responses more successfully to prompts about his knowledge regarding misconceptions and difficulties. He also identified some basic difficulties not commonly documented as misconceptions or difficulties related to the topic. He also revealed his own misconceptions and difficulties in more than one of his responses, and this may create the idea that he should be scored “limited”. However, as discussed, there were

other aspects related to learner understanding in which he proved to be knowledgeable and consequently, he was rated in the second tier for his competence in this component, which is classified as *developing*.

6.1.1.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Prompts 3 and 4 in the post-CoRe were explicitly chosen to elicit information from the teachers regarding their choice of representations and why they deemed them necessary. Mr DN did not amend his responses to these pre-CoRe prompts. During the VSR interview (Question 4), when asked about his satisfaction with the representation he used to explain a particular example in class, he confirmed that he was content with it. At no point in the VSR interview did he mention any representations other than drawings on the board. It was also observed during both his lessons that he mostly used the textbook's drawings to explain the problems.

It is concerning that Mr DN did not revise the responses to Prompt 4, which required him to give particular reasons for the representations used. He kept the general reasons he provided in his pre-CoRe and did not utilise the opportunity to display his knowledge regarding the effect of representations in his teaching strategy.

As indicated earlier, Mr DN did not amend his post-CoRe entry. Therefore, as discussed in Chapter 4, I conclude that he had workable representations that would support the development of concepts related to the big ideas.

There is limited evidence of creative interaction between the teacher and learners looking at the post-CoRe. Mr DN kept his entry at Prompt 5, the same as in the pre-CoRe, where he said:

“By using as SMART board I will use audio (by speaking) and visual (drawing and doing examples) to better their understanding while also asking pertinent questions...”

This comment creates the idea of a formal method of teaching where the planned teaching strategy is very traditional. This view was reinforced when I analysed the data at Prompt 6, which required Mr DN to reveal questions he thought would ascertain learner understanding. Most of his questions require one-word answers, and I do not believe that higher-order thinking skills will be required from the learners to answer the questions. The only addition he made to Prompt 6 was to include questions about gravity and its effects. He realised the need for questions about the crucial concept of gravity, but his lack of explanation does not provide any evidence that he would know which questions to ask.

The lessons Mr DN presented exhibited what was seen in the pre-CoRe. He enacted a traditional way of teaching. The lessons were teacher-centred, with him explaining the problems from the SMART board. The textbook was downloaded on the SMART board; therefore, all solutions were visible. This approach discouraged critical reasoning and problem-solving skills. Learners spoke very little and were not engaged with questions or discussions to enhance conceptual thinking.

During his VSR interview, Mr DN described how he would improve interaction with learners. He mentioned getting the learners more involved when asked if he would change how he presented the lesson (Question 15). In his response to Question 7 he remarked:

“One thing I might want to change is fewer examples that are physically done that are already done on the board, and do more examples with them physically and maybe one or two exam questions, and they can have a cooperative lesson where I pair them two-two. They work on the problem together to learn from each other. Then I am only the facilitator.”

The quote above illustrates Mr DN's improved knowledge of teaching strategies. He indicated that he would include fewer worked examples on the board. He mentioned cooperative learning, where they can work in groups. He also described a more learner-centred strategy when he responded to Question 10 in the VSR interview, asking whether he was satisfied with how he utilised the interactive board. He said: "I can write down an example and tell one of the learners to do the question for me. Now they can see their thought process."

From the VSR interview it was noted (Questions 1 and 15) that Mr DN realised the importance of pre-concepts and indicated he would include them in his introduction for future lessons. He showed good knowledge of teaching strategies when he mentioned the scaffolding of problems when he responded (Question 7) on the sequence of his lesson: "At the end of the lesson, I need to put a higher-order question that comes out of a previous exam." Such an example was discussed in the first section of this chapter, where Mr DN started with an easier example of the hot-air balloon problem and moved to higher-difficulty problems, still focusing on the hot-air balloon scenario. He referred to Bloom's taxonomy, indicating it would assist learners in getting used to the different levels of questions.

When discussing difficult concepts in his VSR interview (Question 8), he spoke of an "unwritten rule" for gravity; the upward direction should be chosen as positive, which entails that gravity is negative since it is downward. He said, "Acceleration is always negative because it is always downwards ... and you don't confuse yourself that you choose upwards as positive." It is not advisable to restrict learners to choosing a specific direction as positive

as this can be confusing for learners, especially when the information in the question prescribes the opposite direction as positive. This approach does not promote conceptual understanding and can lead to rote learning.

Mr DN referred to scaffolding his questions and incorporating the levels of Bloom's taxonomy, similar to what is expected in the examinations, at the end of the lesson, indicating that he considers the sequencing of his concepts. In the VSR interview (Question 1), he said: "Focus less in detail on all the definitions and small detail, and rather get down to the nitty-gritty things that they usually do not get correct in exams, and in questions, and so on." This creates the impression that his focus is on exam preparation rather than conceptual development.

To summarise, Mr DN identified relevant representations, mostly drawings on the board. It is unclear how these representations will be used, as seen in his ambiguous entry at Prompt 4 in the post-CoRe when he provided general reasons for the use of representations. Mr DN planned to ask basic questions, and mostly rote learning questions were posed that do not require higher-order thinking. There is evidence of him considering sequencing, but it is unclear whether his focus is on exam preparation or conceptual development. The overall strategy is workable, although he could have explained the use of it better, and the application thereof could have been more apparent. His competence was regarded as *developing*.

6.2 CASE STUDY 2 – MS NJ

Ms NJ completed the post-CoRe in her handwriting and submitted it electronically. She amended all the pre-CoRe responses while constructing the post-CoRe, except Prompts 2 and 7. The additions to the prompts were highlighted in her post-CoRe for easy reference (see Appendix F). Ms NJ's VSR interview answers elaborated on her responses in the post-CoRe. She completed the post-CoRe and VSR interview in English, her second language. The teacher is not very proficient in English and struggles to express herself. Her post-CoRe and full VSR interview transcript can be found in Appendix F and L, respectively.

6.2.1 ANALYSIS OF DATA FROM THE POST-CORE AND VSR INTERVIEW

The sections below reflect the analysis of Ms NJ's post-CoRe and her VSR interview. The data are compared to the expert CoRe and Graded in terms of the levels described in the rubric. This analysis shows the quality of Ms NJ's PCK in terms of projectile motion after she taught the topic for the first time.

6.2.1.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

As discussed in Chapter 5, Ms NJ had a poster on the wall with crucial concepts regarding vertical projectile motion, which she wanted learners to understand (Lesson 1, Section 1.2). The poster contained a list of relevant new concepts (Figure 5.12) about each big idea. When asked in the VSR interview (Question 3) if she would make any changes to this list, she said: “No, I am satisfied the way it is.” She emphasised the importance of the concepts when she responded to question 1 in the VSR interview when she said:

“Because they [concepts listed on the poster] are very important in answering any of the questions in vertical projectiles. The learner should be made aware of those characteristics. So I felt it is very important for learners to understand first the characteristics or those concepts before answering any questions because I find them very critical in this topic.”

During her lesson presentation (Lesson 1, Section 1.2), Ms NJ utilised her poster (Figure 5.12) to introduce and explain new concepts related to vertical projectile motion. One of the key concepts she covered was the hot-air balloon problem and the assertion that an object dropped from a moving carrier will have the same initial velocity as the carrier. This concept was not previously included in her pre-CoRe and is essential to understanding the problem of a hot-air balloon within the topic of vertical projectile motion.

Figure 6.6 below indicates Ms NJ's responses to Prompts 1 and 2 in the post-CoRe, which was selected to elicit knowledge from her about the curricular saliency of the big ideas.

1. What do you intend the learners to learn about each of the ideas?	→ Difference between distance and displacement. → The displacement vs time graph gives the velocity. → Choosing the sign convention. Choose up as + or up as -.	→ When an object is dropped its initial velocity $v_i = 0$. → The velocity vs time graph give acceleration. → When an object reaches maximum height $v = 0$. → Time symmetry. → When a ball is thrown up, its velocity decreases.
2. What concepts need to be taught before teaching this big idea?	→ In grade 10 learners should have been taught motion in 1 dimension. → Learners should know about equation of motion.	→ In grade 10 learners should have been taught motion in 1D. → Learners are aware of the equations of motion.

Figure 6.6: Extraction of prompts 1 and 2 from Ms NJ's post-CoRe

Ms NJ added the importance of sign conventions (Prompt 1, Big Idea 1) and the important fact that the velocity of a ball thrown upward decreases (Prompt 1, Big Idea 2), which may

not be obvious to learners who encounter the topic for the first time. Sign conventions is actually a pre-concept explained in Grade 10, which forms part of the section *motion in one dimension* that she mentioned at Prompt 2, Big Idea 1. The fact that she mentions sign conventions here as a new concept to be taught that could be ascribed to the fact that Ms NJ has never taught physics in Grade 10.

She made two other new entries in her post-CoRe, responding to Prompt 5 for Big Ideas 1 and 2, which align with the new entry in Prompt 1, Big Idea 2. She indicated (Prompt 5, Big Idea 1): “Throw a marker/duster upward and ask learners what they observe.” Furthermore (Prompt 5, Big Idea 2), “Throw an object upwards to indicate reference point, maximum height, increase and decrease in velocity, time-lapse.” It is possible that these entries originated from her introduction in Lesson 1 (Section 1.1) when she explained that the only force acting on a projectile after launch is the gravitational force. During this lesson, she threw a marker upwards and asked: “Why, when we throw an object up, it always comes back down?” Notably, at Prompt 5 for Big Idea 2, Ms NJ shared more concepts that could be explained using this example, such as reference points, maximum height, time-lapse and increase and decrease in velocity. This was explained during her first lesson (Section 1.2) when a ball was thrown upwards, reached a maximum height, and fell to the ground. It can be concluded that Ms NJ’s knowledge of curricular saliency of the big ideas improved after she had taught her lessons. It should be noted that her use of the phrase “time-lapse” is unclear and not a term typically employed in this context. It can be inferred from her previously mentioned example that she intended to convey “the passing of time”. This confusion may be attributed to the fact that English is not her first language.

As explained in Chapter 4, Ms NJ expressed her belief during her pre-CoRe interview that no particular pre-concepts from Grade 11 were necessary for learners to remember. She did not refer to relevant pre-concepts, such as the contact time of a bouncing object and the distinction between elastic and inelastic collisions. This omission was particularly troubling given the pivotal role these concepts play in fostering learners’ conceptual development within the topic of vertical projectile motion when dealing with bouncing objects.

Notably, she showed improved knowledge of curricular saliency when referring to Grade 11 pre-concepts in her first lesson (Section 1.1). Here, she mentioned forces like the normal force, frictional force, and tension, but emphasised that the only force acting on a projectile is the gravitational force. Her entry (Prompt 6, Big Idea 1), posed a thought-provoking question: “Why [does] the displacement of a bouncing ball decrease?” In her previous statement, when Ms NJ discussed displacement, she was referring to the maximum height an object would reach after each bounce. It is, therefore, important to note that when using the term

displacement, one typically refers to the change in position of an object from one point to another. This concept (displacement) differs from maximum height, which specifically represents the highest point an object reaches in its trajectory. These terms possess distinct meanings, and accuracy in their use is vital to prevent any confusion.

During her second lesson (Section 2.3), Ms NJ expressed her intent to illustrate a bouncing ball scenario while explaining the position-time graph. However, she could not execute the example during the lesson due to time constraints. Nevertheless, in the subsequent VSR interview (Question 19), she substantiated her improved understanding of curricular saliency. She said:

“So there [where the ball bounced] is where there is a time-lapse [contact time between the ball and the ground] when the ball reaches the ground. Some learners might draw the motion straight and not show the time-lapse [contact time] on the velocity and displacement time graphs. So I think that is one important key point for learners to show the time-lapse [contact time] on both the graph, the velocity-time graph, and the position-time graph, especially with a bouncing ball.”

The quote above suggests that in this example Ms NJ referred to the contact time between a bouncing object and the ground when she mentioned "time-lapse." As explained earlier, her use of this term can be attributed to her limited proficiency in the English language. While Ms NJ comprehends the concept of contact time during a bounce, she has not yet connected it to the broader concepts of elastic and inelastic collisions, which are pertinent to understanding why the maximum height of a bouncing ball decreases. This connection will be explored in the following section.

When Ms NJ answered Question 15 in the VSR interview on why she decided first to teach the velocity-time graph, she did not offer any particular sequencing as a reason. She said: “I just chose to start with the velocity-time graph. I don’t have the specific reason why I started with it.” However, when asked if she would keep the sequence the same the next time she has to teach the lesson, she indicated (Question 16): “I would start with the displacement-time graph”, implying that she would consider changing the sequence the next time she teaches a lesson on vertical projectile motion. One possible reason for her contemplating the change could be her response to Question 16 during the VSR interview: “I think the displacement versus time graph, it is easier for learners to understand or even to draw the graph.” It is worth noting that Ms NJ probably meant position-time graph when she talked about the “displacement-time” graph in her responses in the VSR interview and CoRes.

To conclude, Ms NJ identified an extensive list of relevant new concepts and pre-concepts within each big idea, including pre-concepts that she had not mentioned before teaching the

lesson. As explained, some pre-concepts were from other topics and had logical links to the big ideas, although vaguely explained. As discussed, there is evidence that she is considering the sequencing of concepts logically. The third level of competence describes Ms NJ's competency best: *Exemplary*.

6.2.1.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

When Ms NJ was prompted in the post-CoRe (Prompt 7) about typical learner misconceptions and difficulties, no changes or amendments to her responses in the pre-CoRe were made, suggesting that she could not identify additional misconceptions or difficulties other than those mentioned in her pre-CoRe. Her view is corroborated in the VSR interview (Question 14) when asked if she identified learner difficulties or misconceptions after she presented her second lesson, to which she responded: "No, I don't think up to so far."

However, she elaborated on a difficulty experienced during her first lesson when she responded to Question 10 in her VSR interview. She indicated that learners need clarification regarding displacement in a question. She used an example of a ball being thrown upward from the roof of a building, and they needed to calculate the maximum height the ball would reach above the ground. She said:

"Learners must understand that there is displacement from the ground to the roof. And if the ball was thrown vertically upwards, that shows that there is also another displacement from the starting point [top of the roof] up until it reaches maximum height. I can say that there are two displacements or positions that the learners would need to add up. So a learner might use 30 metres [height of building] as the displacement and forget about the distance from the starting point [top of the roof] to the maximum height."

The above-mentioned example was discussed in class (Lesson 1, Section 1.4) where Ms NJ demonstrated the example and divided the motion path of an object into sections using alphabetical letters. As shown in Figure 5.16, she labelled the point of launch (top of the roof) as point A, the maximum height as point B, the point of launch (return) as point C, and the ground as point D. These alphabetical letters served as reference points throughout the question.

As indicated, the question asked was to calculate the maximum height that the object would reach above the ground. Ms NJ approached this problem in two stages. First, she used the equation $v_f^2 = v_i^2 + 2a\Delta y$ to calculate the maximum height the object would reach from the point of launch, using the top of the building (point A) and maximum height (point B) as

reference points. Then, she added the height of the building, 30 metres, as indicated in Figure 5.16, to her previous answer to obtain the displacement from the ground (point D) to the maximum height (point B). A learner asked if he would obtain the same answer if he first calculated the time it would take for the object to reach its maximum height (point B) from the point of launch (point A) using the equation $v_f = v_i + a\Delta t$. Then, using $\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$, he could calculate the maximum height (point B) the object would reach from the point of launch (point A). Finally, by adding the height of the building (30 metres), he could obtain the maximum height (point B) the object would reach from the ground (point D).

Ms NJ responded to the learners' question, indicating that it would be possible and that the answers would be the same. She then proceeded to solve the same question, which was calculating the maximum height (point B) the object would reach from the ground (point D). She used the method suggested by the learner, and indeed, the answers were the same.

In summary, both approaches were valid and yielded the same result for the maximum height above the ground (point D) that the object would reach. The key differences were in the methods used to calculate the maximum height above the ground. Therefore, the difficulty in this problem may not be that learners forget to add the height of the building to the displacement (between points A and B) as Ms NJ indicated but rather in the method and reference points used. The difficulty in understanding problems related to displacement and reference points often comes from the complexity of the problem-solving process rather than a fundamental misunderstanding of the concepts themselves. Learners need to recognise when to apply a certain approach based on the information given and the question asked.

As discussed in Chapter 4, Ms NJ diagnosed a misconception when she said learners think the direction in which the object is moving is the same as the direction in which the velocity-time graph is drawn. She identified a misconception that learners interpret the shape of a graph as a picture of the path of the motion. This misconception means that learners struggle to believe that an object can move upwards, but the slope of the velocity-time graph is negative (downwards). However, when she presented her second lesson (Section 2.4), she created the impression that the position-time graph's shape corresponds with the object's path, as discussed in Chapter 5 (Section 5.2.1.2). Also, her response to Question 16 in the VSR interview on whether she would again explain the velocity-time graph first in her lesson on graphs can cause a reason for concern regarding her misinterpretations. She said:

“No, I think I would start with the displacement versus time graph because that’s the easiest one because it [position-time graph] shows the learner exactly what is happening ... It is easier for learners to understand or even to draw the graph because it shows the object’s motion almost as it is in the scenario or the representation.”

From the above description, Ms NJ creates the impression that the position-time graph resembles the path of the object’s motion. This is considered a misconception in literature (Barclay, 1985; Clement, 1985; Lapp & Cyrus, 2000) and is listed in the expert CoRe at Prompt 7. This response revealed her misconception regarding the position-time graph’s shape and the object’s trajectory being the same.

When she explained the velocity-time graph (Lesson 2, Section 2.1), she used both the upward and downward directions as positive to illustrate the effect of different reference frames on drawing the velocity-time graph. This illustration allowed her to emphasise that the shape of the graph is not the same as the object’s motion path. However, when she explained the position-time graph, she used the upward direction as positive, which then caused the position-time graph to resemble the object’s up and down motion path. During her explanation of the position-time graph, the following dialogue occurred (Lesson 2, Section 2.4):

Learner: “Will the graph be almost the same if we chose downward as positive?”

Ms NJ: “If you chose downward to be positive, your graph is going to be sort of a reflection of what is happening this side [pointing to the original graph].”

Ms NJ drew the mirror image of the existing graph so learners could see how the graph would look if the downward direction were chosen to be positive. However, this may not give them a deep understanding of the concept and conceptual reasoning they can lack in future situations.

When asked about addressing misconceptions and learner difficulties (Prompt 8), Ms NJ offered the following insight: “On the graph, zero axis represents zero velocity.” However, her intended approach to address learner difficulties or misconceptions through this statement remains unclear. The horizontal axis denotes time in a velocity-time graph, while the vertical axis represents velocity. In the context of Grade 12 vertical projectile motion, it is common to establish the point where the two axes intersect as the zero point for both axes. By adopting this convention, when the graph intersects the horizontal axis, it can be inferred that the velocity at that specific time is zero. It appears that Ms NJ may have intended to convey this concept, but her challenge with English proficiency might have hindered a more precise articulation.

Ms NJ made a new entry to Prompt 6, Big Idea 1, stating: “Why the displacement of a bouncing ball decreases.” As discussed in the previous section on curricular saliency, she uses the word *displacement* as a synonym for *maximum height*, which may indicate that her own conception of displacement is not well developed. During this discussion, it was found that she is aware of the contact time between a bouncing object and the ground. However, she was unaware of the pre-concepts of elastic and inelastic collisions that can be used to answer her above question. When she was asked in the VSR interview (Question 20) what she found difficult to teach, she said:

“I think the issue of having to explain to learners what the time-lapse [contact time] means because if we are saying that a ball is thrown up and then there is a time-lapse, even though we are saying it to learners, but you might find it difficult to give the exact reason why we are saying the ball stops momentarily or even when it hits the ground. There is a momentarily stop. So if a learner were to ask me a question to say, Why do you say that? It would be difficult for me to explain why there is that time-lapse [contact time] and what happens during it.”

As indicated, Ms NJ does not teach the physics component of the subject at school. This circumstance might explain her unfamiliarity with concepts like elastic and inelastic collisions covered in the preceding Grade 12 topic of momentum and impulse. It is important to note that no kinetic energy is transferred during an elastic collision between the bouncing object and the ground. Because we ignore the effects of air friction in Grade 12 vertical projectile motion, it is safe to say that, in this case, the ball will reach the same height it was dropped from after the bounce. In contrast, if it was an inelastic collision between the bouncing object and the ground, there is a process of energy transformation where some of the ball's kinetic energy is transferred to heat and sound energy. Additionally, in this case, some of the energy is transformed into elastic potential energy as the ball undergoes deformation. Therefore, the ball will not reach the same height from which it dropped. Hence, the ball's maximum height decreases after each bounce. Lacking this understanding, it becomes unclear how Ms NJ will explain the behaviour of a bouncing object, and as previously highlighted, she might not be able to answer the questions she posed: “Why [does] the displacement of a bouncing ball decrease?”

Ms NJ identified some misconceptions and learner difficulties. She also identified difficulties not commonly documented as related to the topic. I have already pointed out that the difficulty she mentioned regarding displacement is irrelevant and may divert learners' attention from the skills needed to solve the problems. She provided explanations that only partially addressed learner difficulties, some of which can be considered vague. It was concerning to find responses that revealed her misconceptions, as explained regarding the

position-time graph and her use of the word displacement. Her understanding of knowledge and skills related to the learner's understanding of science was regarded as *developing*.

6.2.1.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Prompts 3 and 4 were specifically chosen to elicit knowledge from the teachers regarding their understanding of representations. The changes Ms NJ made to these prompts in the post-CoRe can be seen in Figure 6.7 below.

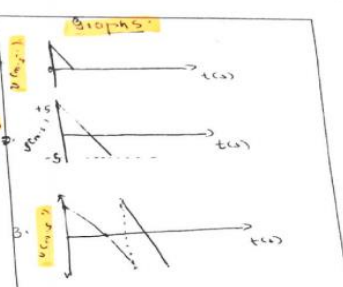
3. What representations would you use in your teaching strategy?	Scenario 1 → Ball is dropped from the top of a roof Scenario 2 → Ball is thrown vertically upwards from a roof, passes the initial point and reaches the ground. Scenario 3 → motion of a bouncing ball	Graphs: 
4. Give particular reasons for the representations used to engage with this idea?	- Equations of motion are taken from the graphs. - We use the graphs for learners to understand the motion of an object. - We use graphs to calculate the unknown variables. - Use graph to interpret the motion.	- Graphs to show motion of an object. → Calculate unknown variables.

Figure 6.7: Extraction of Ms NJ's response to the prompts eliciting information on representations

The changes to Prompt 3 (Big Idea 1) consisted of drawings depicting three scenarios. She used two representations in her recorded lessons (listed below); the specific sections are indicated in brackets. Ms NJ used the representation illustrating a bouncing ball in a lesson that was not recorded.

- 1 Ball dropped from a building. (Lesson 2, Section 2.1)
- 2 Ball thrown upward from the top of a building and falls back to the ground. (Lesson 1, Section 1.4 and Lesson 2, Section 2.4)
- 3 Motion of a bouncing ball.

These representations illustrate projectile-motion problems and may assist more in the conceptual reasoning process than the proposed representations (graphs only) that she suggested in her pre-CoRe (Prompt 3, Big Idea 1). The additions to Prompt 3, Big Idea 2 in her post-CoRe showed three velocity-time graphs:

1. The first graph illustrates an object being thrown upward reaching its maximum height.
2. The second graph depicts an object being thrown upward, reaching its maximum height, and then returning to its starting point.
3. The third graph shows an object being thrown upward, reaching its maximum height, falling back to the ground, bouncing and then ascending to its maximum height before descending to the ground.

Considering her entries in the post-CoRe (Prompt 3, Big Ideas 1 and 2) (Figure 6.7), it was apparently her intention to show the velocity-time graph (Big Idea 2) for each of the situations shown in Big Idea 1, but for the first scenario, the velocity-time graph is wrong and does not depict a dropped object as indicated in Big Idea 1.

Ms NJ still considers graphs of motion to be representations (rather than the concepts to be learned), especially when considering her response to Prompt 4 (Big Idea 1) when she indicated the graphs of motion should be used to interpret the motion of an object as a particular reason for using representations. However, when she was teaching, she did not use graphs to interpret motion; rather, she made use of drawings to assist in drawing the graph. This approach is an indication that Ms NJ lacked knowledge about teaching strategies because her actual teaching strategy does not align with her statement in the pre- and post-CoRes, which indicated an inconsistency between her pPCK and ePCK.

The teacher revealed good PCK when describing the use of a representation at Prompt 5 (Big Idea 1) of a marker or duster thrown upward, and learners should observe what is happening. This would allow learners to witness the object's motion and reason about the phenomena of the concepts she mentioned in her post-CoRe (Prompt 5, Big Idea 2). To elaborate, they could see the velocity decreasing as the object moved upward and increasing as the object moved downward. This response deviates from using only drawings on the board. She suggested (Prompt 5, Big Idea 2) that concepts like reference points, maximum height, increase and decrease in velocity and time should be linked to the before-mentioned representation. She elaborated in her VSR interview (Question 1) by indicating that throwing the marker into the air would demonstrate to learners that the only force acting on the free falling object is the gravitational force. This statement is aligned with her representation used in class (Lesson 1, Section 1.1), where she used a pen and threw it upward. She asked learners what causes the pen to fall back down, to which they responded the gravitational force.

Ms NJ displayed a good representation (Figure 4.4) in her pre-CoRe (Prompt 6, Big Idea 2), where she illustrated an object thrown upwards and caught again at the point of launch using a drawing. She removed this representation from the post-CoRe, which is concerning because the representation in Figure 4.4 displayed how she linked certain concepts to the representation. It may be that the representation in Figure 4.4 (pre-CoRe) corresponds to her example in the post-CoRe of a marker or duster thrown into the air (Prompt 5, Big Idea 1), and she felt she was repeating the representation.

When the teacher was prompted in the post-CoRe (Prompt 5) to describe her teaching strategy, she provided very little information and was ambiguous in her response, as seen in Figure 6.8. However, the VSR interview responses reveal more information about her reasoning.

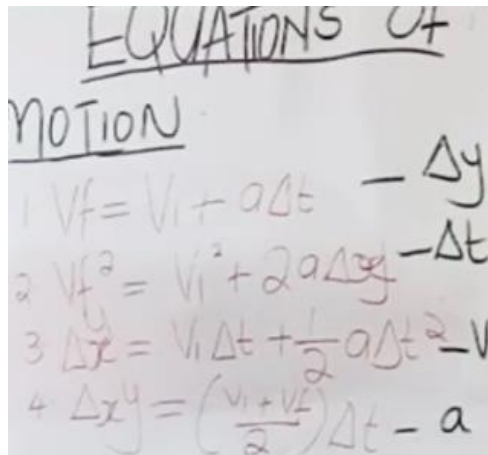
5. Describe the strategy you will use to establish conceptual development of the key idea.	Use real-life examples and ask learners questions that they can relate to. - Throw a marker / duster upward and ask learners what they observe. - throw an object upwards to indicate reference point, maximum height, increase and decrease in velocity, time lapse.
6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	Why is it that when an object is thrown up it always come down? ② Why the displacement of a bouncing ball decreases. → Why is it that when an object is thrown up its velocity decreases →

Figure 6.8: Prompts 5 and 6 Extracted From Ms NJ's Post-Core

Ms NJ revealed sound knowledge of teaching strategies when she indicated in her VSR interview (Question 4) that it is important to implement the concepts learned in an example. This was observed during her first lesson (Section 1.2) when she explained all the characteristics listed on her poster (Figure 5.12) and linked them to examples and representations to ensure learners understood them. In the VSR interview Question 7), she indicated that she implemented a strategy of dividing a motion into sections using alphabetical letters to help learners understand the topic better. She referred to her poster (Figure 5.12) about the characteristics of projectiles. This strategy was observed throughout her lessons (Lesson 1, Section 1.4 and Lesson 2, Section 2.4) and was deemed successful.

During the VSR interview (Question 11), Ms NJ was asked to elaborate on her strategy for explaining the equations of motion. There are slight alterations compared to the data before

she taught a lesson. Initially, she suggested that learners identify and link the unknown variable to one of the four equations of motion and then mathematically solve it. During her first lesson (Section 1.3), she indicated that each of the four motion equations is missing one of the variables, which means you will never be able to use that equation to solve for the missing variable. It also means you do not need that variable to solve another unknown variable in the equation. She indicated this missing variable next to each equation, as seen in Figure 6.9.



EQUATIONS of MOTION

- 1 $V_f = V_i + a\Delta t$ — Δy
- 2 $V_f^2 = V_i^2 + 2a\Delta y$ — Δt
- 3 $\Delta x = V_i\Delta t + \frac{1}{2}a\Delta t^2$ — V_f
- 4 $\Delta x = \left(\frac{V_i + V_f}{2}\right)\Delta t$ — a

Figure 6.9: Ms NJ indicating the missing variable for each equation of motion

Ms NJ identified some relevant representations, including drawings and the throwing of objects. These representations were linked to the underlying concepts, although it can be unclear at times. There is some evidence to suggest that the use of representations can enhance conceptual development. For example, she provided an example of an object being thrown in the air and effectively linked relevant concepts like velocity to it. The strategies can be considered general but workable. Ms NJ considered aspects of curricular saliency and sequencing, although it can be considered ambiguous. Therefore, the second tier in the rubric best describes Ms NJ's knowledge and skills related to conceptual teaching strategies, namely, *Developing*.

6.3 CASE STUDY 3 – MR JP

Mr JP completed and submitted his post-CoRe electronically. When constructing the post-CoRe, he added information to all his responses made in the pre-CoRe except at Prompt 6, Big Idea 2. The information Mr JP added is highlighted in his post-CoRe for easy reference (see Appendix D). This implies that Mr JP has benefited from the lessons he conducted, thereby enabling him to enrich all of the prompts as demonstrated. He provided valuable information in his VSR interview, although he struggled to articulate his thoughts clearly. It is important to note that Mr JP completed the post-CoRe and his VSR interview in his second

language, English. He is not proficient in this language, and it was observed that he had difficulty expressing his thoughts, particularly during the VSR interview. Both his post-CoRe and full VSR interview transcript can be found in Appendices D and J, respectively.

6.3.1 ANALYSIS OF DATA FROM THE POST-CORE AND VSR INTERVIEW

The sections below reflect the analysis of Mr JP's post-CoRe and his VSR interview. The data are compared to the expert CoRe and graded in terms of the levels described in the rubric. This analysis shows the quality of Mr JP's PCK in terms of projectile motion after he taught the topic for the first time.

6.3.1.1 KNOWLEDGE AND SKILLS RELATED TO CURRICULAR SALIENCY

Prompts 1 and 2 were used to elicit knowledge from the teacher regarding his understanding of curricular saliency. The amendments Mr JP made to Prompts 1 and 2 when constructing his post-CoRe are seen in Figure 6.10.

1. What do you intend the learners to learn about each of the ideas?	I intend for learners to learn the concept of displacement and the relation between the initial position and the final position. I intend for them to learn that change in position can be found for the vertical and horizontal axis. I also need them to learn the difference between height and displacement and how to calculate height using displacement.	Firstly, I intend my learners to learn what a projectile is. I also intend for them to learn what free fall is and the difference between the two concepts. I want them to learn that change in velocity is the rate of change of position of an object and how to calculate it. I want them to conceptually understand the difference between the initial velocity and the final velocity. I intend for learners to know that the change in velocity of the horizontal motion is the same as the change in velocity of the vertical motion. I also intend for them to learn to choose the positive direction before calculating the change in velocity. And most importantly I
		want them to learn that at maximum height, the velocity of the object is zero.
2. What concepts need to be taught before teaching this big idea?	The concept of distance and its difference to displacement needs to be revised. Learners must know how to convert units especially kilometres to metres. They also need to be taught about vectors and scalars to know that displacement is a vector. Learners must be familiar with the equation of motions from grade 10.	Learners must know that velocity is the rate of change of displacement. Displacement must first be taught before velocity can be taught. Learners must also have been taught about vectors and scalars.

Figure 6.10: Prompts 1 and 2 extracted from Mr JP's post-CoRe.

An important addition was found at Prompt 1, Big Idea 2, where he said:

“Firstly, I intend my learners to learn what a projectile is. I also intend for them to learn what free fall is and the difference between the two concepts.”

He explained the concept of a projectile in his first lesson (Section 1.1). He said: “The motion of an object that is straight upwards or straight downwards when the only force acting on the object is the gravitational force.” Moreover, for free fall, he indicated that the only force acting on an object in free fall is the gravitational force. There is very little difference in the definitions he provided because an object in free fall can be considered a projectile. Although the definitions of the two concepts mentioned are very similar, learners need to be able to differentiate between them because, in the revised examination guidelines of the DBE (DBE, 2021), separate definitions for free fall and vertical projectile motion were given, which was not the case in the previous 2017 version (DBE, 2017). This could be the reason why Mr JP felt the need to distinguish between the two concepts in his post-CoRe. These explanations enabled Mr JP to instil the understanding that projectiles fall freely and the only force acting on the projectile is the gravitational force.

Mr JP showed improved knowledge of the curricular saliency of the big ideas when he pointed out critical new concepts within the topic of vertical projectile motion, which he did not identify in his pre-CoRe. One of these new concepts was addressed during his first lesson (Section 1.4), where he indicated that when dealing with problems in vertical projectile motion, the acceleration is a constant $9,8\text{ ms}^{-2}$ and always downwards. Furthermore, he addressed the crucial concept of time-symmetry when he explained to learners that an object takes the same amount of time to reach its maximum height from the point of launch as it does to return to its original position from maximum height (Lesson 1, Section 1.4). He also highlighted the concept of time-symmetry in his VSR interview (Question 11) when he mentioned important concepts for learners to know. He said:

“I needed them [learners] to know time symmetry. That the time taken from the initial position to the maximum height will equal the time from the maximum height back to the initial position, that was very important for them [learners] to know, for me.”

During the analysis, several new concepts were identified that were not included in his pre-CoRe. One of these concepts is the emphasis that projectile motion at Grade 12 level is in one dimension. In his VSR interview (Question 7), he indicated: “vertical projectile motion, which goes straight up and goes straight down.” He also explained (Lesson 1, Section 1.4) that when an object passes the same position, it will always have the same velocity and magnitude upon its return, but in an opposite direction.

However, there was an important new concept that Mr JP did not refer to in his pre- or post-CoRe, which was that objects being dropped from a moving carrier would initially move in the direction of the carrier. This concept is important since such information is vital in understanding these scenarios and developing learners' conceptual reasoning skills.

As indicated in Chapter 4, Mr JP identified an extensive list of relevant pre-concepts throughout his pre-CoRe and interview to assist in teaching each of the big ideas. He, therefore, showed improved knowledge of curricular saliency when he identified the following pre-concepts that were not mentioned before in his pre-CoRe: Momentum (Prompt 5, Big Idea 2 and Lesson 1, Section 1.5), gradient (Lesson 2, Section 2.3), tangent to a graph (Lesson 2, Section 2.3 and 2.4) and metric units (Prompt 8, Big Idea 1; and Lesson 1, Section 1.6).

During his second lesson (Section 2.3), Mr JP explained the gradient of the position-time graph and elaborated on using the mathematical formula $\left(\frac{y_2 - y_1}{x_2 - x_1}\right)$ to calculate the gradient. He indicated that the gradient can be used to calculate the velocity of an object for that time interval. He showed good knowledge of the curricular saliency of this concept when he expanded his explanation to include the meaning of tangents in the curved position-time graph. He used an example and explained that if the gradient of the tangent is decreasing, it indicates that the object's velocity is decreasing and if the gradient of the tangent increases, the object's velocity increases. However, in both his pre- and post-CoRes, as well as during the interviews, Mr JP did not address the meaning of the gradient in the velocity-time graph, nor did he address the interpretation of the area under the velocity-time and acceleration-time graphs.

As explained earlier, Mr JP identified many relevant new concepts, which he did not mention in his pre-CoRe. These additions made his list of relevant new concepts in each Big Idea extensive. He also identified an extensive list of pre-concepts relevant to the big ideas, which required an understanding of the big ideas. He formed logical links between the pre-concepts of other topics and vertical projectile motion. However, he was less successful when he attempted to form the link with the preceding Grade 12 topic, momentum. It was concluded that Mr JP provided enough evidence to introduce a logical sequence of concepts. The third category in the rubric describes his knowledge of curricular saliency the best, namely, *Exemplary*.

6.3.1.2 KNOWLEDGE AND SKILLS RELATED TO LEARNER'S UNDERSTANDING OF SCIENCE

In his pre-CoRe, Mr JP had difficulty identifying learner difficulties and misconceptions. For example, in his post-CoRe, he added to Prompt 7 (Big Idea 1) that learners struggle to remember the units of measurement for displacement and how to convert other units to metres. Additionally, for Big Idea 2 (prompt 7), he noted that learners forget to include the direction of velocity in their answers. It is important to note that these difficulties are not documented in research as difficulties in this topic and were not included in the expert CoRe. It is possible that the class Mr JP was teaching lacked the prior knowledge necessary for metric conversions and units of measurement, which may be due to a lack of proper teaching in previous years rather than a typical learner difficulty. As for his entry at Big Idea 2, where he indicated that learners forget to write the direction of velocity in their answers, it seems that this is indeed the case; they forget, and it may not necessarily be a difficulty.

Mr JP made a statement in his post-CoRe (Prompt 1, Big Idea 2) (Figure 6.10) where he said:

"I want them [learners] to learn that change in velocity is the rate of change of position of an object and how to calculate it. I want them to conceptually understand the difference between the initial velocity and the final velocity."

His statement regarding the change in velocity is not correct. The rate of change in position ($\frac{\Delta x}{\Delta t}$) can be used to calculate the average velocity for that time interval and not the change in velocity as indicated. I think this was an oversight by Mr JP because he responded to Prompt 2 (Big Idea 2) in his post-CoRe and said: "Learners must know that velocity is the rate of change of displacement". In Lesson 1 (Section 1.3), Mr JP explained the concept of change in velocity successfully when he said: "Final velocity minus initial velocity equals the change in velocity." He provided further insight during his response in his VSR interview (question 9) where he elaborated on the importance of reference points regarding the initial and final velocity of an object. He said:

"The maximum height velocity [velocity at maximum height] can act as both final [velocity] and initial [velocity]. I think that's very important. I wish I didn't write v_f [final velocity]. I wish I had just written zero metres per second because we can use it [velocity at maximum height] as final [velocity], and we can use it as initial [velocity], so I think that's positive. We can divide the entire motions into different aspects where we can use this [velocity at maximum height] as a final [velocity] and as initial [velocity]"

Another difficulty identified by Mr JP in the VSR interview (Question 13) is related to mathematical calculations. He said:

*“When they [learners] are working with this equation [one of the equations of motion] to put the velocities inside the brackets because a velocity can be negative or positive. And you get a different answer when you use the brackets *and when you don't. So I needed them always to remember to put the brackets.*”*

As indicated, this difficulty is related to mathematical skills rather than conceptual knowledge of physics. However, Mr JP is correct in indicating the importance of the brackets. Since vector quantities can be positive or negative, it is crucial to substitute the values using brackets since $-5^2 = -25$ and $(-5)^2 = 25$. It can be seen that the answers are different, and therefore it is essential to clarify the order of operations and ensure that expressions are evaluated correctly.

Mr JP showed improved knowledge of learner understanding when he was able to correct his misinterpretation, which was evident during his second lesson (Section 2.4). This particular misconception had been thoroughly discussed in Chapter 5 and pertained to his interpretation of a pre-drawn position-time graph found in the textbook. The position-time graph depicted the motion of an object that was dropped, bounced on the ground, and then moved back upward (Figure 5.21). However, it was crucial to note that the graph was plotted with the downward direction considered as positive and given Mr JP's customary practice of considering the upward direction as positive, it created some confusion for him during interpretation. One critical aspect that Mr JP had initially overlooked was the necessity of establishing a clear frame of reference based on the position-time graph. This oversight had impeded his ability to interpret the graph accurately, leading to his difficulties in understanding it and, therefore, enhancing learner difficulties instead of addressing them.

It was, therefore, notable that Mr JP showed improved knowledge of learner understanding when he responded to Questions 23 and 25 in his VSR interview after he taught his lessons and gained teaching experience. During his second lesson (Section 2.4), he indicated that he was concerned about the example discussed in the previous paragraphs. When asked (Question 23) about this concern, he said:

“I'm thinking how the graph would look if downwards is taken as positive... would they be able to interpret it if we are given it downwards as positive?”

He elaborated during his VSR interview (Question 25) and said:

“Definitely this example. I wish I focused on teaching them how to identify the direction of the object. This is what I mean. I wish I told them to; of course, we were taking upwards as positive to identify if the velocity is decreasing or increasing and then come to the conclusion that it is going upwards or downwards based on the change in velocity. I wish I'd done that.”

From his response to Question 23, it is evident that Mr JP realised that his strategy to always choose upward as positive has shortcomings. Additionally, his response to Question 25 indicates his awareness that learners should determine the frame of reference from the given scenario and not decide beforehand on a fixed reference frame. Reflecting on the example of his interpretation of the position-time graph discussed earlier; it is evident that Mr JP's initial approach inadvertently contributed to learner difficulties and misconceptions. However, with the teaching experience he has gained, there is now compelling evidence that he has honed his ability to interpret the same example correctly. This improved PCK, on his part, is poised to enhance the conceptual thinking and reasoning skills of his learners.

To summarise, Mr JP mentioned some misconceptions and learner difficulties; however, most of these are not normally documented as misconceptions or difficulties, and some were not topic-related. He corrected some of his misinterpretations that occurred during the lesson. It was found that he provided standard definitions as a means to counteract the misconceptions or learner difficulties. Therefore, the second tier in the rubric describes his knowledge and skills related to learners' understanding of science as the best, which is *developing*.

6.3.1.3 KNOWLEDGE AND SKILLS RELATED TO CONCEPTUAL TEACHING STRATEGIES

Mr JP vaguely mentioned the use of a video in his pre-CoRe (Prompt 3, Big Idea 1), but did not elaborate on what would be displayed in the video. In his post-CoRe (Prompt 4, Big Idea 2), displayed in Figure 6.11, he provided more information on the video.

3. What representations would you use in your teaching strategy?	I intend to use a video showing a vertical projectile motion so that learners build a conceptual understanding of the motions they are to expect. I will also be using Phet simulations to show how a vertical projectile movement look like exactly. I will use the phet simulations to show the learners the change in position of the object in motion.	I intend to use a video showing a vertical projectile motion so that learners build a conceptual understanding of the motions they are to expect. I will also be using phet simulations where the velocity of the object will be denoted by an arrow. I will also show a video of a moving car that comes to a stop.
4. Give particular reasons for the representations used to engage with this idea?	I want learners to build their conceptual understanding of vertical projectile motions. I also know that they are most likely to not forget the presentation which means there is a chance of them not forgetting the conceptual knowledge. I also want them to know that vertical projectile motions do not have horizontal velocity. Using Simulations help visual learners build the conceptual understanding of the content	I want learners to build their conceptual understanding of vertical projectile motions. I also know that they are most likely to not forget the presentation which means there is a chance of them not forgetting the conceptual knowledge. With the presentation they will be able to tell that at its maximum height the velocity is zero. I will the video of a moving car because I want the learners to understand the difference between the initial and final velocity.

Figure 6.11: Mr JP's response to Prompts 3 and 4 in his post-CoRe

He said: "I will also show a video of a moving car that comes to a stop." Mr JP lacked knowledge when he chose that representation because vertical projectile motion and the motion of a car coming to a stop are two different concepts. Vertical projectile motion deals with objects that move under the influence of gravity only and only move vertically (Grade 12), while the motion of a car coming to a stop involves horizontal motion and the application of brakes, which entails external forces like friction being present. It is possible that using an example that is not directly related to the concept being taught could confuse learners. When teaching this concept, it might be more effective to use examples and analogies that are directly related to vertical projectile motion.

Mr JP felt strongly about using PhET simulations to enhance conceptual thinking and development in his learners, as seen in his responses to Prompts 3 and 4 (Figure 6.7) in his post-CoRe. Simulations can be an effective way to represent vertical projectile concepts to learners. It is also indicated as a method in the expert CoRe (Prompt 3). However, the data analysis of Mr JP before he taught a lesson (Chapter 4) revealed that his responses were vague, and there was no evidence that he had ever looked at the PhET simulation on the topic. This shortcoming could be ascribed to his lack of experience in teaching the topic. The findings in Chapter 4 were confirmed when Mr JP taught the topic for the first time. Although PhET simulations, when used correctly, can help support the discussion of concepts, they

were sometimes futile in Mr JP's lessons as he did not use them to address aspects of one-dimensional vertical projectile motion properly.

Mr JP showed improved knowledge and skills using PhET simulations after his lesson presentations. When asked in the VSR interview (question 3) if his simulation was successful, he said:

"I think it was. Scientifically it is not correct. But I think it was because this is how it looks in their exams and books. It is how it looks, but we know it is not like this. So I think it worked. I think it helped."

In a follow-up question in the VSR interview (Question 4), he was asked to explain what he meant when he responded to Question 3 and said his simulation was not scientifically correct. He said:

"I was reminded that vertical projectile motion does not have horizontal velocity. In reality, the ball was not supposed to move either left or right, but straight up and straight down."

He also added to his post-CoRe (Prompt 4, Big Idea 1): "I also want them to know that vertical projectile motions do not have horizontal velocity."

It is clear from his response that he now knows how to use the simulation correctly after teaching the topic. This understanding may have led to his entry in his post-CoRe (Prompt 3, Big Idea 1), where he indicated: "I will also be using Phet simulations to show how a vertical projectile movement look[s] like exactly." I believe he meant a motion in one dimension (with an elevation angle of 90°), going straight up and down, as he stated in his VSR interview.

Furthermore, regarding his use of the vector arrow in his PhET simulation for velocity (Figure 5.24), he indicated in the VSR interview (Question 2):

"I wanted them to understand that at maximum height, the ball stops before it comes back down. I think with this simulation I wanted them to see that at the maximum height, this thing [object] stops before it goes down. That's why, to have a mental model of projectiles."

This is a good idea and will instil conceptual development. Mr JP is aware of the concept that a vertical projectile's velocity is zero at maximum height. However, as explained earlier, the wrong use of the simulation was futile in his lessons, and he realised this, as can be seen in his response to Question 6. He said:

"I think it is the arrow in the second simulation. I included the arrow because the arrow denotes the velocity, the magnitude and the direction of the velocity. So I

needed them to see. But it did not work out well. But I needed them to see that at the maximum height, the arrow disappears, or the velocity is zero because the arrow is not facing up or down."

Mr JP showed improved knowledge of the use of this stimulation and indicated (Question 7):

"I think next year when I do teach this section again, or maybe when we do our revision for June, I will use the correct representation of vertical projectile motion, which goes straight up and goes straight down. Because I want that arrow to disappear completely, I will explain that, even though it goes straight up and down, we represent it like this, sort of mountain-shaped, but I just need the arrow to disappear. And I will play it in slow motion."

His remark about representing projectile motion as "mountain-shaped" pertains to the general representation of a projectile motion like the ones he used in his lesson presentations, for example, in Lesson 1 (Section 1.6), when he represented the motion of a ball projected upward as seen in Figure 6.12.



Figure 6.12: Representation used by Mr JP to demonstrate the motion of a projectile projected upward

Mr JP needed to ensure that this visual representation (Figure 6.12) accurately conveyed the fundamental principles of projectile motion, including initial velocity, final velocity, and maximum height, with which, in this regard, he succeeded. The representation allows for enhanced learners' understanding of these concepts. He effectively incorporated the "mountain shape" into his teaching strategy, utilising it as a diagram in Lesson 1. Mr JP further enriched his teaching strategy when he included reference points, marked with alphabetical letters, along the object's motion path (Lesson 2). These reference points were linked to the previously mentioned concepts, as elaborated upon later in this section.

Another feasible representation identified by Mr JP was the use of physical objects (Lesson 1, Section 1.1) when he demonstrated basic projectile movement, throwing the chalk in his hand in the air and catching it again at the point of launch. As explained in Chapter 5, most of the representations used by Mr JP were relevant to the concepts he explained. He linked crucial concepts (initial velocity, final velocity, maximum height, displacement, gravitational acceleration, and time-symmetry) to his representations and logically explained the interconnections between them.

As was the case in his pre-CoRe (Chapter 4) and lesson presentation (Chapter 5), Mr JP did not provide adequate questions that would ascertain learner understanding. He showed a lack of knowledge in teaching strategies when he noted in his post-CoRe (Prompt 5, Big Idea 2):

"I will give them questions to do that will demand them to use and develop their understanding of the key idea."

Mr JP made a statement about what good questions would be, but he was not able to identify any. As explained in Chapter 5, he seldom incorporated questions in his lessons to stimulate conceptual reasoning, mainly because his questions required one-word answers and rote learning. He even, at one stage, ignored a wrong answer given by a learner (Lesson 1, Section 1.1). There was no evidence found after he taught a lesson to show development in knowledge about asking questions that would require higher-order thinking skills from his learners.

It was noted that Mr JP did not use the alphabet during his first lesson to indicate critical points along the object's motion path, but he used it during his second lesson (Sections 2.2 and 2.4). In the VSR interview (question 12), he said:

"I saw that he [Another teacher] divided his entire vertical projectile motion using letters. When I explained it, I divided them in my mind, which is not very helpful to the learners. So I saw that he [Another teacher] put the initial position as A, the maximum height as B, back to the initial position as C, and then the ground is D. I think that's very, very helpful, something I was reminded of that I forgot I think. And it is even easier to break down the motion of the graph when you have assigned letters to the different aspects of the graph."

This strategy aligns with the recommendation in the expert CoRe (Prompt 5), which suggests identifying different stages of motion using the alphabet. This approach can help the learners to link physical quantities to specific stages of the motion. Moreover, this strategy enabled him to extract specific data related to a particular reference point, which he linked to the equations of motion, allowing for the successful resolution of complex problems.

However, it is important to note that Mr JP's improved understanding of this strategy cannot be attributed solely to his experience after teaching his first lesson. Instead, it is likely due to his observation of another teacher teaching the topic.

Mr JP was asked to describe the strategy he would use to establish conceptual development of the big ideas (Prompt 5). His response is displayed in Figure 6.13. The teaching strategy Mr JP planned to use is vague and poorly articulated. There is little evidence of an effective planned strategy for explaining the big ideas regarding vertical projectile motion. In his response to Prompt 5 (Figure 6.13), he focused mainly on pre-concepts and how he would explain them.

5. Describe the strategy you will use to establish conceptual development of the key idea.	In addition to the presentation I will use, I am going to explain the difference between distance and displacement to the learners at the beginning of the lesson before diving into the content. In addition to explaining the difference between these two concepts, I will show them how the two are calculated between two points. If time allows, I will take the learners outside, indicate the starting position, and move them to different directions and then find the learners' individual change in position.	In addition to the presentations, I will show them how to calculate the change in velocity of horizontal and vertical motions clearly indicating the directions of each. I will also refer them back to momentum where they learned the concept of change in velocity. I will give them questions to do that will demand them to use and develop their understanding of the key idea.

Figure 6.13: Mr JP's response to Prompt 5 about his planned teaching strategy

In this VSR interview, we find information that Mr JP planned to implement the same teaching strategy that he described in his pre-CoRe, which was analysed in Chapter 4 and demonstrated when he taught lessons, as analysed in Chapter 5. He indicated the importance of pre-concepts at the beginning of his lesson before starting with the new concepts of vertical projectile motion during Question 5 when he said: "They need to understand the concept of displacement. Because if they don't understand the concept of displacement, it becomes really difficult for them to understand how to solve vertical projectile calculations." When he responded to Question 7, he indicated that he would still use his PhET simulations to introduce the new topic of vertical projectile motion but would make the necessary improvements as discussed in the previous section.

In summary, Mr JP identified a variety of representations in the form of drawings, videos, simulations and the use of physical objects. However, the representation he suggested of a video of a car stopping is not considered relevant. The suggested representations will support the development of concepts related to the big ideas, especially his improved strategy regarding the PhET simulations. He correctly linked concepts to his representations,

and evidence was found on how the use of the representations would support conceptual development. Mr JP struggled to ask questions that effectively elicited knowledge from his learners. The majority of his questions were basic and only required one-word answers or rote memorisation. As a result, his questions did not encourage higher-order thinking or facilitate the conceptual development of his learners' knowledge, and in the post-CoRe, no improvement was evident.

The teaching strategy Mr JP suggested is considered generic because he did not clearly explain how this would be employed when teaching the specific big ideas. It is evident from the post-CoRe that he struggled to articulate his PCK clearly. Although he acknowledged learner misconceptions, most of the difficulties he mentioned were not normally documented as misconceptions or difficulties, and some were not even related to the topic, as discussed in the previous section. Mr JP considered sequencing and aspects related to curricular saliency. He showed improved knowledge and skills in teaching strategies, especially in his use of representations. He described a workable strategy that created the impression that his focus is more on conceptual development rather than exam preparation. However, his inability to ask adequate questions and ambiguous articulation of his teaching strategy resulted in the second category of the rubric being the best description of his knowledge and skills related to teaching strategy, namely, *Developing*.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

In Chapters 4, 5 and 6, the data collected throughout this study was presented and discussed to provide answers to the sub-questions that guided the study. Chapter 7 provides an overview of the rationale behind the research and the methodology employed. It offers a summary of the study's findings, explaining how these results address the main research question. An emerging finding is discussed, and the chapter also delves into the study's limitations and how they were managed. It continues with recommendations for future research endeavours and concludes with my reflection on the study.

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

7.2.1 OVERVIEW

Investigating PCK development is crucial for a multitude of reasons. One of the primary reasons is that it enhances teaching quality. Pedagogical content knowledge (PCK) is widely recognised as a crucial element that positively influences the quality of teaching and learning (Mazibe et al., 2023; Park & Oliver, 2008). Teachers with a robust PCK can effectively convert their content knowledge into formats that are understandable and accessible to their learners (Shulman, 1986).

Another benefit of PCK development is that it fosters the expansion of knowledge in teaching. Shulman (1986) characterised PCK as teachers' comprehension of "the most useful forms of representation of the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). This understanding is broadened by teaching experience and adds to the overall growth of knowledge in teaching (Park & Oliver, 2008).

Teaching experience has been identified as an essential factor in PCK development (Chan & Yung, 2018; Van Driel et al., 1998). This study used the RCM as the framework to explore how novice teachers' PCK about vertical projectile motion developed through teaching experience. The selection of vertical projectile motion as the focal point stems from the acknowledged challenges that learners encounter in grasping this particular topic, as reported by Prescott and Mitchelmore (2005b) and Sikhosana and Mudau (2022). This study investigated two realms of the RCM: pPCK and ePCK, which are illustrated in Figure 3.2.

These realms represent the PCK of teachers at the topic level before, after and during teaching. Carlson et al. (2019) explain that pPCK informs ePCK when presenting a lesson, and ePCK is a subset of pPCK. To investigate the development of the PCK of novice science teachers, the following research questions guided this study:

Primary Research Question

How does the PCK of novice teachers about vertical projectile motion develop through teaching experience?

Secondary Research Questions

1. What is the level of novice teachers' PCK revealed before teaching vertical projectile motion for the first time?
2. What is the level of novice teachers' enacted PCK when teaching vertical projectile motion for the first time?
3. What is the level of novice teachers' PCK revealed after teaching a lesson on vertical projectile motion?

To answer these questions, I employed a variety of data collection methods that aligned with the RCM (see Figure 3.2). I used CoRes, which were completed both before and after teaching as structured instruments to gauge the initial and final state of teachers' pPCK. I also conducted semi-structured interviews before (Appendix G – I) and after (Appendix J – L) teaching sessions to gain deeper insights into the teachers' pre-existing knowledge and how it transformed. Moreover, I observed and video-recorded teaching sessions to capture the real-time application of PCK within the classroom context (Appendix M - R). By analysing these data sources, I was able to shed light on the development of novice teachers' PCK concerning vertical projectile motion and how PCK evolved through teaching experience. Collectively, these data collection methods, coupled with the RCM, offered a holistic view of novice teachers' PCK development and enriched our comprehension of the dynamic nature of PCK.

In summary, the RCM served as a valuable model for assessing and understanding the progression of novice teachers' PCK throughout their teaching experience, aligning with both the primary and secondary research questions. It allowed for a systematic evaluation of their PCK levels before, during, and after teaching vertical projectile motion.

The teachers' responses to the prompts in the pre-and post-CoRe tool were scored using a rubric for pPCK (Appendix B), which was adapted from three distinct rubrics, namely those developed by Mazibe (2017), Coetzee (2018), and Mavhunga (2012), to create a suitable

rubric. This rubric focuses on components suggested in the grand PCK rubric (Chan et al., 2019), namely (a) Knowledge and skills related to curricular saliency, (b) Knowledge and skills related to conceptual teaching strategies, (c) Knowledge and skills related to learner's understanding of science. The enacted PCK of the teachers was scored using a modified rubric (Appendix C), similar to the ones used by Coetzee (2018) and Mazibe (2017). This rubric also focused on the same three PCK components.

Both rubrics were adapted and modified, as explained in the previous paragraph, to categorise the teachers within three levels of competence: Limited (1), Developing (2), and Exemplary (3). The same levels were utilised for each rubric to facilitate an easy and effective comparison.

7.2.2 ANSWERING SECONDARY RESEARCH QUESTION 1

To answer the first secondary research question, we utilised the pre-CoRes data found in Chapter 4, which is accessible at the beginning of each teacher's section, along with insights obtained from interviews (see Appendix G – I) conducted before lesson presentations. These selected data sources were deemed comprehensive enough to ascertain the pPCK possessed by the teachers before embarking on their lesson presentations.

7.2.2.1 *Knowledge and skills related to curricular saliency*

Each teacher highlighted fundamental Grade 10 pre-concepts essential for comprehending vertical projectile motion, including frame of reference, displacement, distance, vectors, scalars, velocity, and the application of motion equations. Additionally, Mr DN and Mr JP underscored the importance of revisiting Grade 11 concepts, specifically Newton's laws, which have logical connections to the core ideas preceding the introduction of vertical projectile motion. In contrast, Ms NJ initially did not recall specific Grade 11 concepts. Notably, Mr DN also referred to Grade 12 pre-concepts, such as momentum and impulse, which share logical links with the new topic of vertical projectile motion.

All three teachers identified appropriate new concepts, with a noteworthy example being the recognition that the velocity of an object at its maximum height equals zero. The significance of this example lies in the fact that such information is not provided explicitly in assessment questions. Learners, upon encountering the phrase "maximum height," should intuitively associate it with the velocity being zero at that particular position. However, it is worth noting that the list of new concepts was not exhaustive for each participant, and some important concepts were overlooked. For instance, Mr DN omitted reference to time symmetry, Mr JP did not highlight that the initial velocity of a dropped object is zero, and Ms NJ did not

acknowledge that vertical projectile motion problems in the Grade 12 context are considered to occur in the absence of air resistance.

It is worth noting that neither Mr DN or Mr JP delved much into the crucial concept of gravity, which is fundamental to the topic of vertical projectile motion—neither explicitly mentioned constant gravitational acceleration, a vital concept for understanding and solving projectile motion questions.

Initially, before teaching, Mr JP and Ms NJ encountered challenges in logically sequencing the new concepts of the topic. Only Mr DN's data demonstrated evidence of a logically sequenced presentation of new concepts.

As indicated in Table 7.2, all three teachers received a score in the *developing* category for knowledge and skills related to curricular saliency.

7.2.2.2 Knowledge and skills related to learner's understanding of science

All three teachers faced challenges in identifying learner difficulties and misconceptions, with Mr JP providing minimal information, attributing it to his *limited* score in this component of PCK. He acknowledged that learners struggle to distinguish between distance and displacement, a challenge also highlighted by Mr DN and Ms NJ. Mr JP and Ms NJ recognised the complexity of vectors and scalars for learners, delving into explanations to aid comprehension. It should be noted that the before-mentioned difficulties are basic confusions that should already have been addressed in Grade 10.

Mr DN and Ms NJ were the only teachers who identified other learner difficulties and misconceptions apart from the ones mentioned in the previous paragraph. Both referred to the misconception that learners interpret the shape of a position-time graph as a picture of the path of the motion. Ms NJ also elaborated on the velocity-time graph. She indicated that learners think the direction in which the object is moving is the same as the direction in which the velocity-time graph is drawn, which is also documented in the literature (Barclay, 1985; Clement, 1985; Lapp & Cyrus, 2000). In addition, Mr DN identified the misconception that learners think velocity and acceleration are always in the same direction. These are indeed misconceptions and were also listed in the expert CoRe at Prompt 7.

Furthermore, Ms NJ highlighted the language barrier that learners might face doing a subject like physical sciences in a language other than their home language. Ms NJ did well in mentioning this difficulty, as she is currently experiencing it in her teaching career. Language can be a barrier to learning, especially if you are not taught or assessed in your home language. Rollnick (2000) acknowledged that expecting learners to learn a new and difficult

subject through the medium of a second language is challenging, giving them a double task of mastering both science content and language. Prinsloo et al. (2018) agreed that the language of learning and teaching (LOLT) plays a significant role in the learners' understanding of science. Therefore, when the language of instruction is not the learners' home language, it could potentially impact their understanding of science subjects, which, in this case, is the topic of vertical projectile motion.

Prior to teaching the topic, all three teachers displayed a lack of knowledge of learner understanding, and their own misinterpretations or misconceptions were evident. Such instances were noted, as Mr JP indicated before the lesson presentation, evidently not fully grasping that vertical projectile motion is in one dimension. He alluded to a projectile's horizontal and vertical velocity, which is not considered in Grade 12 vertical projectile motions. Mr DN had the same misinterpretation when he suggested the scenario of a javelin or shot-put ball being thrown as an example to explain vertical projectile motion. These movements are not vertical projectile motions (up and down movements along a straight line) since, in real life, these objects travel in two dimensions. Using these examples without explicit elaboration about the differences between vertical projectile motion and two-dimensional projectile motion can confuse learners. Furthermore, Mr DN had the misconception that the total displacement of an object dropped from a rising carrier is measured from its maximum height instead of the point of release.

Due to the lack of information provided by Mr JP, he was scored in the first tier of the rubric, which was *limited*. Mr DN and Ms NJ were scored in the second tier of the rubric, which was *developing*.

7.2.2.3 Knowledge and skills related to conceptual teaching strategies

In the exploration of teacher strategies related to representations in the context of vertical projectile motion, distinct patterns emerged. Both Mr DN and Ms NJ encountered challenges in diversifying their use of representations, primarily relying on drawings and physical objects to illustrate vertical projectile scenarios. In contrast, Mr JP demonstrated a broader approach, incorporating videos, simulations, and drawings. However, a closer examination revealed that Mr JP's information on his chosen representations lacked depth and specificity, as previously discussed in Chapter 4.

Mr DN's inclusion of real-world examples aimed at enhancing learner engagement fell short due to the choice of examples like throwing a javelin or a shot-put ball. These instances, while tangible, might mislead learners by implying vertical projectile motion exists in two dimensions, contrary to the Grade 12 NSC curriculum. Ms NJ suggested an unfamiliar

approach where she intended to use the motion graphs as representations to explain the object's motion. The sequence suggested by the CAPS document analyses the motion and then draws the corresponding graphs. Explaining the motions of an object using representations in the form of a drawing and the learner's intuitive understanding of the phenomenon can enable the teacher to link concepts to the different parts of the motion. This approach, in turn, can better assist them in drawing the graphs.

Despite their varied strategies, all three teachers suggested drawings as representations before they presented their lessons. This commonality implies a shared recognition of the usefulness of drawings in enhancing learners' conceptual development in the context of vertical projectile motion.

Shulman (1986) posited that effective teaching involves understanding how to present topics so that learners understand them and acknowledging the nuances that make certain topics challenging or accessible. This teaching ability tends to be tacit (Loughran et al., 2006). All three teachers encountered difficulties explaining their teaching strategies during pre-CoRes and interviews. As a result, they presented general approaches without detailing how they planned to introduce and teach the concepts of vertical projectile motion.

A fundamental teaching strategy for fostering conceptual development is the skilful use of questions (Nappi, 2017). Both Mr JP's and Mr DN's questions were about pre-concepts. Although it is good to do revision and reinforce important pre-concepts, it should not have been the only focus of their questions. Ms NJ identified two questions in her pre-CoRe that would be helpful, but they were not merely enough to elicit knowledge from the learners to enhance their conceptual understanding.

Ms NJ had planned an effective teaching strategy that involved segmenting an object's motion path into distinct sections, using alphabet letters to designate reference points. This strategic approach aligns with the expert CoRe's recommendation (Prompt 5) to identify different motion stages using the alphabet. While Ms NJ had concrete plans, there was no evidence in the data indicating a similar strategic approach from Mr JP and Mr DN.

Table 7.2 reveals that, in the pre-teaching phase, Mr JP and Mr DN demonstrated *limited* proficiency in the teaching strategies component, whereas Ms NJ exhibited *developing* competency, earning a score in the second tier of the rubric.

In concluding the answer to secondary research Question 1 across all three PCK components, it is evident from Table 7.2 that none of the teachers achieved an exemplary score for any of the three PCK components. The highest scores were attained in the

component of curricular saliency, with all three teachers placed at the second tier of the rubric, indicating a *developing* level. The component that posed the most challenges to teachers was conceptual teaching strategies, with Mr DN and Mr JP scoring *limited* and Ms NJ scoring *developing*.

7.2.3 ANSWERING SECONDARY RESEARCH QUESTION 2

To answer the second research question, an assessment of data obtained from lesson observations (refer to Appendix M - Appendix R) was conducted. Additionally, insights gleaned from the VSR interviews (refer to Appendix J – L) proved instrumental, providing valuable information concerning the ePCK of the teachers.

7.2.3.1 *Knowledge and skills related to curricular saliency*

During their lesson presentations, all three teachers referred to pre-concepts. Mr DN revisited the pre-concepts selected in the pre-CoRe, aligning them with the Grade 10 and 11 curriculum topics before linking them to the new concepts of vertical projectile motion. On the other hand, Mr JP delved into fewer pre-concepts but dedicated significant time to them, spending over ten minutes solely explaining the distinctions between distance and displacement—topics typically covered extensively in Grade 10. In contrast, Ms NJ allocated minimal time to explaining or reviewing pre-concepts, occasionally mentioning them without detailed explanations. However, when she did explain a pre-concept, she effectively elucidated the interrelatedness between the pre-concept and new concepts.

All three teachers explained relevant new concepts to learners. Mr DN and Mr JP alluded to the characteristics of gravity, emphasising its constancy ($9,8 \text{ ms}^{-2}$) and downward direction. All three teachers effectively conveyed the most important concepts related to the topic of vertical projectile motion.

It was observed that Mr JP and Ms NJ made a specific distinction between free fall and projectile definitions. Although this distinction may seem superficial, it gains significance due to revisions in the examination guidelines for Physical Sciences Grade 12 in 2021 by the Department of Basic Education (DBE, 2021), which included the definition of free fall absent in the previous 2017 version (DBE, 2017). This likely prompted Mr JP and Ms NJ to differentiate between the two concepts to align with the revised guidelines.

Scaffolding of concepts was notably more evident in the teaching of the three teachers (ePCK) than in their pre-teaching pPCK, as revealed in the pre-CoRes. Mr DN progressed to more complex problems, integrating horizontal motion in one dimension with the new challenge of vertical projectile motion. Mr JP scaffolded his examples by initiating a

discussion on the position-time graph, elucidating the meaning of the gradient, and concluding with an application example demonstrating the interpretation of the position-time graph using the gradient. Ms NJ similarly scaffolded her examples, ranging from simpler scenarios, such as a ball being dropped from a tall building to more intricate situations involving a ball thrown upwards from a great height and falling to the ground. The successful scaffolding of content may be attributed, in part, to external resources such as textbooks and an interactive whiteboard, in the case of Mr DN, which guides the teachers in teaching the content.

Mr DN demonstrated exceptional performance, earning an *exemplary* score in the third tier of the rubric. On the other hand, Mr JP and Ms NJ achieved a *developing* score, placing them in the second tier. Table 7.2 shows the improvement in Mr DN's assessment as he progressed from the *developing* level to the *exemplary* level. Both Mr JP and Ms NJ maintained their scores at the *developing* level.

7.2.3.2 Knowledge and skills related to learner's understanding of science

All three teachers identified learner difficulties and misconceptions while teaching vertical projectile motion (ePCK). Mr JP acknowledged that learners are having difficulty realising that gravity is the only force acting on an object during free fall and do not understand that the velocity of an object at maximum height is zero. Mr DN and Ms NJ realised learners were having difficulty interpreting the slope of the position-time graph. Mr DN also understood that learners think that when the direction of movement changes, the direction of gravity changes. These are indeed considered learner difficulties or misconceptions, as indicated in the expert CoRe at Prompt 7.

Mr JP and Mr DN showed improved knowledge of learner understanding when they addressed the mentioned learner difficulties and misconceptions. Although the teachers showed knowledge of learner difficulties and misconceptions while teaching the topic of vertical projectile motion, they unfortunately also displayed their own misinterpretations and misconceptions. Sikhosana and Mudau (2022) indicated that some learners' misconceptions are created while the teacher is teaching the concept. This might have been the case when Mr JP could not interpret a position-time graph because of his rule of always choosing the upward direction as positive. Some of his examples also depicted motion in two dimensions, which is not considered in the Grade 12 NSC curriculum. Mr DN misinterpreted that an object moving upwards from the point of launch would take longer to reach maximum height than it would take to fall from maximum height to the point of launch, and Ms NJ created the impression that the position-time graph's shape resembles the path of the object's motion.

All three teachers received scores in the first tier of the rubric, indicating a *limited* performance in this particular component of PCK. Evidently, teachers found this component challenging, grappling to demonstrate a robust PCK. Strikingly, the scores for Mr DN and Ms NJ deteriorated in comparison to their pre-teaching PCK assessments, while Mr JP maintained his position at the limited level. This example underscores the complexity and difficulty teachers experienced in articulating a comprehensive PCK in this specific component of PCK.

7.2.3.3 Knowledge and skills related to conceptual teaching strategies

In the component of teacher strategies, including representations during their respective lessons on vertical projectile motion, all three educators employed appropriate visual aids to convey and reinforce key concepts effectively. Predominantly, drawings featured across the lessons of all teachers serve as a visual medium to represent the object's motion on the board. Additionally, both Mr JP and Ms NJ incorporated physical objects, such as pens and chalk, which they threw in the air, skilfully linking concepts like gravity and velocity to tangible demonstrations.

However, a nuanced examination reveals certain deviations from the initial plans outlined by Mr JP and Ms NJ. Despite Mr JP's intent (expressed in the pre-CoRe) to present a video, this aspect did not materialise. Instead, he utilised PhET simulations, employing vector arrows to elucidate crucial notions such as the velocity at maximum height being zero. While these simulations have the potential to support conceptual discussions, it became apparent that Mr JP's execution sometimes fell short. His use of PhET simulations lacked precision, occasionally illustrating motion in two dimensions, which could potentially lead to learner confusion. Ms NJ, although planning to use graphs of motion to interpret the object's trajectory like she suggested in the pre-CoRe, opted for drawings to aid in the drawing of graphs.

During their respective lesson presentations where ePCK becomes viable, it was noted that learner participation was limited, with minimal opportunities for meaningful questions or discussions aimed at enhancing conceptual comprehension and reasoning skills. The questions posed by all three teachers predominantly elicited brief, one-word responses, fostering a rote learning approach that fell short of promoting deep conceptual thinking. Notably, Mr JP, at one point during his lesson, overlooked an incorrect answer provided by a learner.

A commendable teaching strategy employed by all three teachers revolved around dividing an object's motion path into distinct sections. Ms NJ successfully implemented this approach

during her lesson, effectively linking different motion sections to relevant concepts and fostering the learners' conceptual development. While Mr DN also applied this strategy during his teaching, Mr JP initially omitted it in his first lesson but effectively implemented it in his second lesson, using the alphabet for reference points.

Throughout the teaching sessions, all three teachers adeptly incorporated the equations of motion into their lessons. Their common strategy involved using visual representations, primarily through board drawings, to illustrate the object's motion. These representations were aligned with segmented sections of the object's path, facilitating the extraction of specific data related to particular reference points and enabling the application of the equations of motion. This approach, in line with problem-solving methods emphasised by Gaigher et al. (2007), allowed the teachers to address complex problems successfully.

It has to be noted that some strategies were considered less successful. During their lesson presentations, all three teachers implemented a strategy where they would always choose the upward direction as positive when addressing vertical projectile motion questions. Mr JP indicated that this is his preferred method and that his learners should note that upwards is always positive. Mr DN also utilised this approach, primarily because it rendered gravity as a consistently negative quantity due to its downward nature. Ms NJ justified her choice by pointing out that selecting upward as positive aligns the position-time graph more closely with the object's motion path. While this strategy demonstrated cohesion among the teachers, Mr JP's subsequent difficulty interpreting a graph in the textbook—utilising downward as the positive reference frame—underscored a potential limitation in this approach.

In summarising the findings about teachers' enacted PCK across all three PCK components, we can turn to Table 7.2. It is observed that the curricular saliency component received the highest scores overall. Mr DN achieved an *exemplary* score, while Mr JP and Ms NJ scored in the *developing* tier. Conversely, the learner understanding component posed challenges, with all three teachers receiving *limited* scores. The conceptual teaching strategies component also proved challenging, with Mr DN and Mr JP scoring in the *limited* tier while Ms NJ remained in the *developing* tier.

7.2.4 ANSWERING SECONDARY RESEARCH QUESTION 3

To answer the third research question, an assessment of data derived from the post-CoRes (refer to Appendix D – F) was undertaken. Additionally, insights from the VSR interviews were considered, particularly focusing on the development of teachers' pPCK after gaining experience through lesson presentations. These selected data sources were deemed

adequate to determine the level of pPCK acquired by the teachers following their engagement in teaching lessons on vertical projectile motion.

7.2.4.1 Knowledge and skills related to curricular saliency

During the VSR interviews following their lessons on vertical projectile motion, all three teachers expanded their lists of Grade 10 pre-concepts. For instance, Mr JP integrated Grade 10 concepts like gradient and tangent into a graph, Mr DN introduced motion concepts in one dimension, and Ms NJ emphasised sign conventions, including Grade 11 forces that were previously omitted. However, even though all three teachers acknowledged the significance of pre-concepts such as area and gradient when working with motion graphs during their post-CoRes and VSR interviews, none of them explicitly addressed the importance of these aspects across all three types of motion graphs before or after teaching.

Both Mr JP and Ms NJ briefly mentioned the Grade 12 pre-concept of momentum and impulse in their post-CoRes and VSR interviews, respectively. It was noticed that in their post-CoRe and interview, none of the teachers addressed the crucial pre-concepts of elastic and inelastic collisions taught in the Grade 12 topic of momentum and impulse. These concepts are essential for explaining the behaviour of bouncing objects. While all three teachers referred to the contact time between a bouncing object and the ground, they still did not explain in their post-CoRe or interview why there is a contact time even after teaching the topic. This omission might be attributed to their limited experience, as novice teachers, in recognising the link between vertical projectile motion and the pre-concepts of elastic and inelastic collisions. This finding concurs with research done by Carrier et al. (2020) that suggests that novice teachers may initially struggle to identify all necessary pre-concepts due to their limited teaching experience, but they become more adept at recognising these pre-concepts as they gain more experience and a deeper understanding of the subject matter.

Table 7.1 illustrates the new concepts each teacher could identify post-teaching that they could not identify before presenting their initial lessons.

Table 7.1: New concepts identified by the teachers after their teaching experience

Teacher	New concepts identified post-teaching
Mr JP	• Gravitational acceleration is constant $9,8 \text{ ms}^{-2}$ and always downwards • Time-symmetry • Projectile motion at the Grade 12 level is in one dimension • He also explained that when an object passes the same position, it will always have the same velocity in magnitude upon its return but in an opposite direction. • Vertical projectile motion (Grade 12) occurs in one dimension.
Mr DN	• Gravitational acceleration being constant $9,8 \text{ ms}^{-2}$, downwards
Ms NJ	• An object dropped from a moving carrier will have the same initial velocity as the carrier.

As indicated in Table 7.1, all three teachers were able to include relevant new concepts in the topic of vertical projectile motion. Moreover, Mr JP's teaching experience proved particularly beneficial, enabling him to introduce several new concepts. This addition is crucial for fostering the conceptual development of learners' understanding and reasoning within the topic.

However, there were still some new concepts that the teachers did not articulate even after teaching the topic. For instance, Mr DN did not mention the crucial concept of time symmetry, and Mr JP omitted that objects being dropped from a rising carrier would initially move in the direction of the carrier. These concepts are significant as they are vital for understanding projectile scenarios and developing learners' conceptual reasoning skills. Despite these omissions, their lists of new concepts expanded after gaining teaching experience and were considered extensive.

Mr JP, Mr DN, and Ms NJ all demonstrated an understanding of the logical sequencing of concepts and scaffolding of examples after they presented their lessons. They explained their intentions to introduce concepts in a sequence that progressed from simple to more complex ideas, facilitating learners' conceptual development.

A noteworthy observation is that all three teachers received scores in the third tier of the rubric, classifying their knowledge and skills related to curricular saliency as *exemplary*. What's particularly significant is the evident improvement in their post-teaching scores in comparison to their pre-teaching scores, underscoring a definite development in their PCK for the component of curricular saliency after gaining teaching experience.

7.2.4.2 Knowledge and skills related to learner's understanding of science

It was notable that Mr JP corrected both his misinterpretations mentioned in Section 7.2.3.2 post-teaching. It was evident that Mr JP realised that his strategy of always choosing upward as positive has shortcomings and that learners should determine the frame of reference from the question and not decide beforehand on a fixed reference frame. He also alluded to the fact that vertical projectile motion problems in Grade 12 are considered in one dimension (going straight up and down) and indicated that he would emphasise this during revision later in the year. Clearly, his teaching experience improved his PCK in terms of the component of learner understanding.

However, Mr DN and Ms NJ did not correct their misinterpretations, which were still evident during their VSR interviews. Mr DN referred to an example he did in class and still explained that the time it takes an object to move upwards will be greater than the time it takes the object to return to its original position. Ms NJ indicated that she would start with the position-time graph in future lessons instead of the velocity-time graph because it resembles the object's motion path. In her words: "It [the position-time graph] shows the learner exactly what is happening". Teachers having misconceptions or misinterpretations can be barriers to conceptual understanding of science for both the teacher and the learner. If teachers have misconceptions about the subject or topic, it can affect their ability to effectively convey scientific concepts to their learners (Qian et al., 2019). This is because these misconceptions can coexist with the new knowledge learners gain in the classroom, leading to a mix of fact and fiction (Qian et al., 2019).

The three teachers identified additional difficulties and misconceptions after their lesson presentations. In his post-CoRe analysis, Mr. JP highlighted several challenges faced by learners. These challenges include difficulties in remembering the units of measurement for displacement and converting other units into metres. He also noted that learners forget to include the direction of velocity in their answers. Mr DN identified vector arrows and the reading ability of learners as difficulties. These identified difficulties can also be categorised as ones that should already have been addressed in Grade 10. The learners' reading ability specified by Mr DN is not a topic-specific difficulty and, therefore, not considered in the expert CoRe as PCK specific to the topic. Ms NJ struggled to identify additional learner difficulties and misconceptions after teaching. She indicated in her VSR interview that she did not identify any during her teaching experience. However, she brought up a perceived challenge that learners encounter, specifically the multiple displacements in a problem depending on chosen reference points. Yet, as highlighted in Chapter 6, this difficulty

concerning displacement is irrelevant and might divert learners' attention from the necessary problem-solving skills.

All three teachers were scored in the second tier of the rubric for their knowledge on learner understanding, which is *developing*. It is notable that Mr JP is the only teacher who improved his score for captured PCK after teaching compared to before teaching.

7.2.4.3 Knowledge and skills related to conceptual teaching strategies

Mr JP demonstrated improved intended use of representations, particularly with PhET simulations post-teaching, acknowledging their shortcomings and outlining future implementation plans. His enhanced understanding promises to elevate learners' conceptual development and critical thinking skills. Notably, a previously misconceived example where his simulation demonstrated motion in two dimensions now serves as a valuable tool in addressing misconceptions, especially to demonstrate the velocity of a projectile at maximum height would be zero when motion in one dimension is considered.

After teaching the topic, Mr DN never mentioned any representations other than drawings on the board. This may be because he used the textbook to explain the topic to learners. The textbook was pre-loaded on his SMART board, and he mostly used the textbook's drawings to explain the problems. Ms NJ, on the other hand, enriched conceptual reasoning by referring back to and linking new concepts with her representations.

After teaching the topic, Mr JP showed a lack of knowledge regarding his teaching strategy, referring to an irrelevant representation of vertical projectile motion. Mr JP referred to a video showing a car coming to a stop. However, this video is not suitable for teaching the concepts of vertical projectile motion, as these involve different principles. Mr DN maintained general reasons for using representations, missing an opportunity to display his knowledge regarding their effectiveness.

As I mentioned earlier, this study found that all three teachers struggled to articulate and describe their teaching strategy before teaching, and this was also the case in their post-CoRes and VSR interviews. While alluding to the importance of questions, the lack of specificity in their explanations raised doubts about their ability to formulate questions that foster higher-order thinking skills. For instance, Mr JP expressed his intention to pose questions aimed at nurturing the learners' grasp of the big ideas. Similarly, Mr DN mentioned he would ask questions related to gravity and its effects, albeit without providing a specific question example. Ms NJ, in her post-CoRe, presented a thought-provoking question as

discussed in Chapter 6, yet it pertained to pre-existing concepts rather than the new concepts crucial to the big ideas of the vertical projectile motion topic.

Both Mr JP and Mr DN emphasised the necessity of revisiting pre-concepts at the outset of their lessons after they taught the topic. This emphasis indicated that they realised the importance of pre-concepts such as velocity, displacement, distance and gravity, which led to understanding the new topic of vertical projectile motion. Although Ms NJ acknowledged pre-concepts, she did not emphasise them being done before starting with new work.

All three teachers continued to employ the effective teaching strategy of dividing an object's motion path into distinct sections. Despite variations in emphasis, the strategy remained a consistent element in their teaching approaches.

Notably, Mr JP recognised the limitation of pre-selecting a fixed reference frame after his lesson presentation, acknowledging the importance of allowing learners to determine the frame of reference based on the scenario provided. Unfortunately, neither Ms NJ nor Mr DN reached the same realisation.

Upon reflection, Mr JP, Mr DN, and Ms NJ demonstrated improvements in their teaching strategies after gaining teaching experience. Mr JP and Mr DN recognised the need for adjustments, aiming to enhance learner interaction and engagement, with Mr DN proposing the incorporation of cooperative learning. Mr JP emphasised improved representations and engaging discussions, while Ms NJ suggested altering the sequence of introducing motion graphs for better learner comprehension.

In concluding the answer to Secondary Research Question 3 across all three PCK components, it is evident from Table 7.2 that, once more, the curricular saliency component yielded the highest scores among the teachers after they taught the topic, with all three achieving *exemplary* ratings. For the remaining two PCK components, all three teachers received *developing* scores for their captured PCK after teaching, placing them in the second tier of the rubric.

7.2.5 CONCLUSION: ANSWERING THE MAIN RESEARCH QUESTION

The following discussion, with reference to Table 7.2, aims to answer the main research question: how does the PCK of novice teachers about vertical projectile motion develop through teaching experience?

As can be seen in Table 7.2, the PCK of teachers after gaining teacher experience was colour-coded to indicate whether their PCK improved (Green) or remained the same

(Yellow). There were no instances where the post PCK was at a lower level than their PCK before teaching the lessons for the first time.

Table 7.2: The competencies of the three participants regarding their captured and enacted PCK

PCK COMPONENT		CAPTURED PCK Pre-CoRes and interview (BEFORE LESSON PRESENTATION)	ENACTED PCK Lesson presentation	CAPTURED PCK Post-CoRes and VSR interview (AFTER LESSON PRESENTATION)
Mr DN	curricular saliency	2	3	3
	learner's understanding of science	2	1	2
	conceptual teaching strategies	1	1	2
Ms NJ	curricular saliency	2	2	3
	learner's understanding of science	2	1	2
	conceptual teaching strategies	2	2	2
Mr JP	curricular saliency	2	2	3
	learner's understanding of science	1	1	2
	conceptual teaching strategies	1	1	2

All three teachers demonstrated an improvement in their PCK scores related to curricular saliency, transitioning from the *developing* level in the pre-teaching phase to the *exemplary* level post-teaching. This shift is indicative of a tangible growth in their understanding, application, and integration of knowledge of curricular saliency specific to the topic of *vertical projectile motion*. The development in their PCK is particularly evident in their incorporation of new concepts (see Table 7.1), logical sequencing of content, and scaffolding of examples, as explained in the previous sections.

All three teachers scored *developing* for their PCK in the PCK component for learner understanding after they taught their lessons. Only Mr JP showed that he improved his knowledge of learners' understanding after gaining teaching experience. This improvement was mainly achieved because he could address his own misinterpretations during teaching and identified additional learner difficulties, which he could not do prior to teaching. The PCK of Mr DN and Ms NJ post-teaching remained unchanged compared to their PCK on learner understanding before teaching the topic of vertical projectile motion for the first time. Both Mr DN and Ms NJ did not exhibit (post-teaching) improvement regarding the misconceptions

they had prior to and during teaching (see Sections 7.2.2.2 and 7.2.3.2). These instances underscore the challenges teachers face when addressing their own misconceptions, which can potentially hinder effective knowledge transmission. Also, the longer a misconception remains unchallenged, the more likely it becomes entrenched (Gooding & Metz, 2011).

The journey of these teachers in developing their PCK on learner understanding underscores the complex interplay between teaching experiences, reflective practices, and the challenges of addressing both teacher and learner misconceptions. Coetzee (2018) also found that this component of PCK remained one of the more challenging components that improved after an intervention. The continuous refinement of PCK in this component highlights the dynamic nature of teacher growth, providing valuable insights for the ongoing enhancement of science education practices.

Mr JP's progression regarding representations is particularly noteworthy, as evidenced in his post-teaching reflections on PhET simulations. Acknowledging the initial limitations, he articulated a more informed and strategic vision for incorporating simulations in future lessons. This development underscores the transformative impact of teaching experience on refining pedagogical strategies.

Conversely, Mr DN's reliance on drawings in both pre- and post-teaching analyses suggests a possible dependence on traditional visual aids. The analysis hints at a limited evolution in his skills, possibly influenced by a consistent use of the textbook during instruction. Ms NJ's incongruence between her intended use of motion graphs as representations and the observed teaching practices highlights misalignment between her pPCK and ePCK. This finding aligns with Mazibe (2017) that teachers' captured PCK is not necessarily a true reflection of the PCK they reveal during lesson presentation.

In examining teaching strategies, all three teachers encountered challenges articulating them, which were observed in pre- and post-CoRes and interviews. This difficulty, attributed to the tacit nature of PCK, was highlighted by various scholars (Loughran et al., 2004; Mazibe et al., 2020). Despite obtaining more information through interviews, it remained vague, partly due to the tacit nature of PCK and English language proficiency issues (see Section 7.3).

One of the major concerns identified in the teaching strategy of all three teachers before (pPCK), during (ePCK), and after (pPCK) lesson presentations was their inability to ask adequate questions that would ascertain learner understanding. There was a common limitation in learner participation and the creation of opportunities for meaningful discussions.

Questions posed by the teachers tended to demand brief, one-word responses, indicating a reliance on rote learning rather than fostering higher-order thinking. Additionally, as noted by Coetzee (2018), pre-service teachers may not consistently contemplate the connection between the questions they pose and their teaching approach; this finding is relevant to this study because novice teachers teaching a topic for the first time have the knowledge level they had as pre-service teachers. Novice teachers might lack the experience and confidence to ask higher-order questions. As they gain more teaching experience and become more comfortable with their subject matter, they may improve their ability to ask such questions. Moodley (2013) suggested that continuous professional development and support are essential for teachers to refine their questioning skills and foster higher-level thinking in their learners.

All three teachers consistently divided an object's motion into sections, emphasising equations of motion in problem-solving scenarios. Visual representations, primarily drawings on the board, aligned with segmented sections, facilitating the application of equations and problem resolution. This approach aligns with Gaigher et al. (2007) emphasis on problem-solving methods.

All three teachers suggested pPCK and implemented ePCK, a formal teaching style that is mainly teacher-centred. Coetzee (2018) found that teacher-centred teaching does not necessarily reflect poor PCK as long as the teacher is in command of the content and skillfully employs sound PCK.

The findings consequently led to the following concluding remarks, and they also address the main research question of this study: Importantly, this study revealed that the pPCK of the three teachers improved across the PCK components of curricular saliency and conceptual teaching strategies after they taught their lessons and gained teaching experience. Notably, there was no case where a teacher's pPCK after lesson presentations scored lower than their pPCK before lesson presentations in any of the three PCK components. Lastly, it was noticed that only Mr JP improved his PCK on the component of learners' understanding of science, whereas Mr DN and Ms NJ remained at the developing level.

It is noteworthy to mention that Mr JP improved his PCK across all three PCK components after gaining teaching experience. Mr DN improved in two of the PCK components, namely curricular saliency and conceptual teaching strategies, and Ms NJ only improved in one PCK component, which was curricular saliency.

7.3 EMERGING FINDING

The three teachers made an effort to submit their data in English, which is not their home language. They encountered challenges due to their limited proficiency in English. These teachers struggled to effectively convey their thoughts and insights in a language other than their primary means of communication. Such examples were noted when Mr DN used “amplitude” instead of *altitude* to describe the maximum height an object would reach, and Ms NJ used the term “time-lapse” when she referred to the *contact time* between a bouncing object and the ground. At some point, all three teachers also referred to the “displacement-time” graph instead of the *position-time* graph.

Furthermore, Ms NJ referred to the *displacement* (instead of *maximum height*) of a bouncing ball decreasing after each bounce, and Mr DN referred to the *surface area* underneath a motion graph instead of just the *area*. These terms have distinct meanings, and using them accurately is crucial to avoid confusion. Oyoo (2015) found that language plays a critical role in concept formation and development. Therefore, if educators are not proficient in the instruction language, it might affect their ability to convey scientific concepts to their learners effectively.

Novice teachers may be equipped with theoretical knowledge but lack practical teaching experience. Hence, they may struggle to apply their theoretical knowledge in classroom situations (Sözen, 2018). As I pointed out, effective communication between the teachers and learners may be a problem, especially in the cases of Mr JP and Ms NJ, where the LOLT were not the teacher’s or learners’ home language. As Sözen (2018) stated, effective communication is key in teaching, and novice teachers might face communicative problems when trying to explain complex concepts in a way that learners can understand.

Expert teachers are widely acknowledged to cultivate their PCK over time, while novice teachers must acquire diverse skills and new knowledge to attain proficiency in their fields (Williams & Lockley, 2012). Consequently, both prospective and novice teachers often find themselves with insufficient PCK at their disposal (Shing et al., 2018). Developing the PCK of a teacher requires not only mastering the subject matter but also adapting it to the linguistic backgrounds of the teachers and learners and applying it in various classroom situations.

In terms of the framework that guided this study (RCM) teachers’ language proficiency moderated the transformation process between pPCK and ePCK, and, therefore, can be defined as a filter between the two realms of PCK.

7.4 CONTRIBUTION OF THE STUDY

This study revealed that teachers' experience gained while teaching a topic for the first time mostly contributes to their PCK development across the three PCK components. Notably, the component of curricular saliency obtained the highest scores. Achieving high scores in the PCK component of curricular saliency indicates that teachers possess a strong grasp of selecting and organising content in a manner that is relevant and meaningful for their learners.

Conversely, the findings underscored that teachers' PCK development was most lacking in the component of learner understanding of science. Scoring poorly in this PCK component suggests that teachers may encounter challenges in accurately assessing and addressing their learners' learning needs, abilities, and misconceptions.

This study has made a contribution by developing an expert CoRe and two accompanying rubrics focused on the intricacies of vertical projectile motion. It is important to highlight that the expert CoRe was meticulously drafted to align with the South African FET science curriculum, tailoring its content to the specific context.

The first rubric employed in this study served the purpose of evaluating the pPCK of teachers concerning vertical projectile motion. This assessment was conducted both before and after teachers delivered their lessons. The second rubric was utilised to gauge the ePCK of teachers during the actual teaching of vertical projectile motion.

7.5 LIMITATIONS OF THE STUDY

A qualitative case study involving three novice teachers teaching for the first time has several limitations that must be considered. Firstly, as Ochieng (2009) pointed out, the findings may not apply to a larger population, a common limitation in case study research. The small sample size of three participants in this study may limit the generalizability of the findings. Furthermore, each qualitative study is unique and often tied to the individual researcher, making it difficult for other researchers to replicate the study (Diefenbach, 2009). However, this study can contribute to the broader understanding of the development of PCK and may, together with similar studies, apply to the larger population.

The data quality in qualitative research can be debatable due to the subjective nature of data collection. This concern arises because the researcher's personal beliefs and biases can influence the design of the study and the interpretation of the data, which can affect the validity of the results (Hyett et al., 2014). In my role as a physical sciences subject advisor,

the researcher holds personal convictions regarding the optimal approach to teaching vertical projectile motion to learners. These convictions could have potentially influenced my evaluation of the teachers' captured and enacted PCK. Nevertheless, the analysis of the data by the supervisors and the strict adherence to the category descriptions of the rubrics served to mitigate any potential researcher bias present in the study.

A similar constraint, akin to what Mazibe (2017) observed in their study, is the absence of incentives for the teachers who participated in this research. This lack of motivation might explain why the teachers did not fully or extensively complete their CoRes. Nevertheless, the interviews proved instrumental in collecting data that could not be acquired through the CoRes. This type of research can also be time-consuming, as analysing the PCK of novice teachers at different stages requires a significant amount of time.

7.6 RECOMMENDATIONS FOR FUTURE RESEARCH

Exploring the extension of this research study to encompass other physics topics could offer valuable insights. These insights will allow researchers to determine if the findings from this study are consistent across different subject areas.

A longitudinal study could be conducted to track changes in a teacher's pPCK over a more extended period, providing insights into how PCK develops and evolves with experience regarding vertical projectile motion. It would also be interesting to explore how PCK changes when teaching the same section to different grades, such as the topic of electric circuits across the entire FET phase in South African schools.

Comparing the PCK of novice teachers with that of experienced teachers regarding vertical projectile motion could provide insights into how PCK develops over time and with experience. There is minimal or inadequate emphasis on guiding teachers in understanding how their knowledge is constructed and the methods by which they acquire knowledge to impart meaningful science education to learners (Sikhosana & Mudau, 2022). Therefore, investigating the impact of specific training programs or professional development activities on the development of PCK could be beneficial. As Sikhosana and Mudau (2022) pointed out, teaching a physical science topic does not necessarily improve teachers' comprehension of that topic.

While this study adopts a qualitative approach, future research could consider incorporating quantitative methods to complement and enrich the qualitative findings. Quantitative assessments, like pre- and post-tests, could help quantify the impact of specific interventions, training programmes, or teaching experience gained on teachers' PCK,

providing a more comprehensive understanding of the quantitative aspects associated with PCK development.

7.7 RECOMMENDATIONS FOR FUTURE PRACTICE

The findings of the study underscore the significance of examining and evaluating PCK across its various defining components, as competence in one component does not necessarily translate to competence in others. Additionally, it is essential to assess teachers' competencies in relation to various fundamental concepts within the subject matter. Although CoRes was initially designed to aid teachers in expressing their PCK, it is insufficient on its own for comprehensively appraising one's PCK. Therefore, it becomes imperative to observe teachers in actual teaching scenarios to gauge the effectiveness of their enacted PCK, as this is the PCK that ultimately influences the learning process.

In this context, teacher workshops emerge as a crucial component in the ongoing professional development of educators. Workshops can serve as platforms for refining and expanding teachers' PCK by addressing specific challenges and fostering a deeper understanding of subject matter concepts. Through interactive sessions, collaborative discussions, and practical exercises, teacher workshops create opportunities for educators to enhance their instructional strategies and communication skills. These hands-on experiences in a workshop setting can contribute significantly to bridging the gap between theoretical knowledge and its practical application in the classroom. Therefore, the inclusion of teacher workshops in professional development initiatives becomes imperative for nurturing and advancing the multifaceted aspects of PCK.

7.8 REFLECTION

I thoroughly enjoyed engaging with this study, and unquestionably, my own PCK developed. The experience granted me a deeper understanding of teacher PCK, shedding light on its tacit nature. It became evident that teachers often grapple with articulating their PCK, and diverse methods are more suitable for different individuals in eliciting their PCK.

Witnessing the positive transformation in teacher PCK across various components was encouraging. However, it was equally concerning to recognise that without support from the broader science community (cPCK), some aspects of a teacher's PCK may remain stagnant.

This experience has significantly influenced my approach to planning workshops for teacher training. Emphasising the topic-specific nature of PCK within a given subject has become a focal point, allowing for a more tailored and effective strategy in enhancing teacher PCK.

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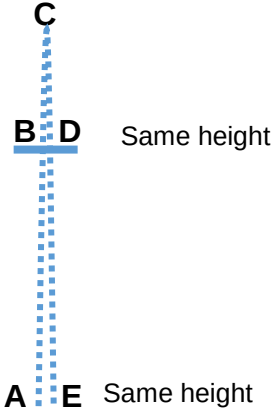
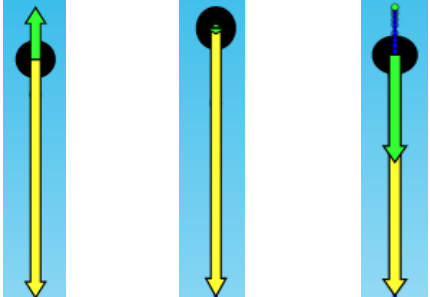
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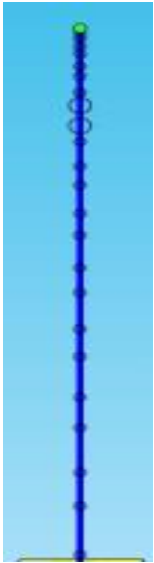
APPENDICES

8.1 APPENDIX A: CONTENT REPRESENTATION TOOL COMPLETED BY THE RESEARCHER AND EXPERTS: EXPERT CORE

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
1. "What do you intend the learners to learn about each of the ideas?"	➤ Projectile motion is analysed near the Earth's surface, assuming there is no air resistance. ➤ Vertical projectile motion is motion in 1D. ➤ Time symmetry is when projectiles take the same time to reach their greatest height from the point of upward launch as the time they take to fall back to the point of launch. ➤ Displacement is measured in metres (m). Δy = Vertical displacement. Δx = Horizontal displacement. ➤ The displacement of an object being launched upwards will be 0 when it reaches the point of launch again. ➤ Objects being dropped from a moving carrier will initially move in the direction of the carrier (inertia).	➤ Projectiles is considered objects which has been given an initial velocity and then it moves under the influence of the gravitational force only (air resistance is neglected). ➤ Constant acceleration of $9,8 \text{ m.s}^{-2}$ downwards irrespective of whether the projectile is moving upwards, downwards or is at maximum height. ➤ The initial velocity of an object which is dropped is 0 m.s^{-1} ➤ The velocity of an object will always be 0 m.s^{-1} at its maximum height. ➤ An object passing the same position will always have the same velocity in magnitude upon its return, but in an opposite direction. ➤ Projectile motion can be described by a single set of equations. ➤ $v_f = v_i + g\Delta t$ ➤ $v_f^2 = v_i^2 + 2g\Delta y$ ➤ $\Delta y = v_i\Delta t + \frac{1}{2}g\Delta t^2$ ➤ $\Delta y = (\frac{v_i+v_f}{2})\Delta t$ ➤ Velocity is represented by v_i and v_f in the above listed equations and is measured in m.s^{-1}. v_i = Initial velocity. v_f = Final velocity. g = Gravitational acceleration ($9,8 \text{ m.s}^{-2}$)

Expert CoRe - Tool		
CoRe prompts	Big Idea 1	Big Idea 2
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
2. What concepts need to be taught before teaching this big idea?	➤ The frame of reference we use has an origin and set of axes with directions eg. (up or down) (North or South) ➤ Position is a point in space held by an object relative to a reference point. ➤ Displacement is the change in an objects position. ➤ Displacement is a vector quantity and consists of magnitude and direction ➤ Distance is a scalar quantity and is measured along the total path length that an object travels. ➤ Distinguish between different kinds of forces eg. Weight and gravitational force. ➤ Each particle in the universe attracts every other particle with a gravitational force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres. ➤ Draw force diagrams indicating the direction and magnitude of forces acting on a body. ➤ A net force is the sum of all the forces acting on an object.	➤ Speed is the rate at which an object covers distance. ➤ Velocity is the rate of change in the position of an object and considered a vector quantity. ➤ Acceleration is the rate of change in an objects velocity and considered a vector quantity ➤ Instantaneous velocity is the displacement of an object divided by a very small time interval. ➤ Gradient of a velocity-time graph represents the acceleration. ($\Delta v / \Delta t = a$) ➤ Area under a velocity time graph (area between the graph and the horizontal axis) represents the displacement or change in position for that time interval. ➤ Gradient of a position-time graph (including tangents and secants) represents the velocity for that interval (instantaneous and average velocity) ($\Delta x / \Delta t = v$) ➤ Introduction to the equations of motion in Gr 10 are used to solve problems involving motion in one dimension and in the horizontal plane only. ➤ $v_f = v_i + a\Delta t$ ➤ $v_f^2 = v_i^2 + 2a\Delta x$ ➤ $\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$ ➤ $\Delta x = (\frac{v_i + v_f}{2})\Delta t$ $a = \text{acceleration (m.s}^{-2}\text{)}$ is being used, because we are not working with free falling objects in Grade 10. ➤ An elastic collision is a collision in which there is no net loss in kinetic energy in the system as a result of the collision.

Expert CoRe - Tool		
CoRe prompts	Big Idea 1	Big Idea 2
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
		➤ An inelastic collision is a collision in which part of the kinetic energy in the system changes into another form of energy as a result of the collision.
3. What representations would you use in your teaching strategy?	- UPWARDS MOTION IS CONSIDERED TO BE THE POSITIVE DIRECTION Representation 1: Drawing of an object being thrown upwards and falls back to the ground.  Representation 2: Drawing of a bouncing object. 	- UPWARDS MOTION IS CONSIDERED TO BE THE POSITIVE DIRECTION - The same representations will be used as in Big Idea 1. Representation 6: Simulations (virtually)  Representation 7: Videos

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
	• Representation 3: Object dropped from a moving carrier:  • Representation 4: Simulations (virtually) 	

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
	• Representation 5: Actual objects that are being thrown into the air or dropped from a certain height. As an example make use of a tennis and golf ball to showcase the following: ➤ Falling object ➤ Object thrown upwards or downwards ➤ Bouncing object	
4. Give particular reasons for the representations used to engage with this idea?	• It will engage the visual sense of learners. • Drawings on the board can be used to illustrate: ➤ Falling object ➤ Object thrown upwards or downwards ➤ Bouncing object ➤ Object dropped from moving carrier. • In all the above mentioned drawings emphasis will be placed on: – Frame of reference (includes sign conventions) – Displacement – Maximum height – Contact time if it is an bouncing object • Representation 1: ➤ Only vertical movement (up and down) is considered, no horizontal movement is taken into account because vertical projectile motion is motion in 1D. ➤ Learners will be able to identify the different stages of the motion, and this will assist them in processing the information. ➤ Point C represents the maximum height. ➤ Object thrown upwards and return to point of launch: $A \rightarrow E$	• The same drawings as Big Idea 1. Emphasise will be placed on: – Initial velocity – Final velocity – Acceleration – Velocity at maximum height – Acceleration throughout the movement • Consider representation 1 from Big Idea 1: ➤ $v_{iA} = -v_{fE}$ ➤ $v_{fB} = -v_{iD}$ ➤ $v_{iB} = -v_{fD}$ ➤ $v_{fC} = v_{iC} = 0 \text{ m} \cdot \text{s}^{-1}$ (maximum height) ➤ Velocity will decrease from $A \rightarrow C$ ➤ Velocity will increase from $C \rightarrow E$ ➤ Acceleration of the object remains constant ($9,8 \text{ ms}^{-2}$ downwards) throughout the motion $A \rightarrow E$ • Consider representation 2 from Big Idea 1: ➤ Each bounce causes the object to change direction, therefore the velocity changes. ➤ In an elastic collision the magnitude of the velocity will remain the same before and after a bounce. ➤ In an inelastic collision the magnitude of the velocity will not remain the same

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
	(Displacement = 0 m) ➤ Dropped object represented by: $C \rightarrow E$ ➤ Object thrown upwards and falls on the roof of a building: $A \rightarrow D$ ➤ Object thrown from the roof of a building and falls to the ground: $B \rightarrow E$ • Displacement: ➤ $\Delta y_{AB} = -\Delta y_{DE}$ ➤ $\Delta y_{BC} = -\Delta y_{CD}$ ➤ $\Delta y_{AC} = -\Delta y_{CE}$ ➤ $\Delta y_{AE} = 0 \text{ m}$ • Time symmetry can be explained and observed. ➤ The time it takes the object to reach its maximum height from the point of launch ($A \rightarrow C$), is equal to the time it takes to object to fall back to its point of launch form maximum height ($C \rightarrow E$). • Representation 2: ➤ The bouncing motion is a repetition of representation 1 ($A \rightarrow E$). ➤ Contact time can be observed using different balls. ➤ If the maximum height after each bounce decreases it indicates an inelastic collision between the object and the surface. ➤ If the maximum height after each bounce remains the same it indicates an elastic collision between the object and the surface. • Representation 3: ➤ The motion corresponds to representation 1 ($B \rightarrow E$). ➤ The object will initially move upwards until it reaches maximum height, where after it falls to the ground.	before and after a bounce. • Consider representation 3 from Big Idea 1: ➤ The initial velocity of the object once it is dropped will be the same as that of the carrier. ➤ The velocity of the object will be $0 \text{ m} \cdot \text{s}^{-1}$ at maximum height. ➤ The acceleration of the object once it is dropped remains $9,8 \text{ ms}^{-2}$ downwards throughout the movement. • Consider representation 5 from Big Idea 1: ➤ All the sub-ordinate ideas from representation 1 and representation 2 can be demonstrated. • Representation 6 ➤ PHET simulation showcasing the vector arrows of a motion. ➤ The green arrow represents the velocity of the object and the yellow arrow represents the gravitational acceleration. ➤ Initially the object has an upward velocity and this velocity is decreasing as the object moves upwards. ➤ At maximum height the velocity is $0 \text{ m} \cdot \text{s}^{-1}$, ➤ When the object returns to the earth the velocity increases. ➤ The gravitational acceleration (yellow arrow) remains constant ($9,8 \text{ m} \cdot \text{s}^{-2}$ downwards) throughout the whole motion. ➤ Vector arrows of the velocity and acceleration will enhance learner understanding of the forces acting on the object.

Expert CoRe - Tool		
CoRe prompts	Big Idea 1	Big Idea 2
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
	➤ $B + C + D + E = \text{Distance}$ ➤ $B \rightarrow E = \text{Displacement}$ • Representation 4: ➤ PHET simulation showcasing the path or trajectory of the object in 1D. ➤ All the sub-ordinate ideas from representation 1 and representation 2 can be demonstrated. • Representation 5: ➤ All the sub-ordinate ideas from representation 1 and representation 2 can be demonstrated. ➤ Illustrate real world situations to which learners can relate.	➤ Show learners that the velocity at maximum height equals $0 \text{ m} \cdot \text{s}^{-1}$, but the acceleration remains $9,8 \text{ m} \cdot \text{s}^{-2}$ downwards. • Representation 7: ➤ Videos can be used to demonstrate to learners all the sub-ordinate ideas from previous representations mentioned.
5. Describe the strategy you will use to establish conceptual development of the main idea.	• Revision of pre-knowledge from Grade 10 and Grade 11. ➤ Vectors and Scalars ➤ Motion in 1 dimension ➤ Newton's laws • Frame of reference and sign convention – Learners should choose a reference point. – Make sure learners are able to choose a positive direction of motion. This sign convention should be used throughout the question. • Direct questions throughout the examples to learners to elicit conceptual understanding and development. (Refer to question 6 on the CoRe tool) • Start with a representation of an object that is being dropped. (more difficult representations can be introduced when learners are comfortable with the concepts) – Make use of a drawing on the board showing the trajectory of the object. Focus on:	• The same as Big Idea 1 with focus on: ➤ Initial velocity ➤ Final velocity ➤ Velocity at maximum height ➤ Acceleration ➤ Time • With the object that is being dropped and data is gathered learners will be able to determine, using the equations of motion, the velocity with which the object reaches the ground • Having the data learners can now plot a velocity-time graph. • Calculating the gradient of the velocity-time graph will provide the acceleration. • Calculating the area between the graph and horizontal (x-axis) will provide the displacement of the object for that time interval. • Compare the three graphs that are obtained in each example with each other.

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
	➤ Reference points. ➤ Change in position. ➤ Maximum height. • Make use of real life examples; drop an object in class e.g pen or ball. Link this representation with the drawing on the board. • Make use of the PHET simulation showcasing the same example of a dropped object. – Learners should choose a positive direction for this motion (all learners should start with the same choice) – The simulation provides data points along the path of the object. – Having the data learners can now plot a position-time graph. – The gradient of the position-graph represents the velocity for that time interval. • The above procedure can be repeated with other examples. • Identify the different stages during the motion (label them using alphabet letters) and focus on the following physical quantities during each stage. • Reference points • Displacement • Maximum height • Time	
6. What questions would you consider important to ask when teaching this	• Where would you choose the origin of a projectile? • What is the displacement of a projectile at its highest height? • What is the displacement of an object that is launched into the air, and returns to the point of launch? • Explain what the displacement of an	• During a motion (draw it on the board) where will the acceleration due to gravity be the greatest? • What will the acceleration of an object be at maximum height? • Draw a free body diagram of an object at maximum height indicating all the forces acting on the object.

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
topic, to ascertain learner understanding?	object would be when thrown from the top of a building, and falls to the ground? NOTE: • These questions are not exhaustive of the Big Idea • Questions should elicit conceptual reasoning and conceptual understanding from the learners.	• Why does an object move slower when thrown upwards? • Why does an object move faster when falling to the ground? • Do you think the velocity and acceleration of a vertical projectile motion is always in the same direction? Explain your answer. NOTE: • These questions are not exhaustive of the Big Idea • Questions should elicit conceptual reasoning and conceptual understanding from the learners.
7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	• Misconceptions ➤ Objects at a certain height above the earth experience more gravity than stationary objects, which may experience none at all. ➤ Unable to distinguish between the shape of a position-time graph and the path of the motion. • Learner difficulties ➤ Not using a frame of reference to interpret the question. ➤ Displacement confused with distance. ➤ Incorrect sign conventions used for vectors ➤ Learners are struggling to solve the equations of motion, especially if they have to manipulate the formula. ➤ Interpreting the slope of the position versus time graph.	• Misconceptions ➤ Learners think gravity is not the only force acting on an object during free fall. They believe there are other external forces fuelling the movement. ➤ Learners don't believe the velocity at maximum height is $0 \text{ m} \cdot \text{s}^{-1}$ ➤ Learners think the acceleration at maximum height is $0 \text{ m} \cdot \text{s}^{-2}$ because the velocity is $0 \text{ m} \cdot \text{s}^{-1}$. ➤ Fast moving objects are associated with high acceleration. ➤ Slow moving objects are associated with low acceleration ➤ Acceleration and velocity are always in the same direction. ➤ Dropped objects from a moving carrier fall straight down. • Learner difficulties ➤ Velocity confused with speed. ➤ Interpreting the area underneath the velocity versus time graph. ➤ Interpreting the gradient of the velocity versus time graph.

Expert CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
Consider the following two ideas as Big Ideas for the topic <i>vertical projectile motion</i>	Change in position of a projectile	Change in velocity of a projectile
8. How do you address the misconceptions and or learner difficulties?	• Make sure the pre-knowledge of concepts in Grade 10 and Grade 11 are sound. • Make learners aware of their misconceptions, and discuss it in class. • Make use of representations to assist learners in visualising the problem. • Break the motion up into different stages of motion. Allocate alphabet letters to the different stages – this can assist learners in having a better frame of reference. • Having the motion in different stages can assist learners to link parts of the motion to the graph.	• All points of Big Idea 1 are applicable. • Get learners involved in analysing the movement of objects, drawing free-body diagrams along the trajectory path can assist learners in remembering gravity is the only force acting on a free falling object. • Simulations will assist learners in realising the velocity at maximum height is $0 \text{ m} \cdot \text{s}^{-1}$, because the instantaneous velocity at that point is $0 \text{ m} \cdot \text{s}^{-1}$ (no change in the position of the object) but the acceleration remains $9,8 \text{ ms}^{-2}$

8.2 APPENDIX B: RUBRIC FOR QUANTIFYING THE PCK OF TEACHERS AS CAPTURED IN THE INTERVIEW AND IN A CORE

		Limited	Developing	Exemplary
		Curricular saliency		
Knowledge and Skills related to Curricular Saliency	What do you intend the learners to learn about each of the ideas?	Identified irrelevant concepts within the big ideas.	Identified some relevant concepts within each of the big ideas.	Identified an extensive list of relevant concepts within each of the big ideas.
		Only identified pre-concepts.	Pre-concepts are mixed with relevant concepts.	No pre-concepts are included.
	What concepts need to be taught before teaching this big idea?	Most pre-concepts that are directly related to the Big Idea were omitted.	Identified pre-concepts are relevant to the big idea.	Identified an extensive list of pre-concepts that are relevant to the big idea.
		The pre-concepts mentioned are not appropriate for the main idea.	Identified pre-concepts consist of those required to understand the current big idea.	Pre-concepts from other topics having logical links with the Big Idea are included.
		Sequencing has no value due to mixed concepts.	No apparent logical sequencing	Provides logical sequence of concepts.
		Representations and analogies		
Knowledge and Skills related to Conceptual Teaching Strategies	What representations would you use in your teaching strategy?	No representations are identified.	Identified some relevant representations.	Identified a variety of relevant representations.
		The suggested representations are not feasible.	It is not clear how these representations will be used.	Suggested representations will support the development of concepts

		Limited	Developing	Exemplary
				related to big ideas.
	Give particular reasons for the representations used to engage with this idea?	No explanation of specific links to the concepts considered	Concepts are linked vaguely or incorrectly to the representations.	Outlined how the representations are sufficient to support the explanation of concepts.
		There is no evidence how the use of the representation will lead to increased understanding of concepts.	Some evidence is given of the use of representations to support conceptual development.	Explanatory notes link the different kinds of representations to aspect(s) of the concepts being explained.
		Conceptual Teaching Strategies		
Knowledge and Skills related to Conceptual Teaching Strategies	Describe the strategy you will use to establish conceptual development of the key idea.	List of general strategies without indications of how they will be employed, is given.	General teaching strategies with limited explanation of application.	An overall excellent and creative strategy to teach the required concepts is presented.
		No evidence or acknowledgement of student prior knowledge and misconceptions.	Acknowledges student misconceptions with no corresponding confrontation strategy	Considers student prior knowledge and evidence of confrontation of misconceptions
		No strategy to expose learners' difficulties and misconceptions.	The overall strategy is workable.	There is evidence that the strategy will support conceptual understanding.
		No indication of how main ideas will be explained.	Attention given to the explanation of only one big idea.	There is evidence of integration and creative interaction of other

		Limited	Developing	Exemplary
				components.
		Lacks aspects of curriculum saliency	At least one aspect related to curriculum saliency or sequencing is considered.	Considers at least two aspects related to curriculum saliency or sequencing is considered.
	What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	Questions asked do not require the learner to explain his/her response.	Questions are basic and mostly rote learning questions are posed.	Questions require higher order thinking skills.
		There is no evidence of questions that will support conceptual understanding.	Questions do not require higher order thinking skills.	
		There is no evidence of sequential development of concepts	Sequencing for conceptual development is ambiguous	Knowledge of sequencing is evident.
		Learner prior knowledge		
Knowledge and Skills related to Learner Understanding of Science	What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	No misconceptions or learner difficulties are identified.	Identifies some misconceptions or learner difficulties.	Identifies and describes a number of misconceptions and learner difficulties.
		Selection of inappropriate misconceptions.	Identifies very basic alternative ideas or difficulties that are not normally documented as misconceptions or	An indication of knowledge about misconceptions and their origin is evident.

		Limited	Developing	Exemplary
			difficulties related to the topic.	
	How do you address the misconceptions and or learner difficulties?	No attempt to address learner misconceptions or difficulties.	Provides standardized definition as a means to counteract the misconception or learner difficulty.	- Expands and re-phrases explanation correctly to address the misconceptions or learner difficulty. - Workable strategy is given
		The response reveals own misconceptions	Response addressed the misconception or learner difficulty only partially.	An indication of knowledge about misconceptions and their origin is evident.

8.3 APPENDIX C: RUBRIC FOR ASSESSING PCK AS ENACTED DURING THE TEACHING OF VERTICAL PROJECTILE MOTION

	Limited	Developing	Exemplary
	Curricular saliency		
Knowledge and Skills related to Curricular Saliency	No pre-concepts are mentioned	Some pre-concepts are only mentioned	An extensive amount of pre-concepts are mentioned and discussed.
	Never obtains learners' knowledge of pre-concepts.	Obtains knowledge of only certain pre-concepts.	- Elicits knowledge of all applicable pre-concepts at appropriate phases in the lesson. - Pre-concepts that are applicable in the conceptualisation of new ideas are emphasised.
	Explains irrelevant concepts.	Relevant concepts are explained.	
	Important concepts regarding the topic are not explained.	Most of the important concepts regarding the topic are explained.	An extensive amount of important concepts regarding the topic are explained.
	Sequencing of concepts is illogical.	Concepts are sequenced logical.	Main ideas and sub-ordinate ideas have a logical sequencing.
	The interconnections amongst concepts are not explained.	The interconnections amongst concepts are clumsy.	The interconnections between concepts are explained and logical.

	Limited	Developing	Exemplary
	Representations and analogies		
Knowledge and Skills related to Conceptual Teaching Strategies	No representations are used in the lesson	Representations restricted to one type of representation only.	Makes extensive use of representations in combination, e.g. videos and diagrams or demonstrations (simulations) and diagrams.
	Representations are irrelevant	Representations that are applicable to the concepts explained are used.	Representations used to confront and expand explanations of difficult concepts.
	Relies mostly on explaining and telling.	Uses objects as illustrations or artefacts.	Uses variety of representations effectively to stimulate conceptual reasoning.
	Representations will cause misconceptions	Representations have the potential to induce misconceptions.	Representations are clear and will confirm learner understanding.
	Conceptual Teaching Strategies		
Knowledge and Skills related to Conceptual Teaching Strategies	Explains new concepts without exploring and developing prior knowledge	Main ideas are explained in isolation	Shows creative interaction of pre-concepts with main ideas.
	Jumps around between concepts, does not follow a logical order when explaining concepts	Does not refer to interrelatedness between concepts	Logical order of explaining and linking concepts are followed
	Questions asked only requires yes/no responses from learners	Questions asked requires mostly rote learning.	Higher order questions are asked than inquires problem-solving and inquiry skills from learners.
	Answers own questions before learners can answer	Answers own questions if learners failed to respond	Rephrases questions to elicit learner thinking that requires conceptual

	Limited	Developing	Exemplary
		correctly after one or two attempts.	reasoning and allows learners to answer.
	• Ignores wrong answers from learners	• Confirms that the answers are wrong, but does not expand explanations.	• Expands confrontation of wrong answers and confirms learner understanding.
	• Does not show awareness of possible misconceptions	• Addresses misconceptions through procedural teaching	• Shows awareness of common learner difficulties and misconceptions and works towards conceptual change.
	• Does not incorporate representations to support conceptual understanding.	• Representations seldom used or used ineffectively to engage with concepts.	• Variety of representations used to explain relevant and appropriate questions in a logical sequence.
	• Lesson is highly teacher centred	• Limited involvement of learners.	• Generally learner centred
	Learner prior knowledge		
Knowledge and Skills related to Learner Understanding of Science	• Does not explore learners' knowledge and understanding on relevant pre-concepts.	• Learners are spoon-fed with the necessary prior knowledge	• Responds to and addresses gaps in knowledge of pre-concepts
	• No facilitation of discussions that expose difficulties.	• Discussions expose learner difficulties or misconceptions.	• Discussions address learner difficulties and misconceptions.
	• Identified difficult concepts are not addressed and explained correctly.	• Difficult concepts are addressed using	• Difficult concepts are explained by

	Limited	Developing	Exemplary
		standardised definitions.	expanding and rephrasing the solution.
	• Own misinterpretations and misconceptions are evident.	• Pays attention to some known misconceptions	• Pays attention to most known misconceptions.
			• Knowledge of learner thinking evident

8.4 APPENDIX D: CONTENT REPRESENTATION TOOL COMPLETED BY MR JP AFTER TEACHING: POST- CORE

Mr JP: post CoRe - Tool		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i> ?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?	I intend for learners to learn the concept of displacement and the relation between the initial position and the final position. I intend for them to learn that change in position can be found for the vertical and horizontal axis. I also need them to learn the difference between height and displacement and how to calculate height, using displacement.	Firstly, I intend my learners to learn what a projectile is. I also intend for them to learn what free fall is and the difference between the two concepts. I want them to learn that change in velocity is the rate of change of position of an object and how to calculate it. I want them to conceptually understand the difference between the initial velocity and the final velocity. I intend for learners to know that the change in velocity of the horizontal motion is the same as the change in velocity of the vertical motion. I also intend for them to learn to choose the positive direction before calculating the change in velocity. And most importantly I want them to learn that at maximum height, the velocity of the object is zero.
2. What concepts need to be taught before teaching this big idea?	The concept of distance and its difference to displacement needs to be revised. Learners must know how to convert units especially kilometres to metres. They also need to be taught about vectors and scalars to know that displacement is a vector. Learners must be familiar with the equation of motions from grade 10.	Learners must know that velocity is the rate of change of displacement. Displacement must first be taught before velocity can be taught. Learners must also have been taught about vectors and scalars.

3. What representations would you use in your teaching strategy?	I intend to use a video showing a vertical projectile motion so that learners build a conceptual understanding of the motions they are to expect. I will also be using Phet simulations to show how a vertical projectile movement look like exactly. I will use the phet simulations to show the learners the change in position of the object in motion.	I intend to use a video showing a vertical projectile motion so that learners build a conceptual understanding of the motions they are to expect. I will also be using phet simulations where the velocity of the object will be denoted by an arrow. I will also show a video of a moving car that comes to a stop.
4. Give particular reasons for the representations used to engage with this idea?	I want learners to build their conceptual understanding of vertical projectile motions. I also know that they are most likely to not forget the presentation which means there is a chance of them not forgetting the conceptual knowledge. I also want them to know that vertical projectile motions do not have horizontal velocity. Using Simulations help visual learners build the conceptual understanding of the content.	I want learners to build their conceptual understanding of vertical projectile motions. I also know that they are most likely to not forget the presentation which means there is a chance of them not forgetting the conceptual knowledge. With the presentation they will be able to tell that at its maximum height the velocity is zero. I will the video of a moving car because I want the learners to understand the difference between the initial and final velocity.
5. Describe the strategy you will use to establish conceptual development of the key idea.	In addition to the presentation I will use, I am going to explain the difference between distance and displacement to the learners at the beginning of the lesson before diving into the content. In addition to explaining the difference between these two concepts, I will show them how the two are calculated between two points. If time allows, I will take the learners outside, indicate the starting position, and move them to different directions and then find the learners' individual change in position.	In addition to the presentations, I will show them how to calculate the change in velocity of horizontal and vertical motions clearly indicating the directions of each. I will also refer them back to momentum where the learned the concept of change in velocity. I will give them questions to do that will demand them to use and develop their understanding of the key idea.

6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	I would give them few scenarios to calculate the change in displacement, the first where they get a positive displacement, the second where they get a negative displacement and the last one where they get a zero displacement. I will ask them to calculate the maximum height a ball reaches when they have the height of a building and the height it reaches from the building.	I will ask them to calculate a change in velocity for both horizontal and vertical motions.
7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	Learners often confuse displacement with the distance travelled. Learners also often forget that displacement is in metres and they struggle with converting other units to metres.	They usually confuse speed and velocity. They also forget to designate a positive direction when dealing with a change in velocity. Learners usually forget to write the direction of the velocity at the end of the answer.
8. How do you address the misconceptions and or learner difficulties?	I will address this by having learners move around and determining their distance and displacement. I will also remind learners how to convert units.	Before starting any calculations, I will be clearly choosing the positive and the negative direction. I will do this often so they can build the habit of doing so as well. If I am calculating a vector, I will indicate the direction at the end of the answer unless stated otherwise. I will also ensure I instruct the learners to do this often.

8.5 APPENDIX E: CONTENT REPRESENTATION TOOL COMPLETED BY MR DN AFTER TEACHING: POST- CORE

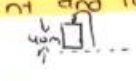
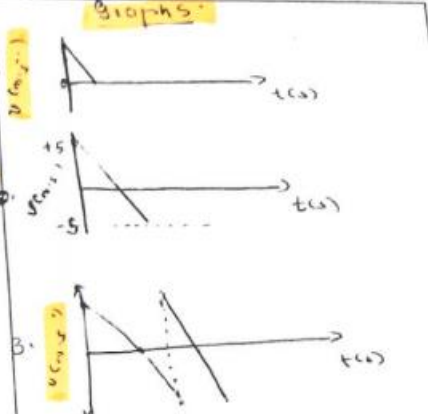
Mr DN Post-CoRe		
CoRe prompts	<i>Big Idea 1</i>	<i>Big Idea 2</i>
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i> ?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?	How the displacement is affected by the other variables and how it affects them. That displacement can be 0, for example when you throw a ball in the air and catch it at its release point the total displacement = 0 m. It can be + and -. If a projectile is thrown upwards and comes down the maximum displacement is at the amplitude. When a projectile is let go while moving up wards like in a hot air balloon it will first move initially upwards and then fall down so the displacement is the total from the highest point to the lowest point. If a projectile bounces down from one level to a next like a ball falling down stairs the displacement is the total of the vertical downward movement and not the total of each bounce. At the displacement time graphs it is important to teach the students the shape of each graph according to what direction the ball is being thrown in which causes a either positive constant acceleration or a negative constant acceleration and that the gradient is the velocity.	How the velocity is impacted by the direction in which it moves like when it is moving upwards the change in velocity will go to 0 and when it falls downward the velocity changes from 0. The sign + and – on velocity and the relation that it will have with the other variables in projectile movement. The velocity is always 0 at the amplitude when it moves up and down. If a projectile is thrown upwards from a building and it falls down to the ground, when it passes the point from which it was thrown the velocity will be of the same size in the opposite direction. Once again the direction of the movement is important. They must also know if the is hard or soft so as to sketch the correct graph. At the velocity time graph we can see that if a ball bounces or changes direction each movement is plotted on the graph “independently”. The surface area is equal to the displacement.

2. What concepts need to be taught before teaching this big idea?	The relationship of displacement to acceleration time and velocity. In short all the movement equations and how to use them. As well as the concept of Newton 1 at the hot air balloon examples. Simple graph skills. The effects of gravity and the direction of gravity and how it reacts in the real world	The relationship of velocity to time acceleration, time and displacement. In short all the movement equations and how to use them. The learners need to know Impulse so they can understand why a soft ball's graph will look different to that of a hard ball's. How gravity effects the speed of an object over time
3. What representations would you use in your teaching strategy?	For displacement I will use the following representations an object being falling downward. An object being thrown upward then falling past the point it was thrown from. I will use all the relevant graphs (positive and negative constant acceleration) A hot air balloon since it is asked a lot and it is with this.	I will use the same representations as that for displacement since the two concepts will be explained together. I will also use a soft ball and hard ball at the graphs.
4. Give particular reasons for the representations used to engage with this idea?	These representations are where the most misconceptions are formed and it usually the most difficult type of questions and is the easiest way to explain difficult concepts and address certain misconceptions. These representations will be able to address not only difficult misconceptions but also misconceptions at the introductory level	
5. Describe the strategy you will use to establish conceptual development of the key idea.	By using as SMART board I will use audio (by speaking) and visual (drawing and doing examples) to better their understanding while also asking pertinent questions about displacement and how they align with other variables throughout to further establish their understanding an knowledge.	By using as SMART board I will use audio (by speaking) and visual (drawing and doing examples) to better their understanding while also asking pertinent questions. Also by relating velocity the whole time to the other
6. What questions would you consider important to ask when	What is the difference between displacement and distance? Is displacement a vector or scalar?	Is velocity a Vector or scalar? Does velocity have a sign (+ or -)? What is the difference between

teaching this topic, to ascertain learner understanding?	Can displacement be + and -? I will have to ask questions about gravity and its effects	acceleration and velocity? How does velocity relate to acceleration
7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	That displacement should be handled like distance and they take the whole road length and not just the movement from a certain point. That if I throw a ball upward from a building and let it fall to the ground the displacement is all the downward movement from the amplitude. That a ball with in a hot air balloon's displacement is from where it has been dropped. That since the direction of the movement changes the direction of gravity or the sign of gravity changes	That velocity is in the same direction as acceleration. That the velocity is always positive. At a hot air balloon the starting velocity is zero . Velocity is zero when you throw the ball in the air.
8. How do you address the misconceptions and or learner difficulties?	I believe you address them head on by using examples in the class that are formulated in a way so that the misconceptions are almost visible to me in the question. The learners must see for themselves where they have gone wrong. Firstly we must identify the misconceptions so a good class discussion on the topic after the first home work exercise will identify what type of questions the next exercise should have. Have a brief explanation about gravity in the beginning to make sure they understand the concept	I believe you address them head on by using examples in the class that are formulated in a way so that the misconceptions are almost visible to me in the question. The learners must see for themselves where they have gone wrong. Firstly we must identify the misconceptions so a good class discussion on the topic after the first home work exercise will identify what type of questions the next exercise should have

8.6 APPENDIX F: CONTENT REPRESENTATION TOOL COMPLETED BY MS NJ AFTER TEACHING: POST-CORE

MS NJ post - CoRe		
CoRe prompts	Big Idea 1	Big Idea 2
What would you consider as Big Ideas for the topic <i>vertical projectile motion</i> ?	Change in position of a projectile	Change in velocity of a projectile
1. What do you intend the learners to learn about each of the ideas?	→ Difference between distance and displacement. → The displacement vs time graph gives the velocity. → Choosing the sign convention. Choose up as + or up as -.	→ When an object is dropped its initial velocity $v_i = 0$. → The velocity vs time graph give acceleration. → When an object reaches maximum height $v = 0$. → Time symmetry. → When a ball is thrown up, its velocity decreases.
2. What concepts need to be taught before teaching this big idea?	- In grade 10 learners should have been taught motion in 1 dimension. - Learners should know about equation of motion	→ In grade 10 learners should have been taught motion in 1D. - Learners are aware of the equations of motion.

3. What representations would you use in your teaching strategy?	<u>Scenario 1</u> → Ball is dropped from the top of a roof  <u>Scenario 2</u> → Ball is thrown vertically upwards from a roof, passes the initial point and reaches the ground.  <u>Scenario 3</u> → motion of a bouncing ball 	<u>Graphs:</u> 
4. Give particular reasons for the representations used to engage with this idea?	- Equations of motion are taken from the graphs. - We use the graphs for learners to understand the motion of an object. - We use graphs to calculate the unknown variables. - → Use graph to interpret the motion.	- Graphs to show motion of an object. - → calculate unknown variables.

5. Describe the strategy you will use to establish conceptual development of the key idea.	- Use real-life examples and ask learners questions that they can relate to. - Throw a marker / duster upward and ask learners what they observe.	- Throw an object upwards to indicate reference point, maximum height, increase and decrease in velocity, time lapse.
6. What questions would you consider important to ask when teaching this topic, to ascertain learner understanding?	① Why is it that when an object is thrown up it always come down? ② Why the displacement of a bouncing ball decreases.	→ Why is it that when an object is thrown up its velocity decreases →

7. What are the typical student misconceptions and or learner difficulties that affect the teaching of this big idea?	- Learners confuse the difference between displacement and position - They cannot differentiate between vector and scalar quantity - They cannot draw the displacement vs time graph	→ Interpretation of the graphs.
8. How do you address the misconceptions and or learner difficulties?	- Explain to learners the difference between displacement and position - Explain vector → magnitude & direction scalar - magnitude only - Use more representations of graphs	→ more representations of velocity vs time graph - Explain the distance between the motion of a bouncing object and a dropped object → On the graph zero axis represent zero velocity

8.7 APPENDIX G: TRANSCRIBED AND CODED INTERVIEW WITH MR JP

Interview	Analysis of interview	
	Components and competences	Comments
Mr JP		
1. Interviewer: “What would you consider key concepts in vertical projectile motion?” Interviewee: “I would say displacement, change in velocity and signs, choosing the right direction. Choosing the right direction for your motions like positive direction and negative direction and most importantly, the gravitational force and gravitational acceleration.”	Curricular salience Teaching strategy	Important concept for learners to understand. Pre-concepts identified.
2. Interviewer: “These key concepts that you've just mentioned, why do you think it is important for learners to know them in the topic?” Interviewee: “I think it is because most of the motions in vertical projectiles include displacement, which most of the time they confuse it with distance. You need to show them the difference between the two. Of course there is change in velocities initial and final, that's as important in this chapter as well. The gravitational acceleration is always downwards. The gravitational force and the gravitational acceleration is always downwards.”	Curricular salience Learner understanding	Pre-concepts identified. Important concept for learners to understand (new knowledge) Learner difficulty identified
3. Interviewer: “From grade 10 and grade 11, which topics do you think are important for learners to know before they start with vertical projectile motion in grade 12?” Interviewee: “In grade 10 definitely motion in one dimension. They need to be used to the use of the four equations of motions. They need to understand velocity because if I remember correctly, it is introduced in grade 10 and displacement. In grade 11 they need to understand gravity. The gravitational force the gravitational acceleration from Newton's law of universal gravitation.”	Curricular saliency	Pre-concepts identified from grade 10 and grade 11.

Interview	Analysis of interview	
	Components and competences	Comments
4. Interviewer: “In your personal opinion, what do you think is difficult for yourself to teach in vertical projectile motion? So, what are difficulties or limitations in teaching the topic?” Interviewee: “At the moment, I would say graphs. I don't have a lot of experience teaching graphs. I don't think I have any because when we were doing our practical in university it was during a time when vertical projectile was already done, or before it was done, so I don't have much experience teaching graphs. I do understand them very well. But I think that's going to be a limitation.”	Learner understanding	
5. Interviewer: “What misconceptions do you believe learners have in vertical projectile motion?” Interviewee: “I think distance and displacement, they might confuse the two. This is the biggest one. I think they are used to changing velocity from momentum. So I don't think that'll be a problem. So I would say displacement.”	Learner understanding	Learner difficulty identified.
6. Interviewer: “and learning difficulties?” Interviewee: “Meaning?”		
7. Interviewer: “What do you think in vertical projectile motion is creating a difficulty for learners? It doesn't necessarily have to be a misconception is just a difficulty they experience?” Interviewee: “I think interpreting the motion. They have a difficult time interpreting. I'm not completely sure because of my lack of experience in teaching this particular chapter, but I would say interpreting the entire motion. I think that I need to focus on teaching them how to break down their entire motion into manageable pieces that can be easily understood. So I think interpretation of a motion.”	Learner understanding Teaching strategy	Learner difficulty identified. Strategy to divide motion of object into sections

Interview	Analysis of interview	
	Components and competences	Comments
8. Interviewer: “What strategies do you use in teaching the topic?” Interviewee: “Separating the entire motion like breaking it down into different parts. Separating the beginning of the motion, the initial velocity to the maximum height and the final velocity, and from the maximum height to the ground. That's a strategy that I'm going to be using a lot instead of focusing on the initial velocity and straight to the final velocity. I don't know if that makes sense.”	Teaching strategy	Good strategy Focuses on reference points
9. Interviewer: “What representations would you use in teaching the topic?” Interviewee: “This is a good one. I'm going to be using PhET simulations. I think they play a big role in helping learners understand. I know that from experience. So I'm going to be using simulations and representations drawing the motion on the board.”	Representations and analogies Teaching strategy	Different type of representations identified.
10. Interviewer: “You mentioned PHET simulations? Could you please explain just what that is?” Interviewee: “They are simulations that show concepts, physics concepts. I don't know how to explain it. Simulations to denote or show abstract concepts in a way that can be easily understood. Yeah, I think they help the learners to sort of like imagine or conceptualize our understanding of abstract concepts.”	Representations and analogies Teaching strategy Learner understanding	Reasons provided for the use of representations.
11. Interviewer: “What do you think works well, in explaining the topic?” Interviewee: “I think the PHET simulations will be helpful. I think breaking down the motion will also be helpful. I think the idea of having the four different equation of motions in front of them as we deal with problems will be helpful as well.”	Curricular saliency Representations and analogies Teaching strategy	

Interview	Analysis of interview	
	Components and competences	Comments
12. Interviewer: “If you had to give advice to someone on how to teach the topic from the very beginning, what would you say?” Interviewee: “I would say start with making sure that they understand what vertical projectile motion is. Build their conceptual understanding of the chapter of motions you'd be dealing with before focusing on calculations. Help them understand the motions by breaking it down, final velocities and initial velocities, because you might think they know what initial velocity and final velocities are but make sure they understand all of those different small things. You can then go to solving problems, helping them, teaching them how to solve projectile problems.”	Curricular saliency Teaching strategy Learner understanding	Good idea to build conceptual knowledge before solving problems

8.8 APPENDIX H: TRANSCRIBED AND CODED INTERVIEW WITH MR DN

Interview	Analysis of interview	
	Components and competences	Comments
Mr DN		
1. Interviewer: "What would you consider key concepts in vertical projectile motion?" Interviewee: "Displacement, acceleration, velocity and the direction of movements."	Curricular saliency.	Appropriate and accurate pre-concepts are mentioned.
2. Interviewer: "These key concepts that you've just mentioned, why do you think it is important for learners to know them?" Interviewee: "I think it is important for learners to know them because they all are integrated with each other and they depend on each other. So for instance, if the displacement is a certain height, the velocity will be a certain height according to the acceleration it will undergo. I think all of this and then the direction when they need to know these concepts, the direction concept, especially when you look at these objects in which direction they will move. It is very important so that they can have that insight into what is actually happening at each time for that ball, or that object."	Curricular saliency	Pre-concepts identified Referred to interconnections between concepts
3. Interviewer: "Do you think there's grade 10 and grade 11 topics that are important for learners to know before you teach vertical projectile motion?" Interviewee: "Yes, there are."		
4. Interviewer: "What would you say those topics are?" Interviewee: "Definitely at the grade 10 side I think the movement, formulas with movement and everything. That is basically the whole basis of projectile movement. In grade 11 we can sometimes look at one situation where we need to know about the forces working in on this ball being thrown. So maybe like Newton's laws and so on."	Curricular saliency	Some pre-concepts identified.
5. Interviewer: "What do you think is difficulties in teaching the topic or what would you say can be limitations in teaching vertical projectile motion?" Interviewee: "I think the biggest challenges that children might have is noticing in which direction I'm working and should I work with the whole movement or should I work just with a certain movement	Learner understanding Curricular saliency	Identifies learner difficulties. Identified pre-concepts: Linking it with new

and then also, at grade 10 they already get confused with the difference between the displacement and distance. So the vectors and the scalars the difference between those things that you should usually struggle with."		knowledge
6. Interviewer: "What misconceptions do you think learners have?" Interviewee: "If I throw the ball in the air, it doesn't have a starting velocity or something like that. Sometimes they might think, I'm working with the entire distance that entire path it is following. If I throw a ball into the air and it comes back down, they might think I'm working with the entire distance and rather than just the displacement that you need to be working with. As well as the acceleration sign might change. They might think like time is a negative, there's a negative time. Suppose it is sometimes let's say simple mistakes that make huge misconceptions."	Learner understanding	Identified a misconception that is not generally recognised in vertical projectile motion. Identified learner difficulties.
7. Interviewer: "What strategies would you use to teach this topic to learners?" Interviewee: "The main strategy I would use is basically using diagrams, these topics are basically teach with diagrams so that I can focus on the visual, audio and all these types of senses. The strategies I will use are basically using the graphs as well as just the normal formulas that you use to put it together. I'll explain more of a talk and chalk type of things and give them physical examples and taking it to the real world experiences that they might have. Like, let's say one of them is an athlete, you can say, you can take a javelin throwing a javelin into the air or throwing a shot put ball into the air or something like that. So I will take it to the real world as well."	Learner understanding Curricular saliency Teaching strategy	Examples used can create misconceptions with learners. Traditional method of teaching. Two types of representations.
8. Interviewer: "If you have to give advice to a teacher whose teaching this topic for the very first time, what advice would you give them to teach the topic?" Interviewee: "I think the biggest advice I'd give them is to make sure that your students understand the concept of the movement. In which direction. Make sure that you take it to the real world. Give them the diagram, so as soon as they see a picture they can see the movement. So given this illustrations to see movements on how they work. I would recommend that they make sure that the students they have in front of them do know and have the previous knowledge from grade 10 and 11 for this topic. As well as necessary grade 12 knowledge that you need for this topic. Then your repetition and giving them as much as possible different types of questions like have a hot air balloon, have a projectile being thrown up in the air and then falling down, just falling. You know from free fall all these types of things. Give them a wider range of options and examples so that when they are faced with it they can easily identify what type of question that is."	Teaching strategies Representations and analogies Curricular saliency Learner understanding	Describes a workable strategy, with limitations to application and explanations. Identified relevant representations. Pre-concepts included Good examples used that can assist in learner conceptual development.

8.9 APPENDIX I: TRANSCRIBED AND CODED INTERVIEW WITH MS NJ

Interview	Analysis of interview	
	Components and competences	Comments
Ms NJ		
1. Interviewer: "What would you consider key concepts in vertical projectile motion?" Interviewee: "Firstly the main key points, the learners have to understand the definition or the difference between free fall and projectile. Then also the learners have to understand the difference between displacement and position. They also have to understand the sign convention to say that if they are given a question and then they're saying probably maybe a ball is thrown upwards. So the first thing that the learner must know is that they must choose the direction that they're going to use throughout. The other thing that they must understand is the time symmetry, which gives us three things. It can give us the maximum height, it can also we have to understand that if a ball is thrown vertically upwards, the velocity decreases as the ball goes up. And also if when it reaches the maximum height our velocity is going to be zero. Once it comes back it will have the same speed but in different directions. So that means if they have taken up as positive and the ball is going up the initial velocity will take the positive sign and then when it goes down, then it will take the negative sign."	Curricular saliency. Learner understanding Teaching strategy	A projectile is an object in free-fall Did identify new concepts related to the topic. Pre-concepts are considered Difficulty of teacher visible regarding time-symmetry
2. Interviewer: "Do you think there's grade 10 or grade 11 topics that is important for learners to know before you teach vertical projectile motion?" Interviewee: "Yes, in grade 10, I think there is that introduction of vertical projectile in one dimension. So learners already have that information from grade 10 because they are now exposed to the equations of motion. So I think in grade 10 There is that background and it is important."	Curricular saliency.	Pre-concepts from grade 10
3. Interviewer: Okay, in grade 11. Do you think there are any topics? Interviewee: "No."	Learner understanding	Lack of knowledge from grade 11

4. Interviewer: “What do you think is difficulties or limitations in teaching the topic? So the teachers perspective, what do you think is difficulties or limitations for a teacher to address the topic?” Interviewee: “I think one of the problems or I would say limitations are the matter of language, the language that has been used with those vertical projectile motion questions. Learners can have a problem with the language that is being used. Then the other thing I think teachers we normally do not use more real life situations in class. We can just say a ball is thrown upward, but instead of bringing that ball to the class so that learners can experience that or can see that with their own eyes we just assume that they already know what we are talking about. So I think the language that is being used there and also not relating it to the real life situations could be the problem. The other thing I think it is with the graphs. I think it is a problem for both teachers and the learners. The interpretation of the graphs, I think that is the other thing. Maybe we do not have the right approach on how to explain the graphs in vertical projectile.”	Learner understanding Teaching strategy Representations and analogies	Identified a difficulty not normally considered. Different type of representation
5. Interviewer: “Do you think learners have misconceptions regarding some of the concepts in vertical projectile motion?” Interviewee: “Yes, they do.”		
6. Interviewer: “What would you say is that misconceptions?” Interviewee: “One of the misconceptions that they have is with the sign convention. Sometimes if they take upward as positive, you find that they know if the ball is going up, they're working with gravitational acceleration instead of writing negative 9.8. They just assumed that it is just going to be 9.8 those are one of the misconceptions. The other one is with the confusion between at maximum height, learners know that if a ball is thrown up at maximum height velocity is zero some confuse that with height. They say height is zero instead of the velocity being zero at maximum height. The other one is with the graphs, so the other misconception normally when we look at the graphs isn't it is the opposite. You find that a ball is thrown up but the graph is going down. So that causes the confusion because learners believe that if a ball is thrown up, that means my graph should maybe velocity time graph should also go up. So I think those are the misconceptions I can think of right now.”	Curricular saliency. Learner understanding	Identified a difficulty not usually considered by literature. Very important difficulty identified regarding graphs.
7. Interviewer: “Do you use representations in your lessons for vertical projectile motion?” Interviewee: “Normally, I use graphs on the board. I just draw graphs before explaining, before getting into the questions. I just draw the graphs and then just explain the important key points. We can use a normal ball or any object that could be in my hand at that moment, probably a duster or anything, just to show that if I'm	Curricular saliency. Teaching strategy Representations and analogies	Two types of representations identified Uncommon

throwing it up, it is going to come back down. Then the learners can explain what causes that what do they think could have happened? And also you can even use the normal ruler when talking about displacement. I mean, that is a distance on a straight line."		teaching strategy
8. Interviewer: "So what do you think works very well in explaining this topic to learners?" Interviewee: "In terms of?"		
9. Interviewer: "The way you teach learners this topic, what do you think will work well? For learners to understand what you're teaching them better. So what strategy do you use, that you think really equips yourself to teach the learners the content so that they understand it clearly." Interviewee: "Okay, normally what I do I encourage learners that if they get a question, I'm explaining that they should draw that diagram on their own. I think the first thing is being able to interpret whatever that is happening. So the best way is that they take that information and they make it their own, try to interpret it in their own understanding. Have a drawing to say this is the motion of the ball, this is what is happening and then also have points to say I will take this as my point A, then maybe the maximum height as my B, the ground as point C. Then they should take out the information that is given after taking out the information that is given, they should check what the unknown variables is. With that information that they take then they relate it to the four equations of motions that they have to see what it that I have is, what it that I do not have is. They will be able to know which equation of motion that they can use but the main thing is learners being able to interpret what is given making it their own, drawing and making their own representation out of what is being given."	Curricular saliency. Teaching strategy Representations and analogies	General teaching strategy described.
10. Interviewer: "If you had to give advice to a new teacher teaching this topic, what advice would you give them on how to go about this topic?" Interviewee: "Okay, I think one advice I would give them is that they should not only stick to the textbook that is provided because sometimes you find that there is limited information on the textbook so they must use even other forms of media even YouTube's you can watch different videos of other teachers teaching the same topic. They should also consult with other teachers because you find that you're only limited to only one source of information and you find that there is like some loopholes or some of the things that are not there. So using YouTube to see other videos also interacting with other teachers making sure that you have all the information and also using previous question papers because that is where now you get to see a different question or a new question. Then you try to find the approach. So I could say that collaborating with others and also searching out for information from different sources before teaching the topic could assist."	Teaching strategy Representations and analogies	Plan to introduce media in the lesson which is another form of representations

8.10 APPENDIX J: TRANSCRIBED AND CODED VSR INTERVIEW WITH MR JP

Interview 2 – Mr JP		Analysis of interview	
		Components and competences	Comments
Mr JP			
1. Interviewer: “Why did you decide to use this representation in your lesson?” Interviewee: “First, to understand what a vertical projectile motion is. And I thought that if they see it play out in real life with simulations, they might understand the concepts better if they see it with their eyes playing out.”		Learner understanding Curricular saliency Teaching strategy Representations and analogies	Different type of representation Linking concepts to representation
2. Interviewer: “What main concepts did you want to show them in using this?” Interviewee: “I think it is the maximum height, displacement, velocity and time. I wanted them to understand that at maximum height, the ball stops before it comes back down. I think with this simulation I wanted them to see that at the maximum height, this thing stops before it goes down. That's why, to have a mental model of projectiles.”		Learner understanding Curricular saliency Representations and analogies	Addressing learner difficulty. Linking concepts to representation
3. Interviewer: “Do you think this representation of yours was successful? So will you use it again?” Interviewee: “I think it was. Scientifically it is not correct. But I think it was because this is how it looks in their exams and books. It is how it looks, but we know it is not like this. So I think it worked. I think it helped.”		Learner understanding Teaching strategy	Teachers' misinterpretation.
4. Interviewer: “Can you elaborate on what you mean when you say it is not scientifically correct?” Interviewee: “I was reminded that vertical projectile motion does not have horizontal velocity. In reality, the ball was not supposed to move either left or right, but straight up and straight down.”		Learner understanding Curricular saliency Representations and analogies	Realised his representation can cause a misconception

5. Interviewer: "Why did you consider this part so important? You did spend a lot of time on it. Why was it so important for you to explain this to learners?" Interviewee: "They need to understand the concept of displacement. Because if they don't understand the concept of displacement, it becomes really difficult for them to understand how to solve vertical projectile calculations. Like they need to understand that if let's say, a ball is projected upwards and comes back to the same position, the displacement will be zero. They need to understand that concept. And they need to understand that other displacement concepts can play out horizontally and vertically."	Learner understanding Curricular saliency Teaching strategy	Ambiguous in his response to concepts play out horizontally
6. Interviewer: "You used a representation here. What was the main difference between this representation and your first one?" Interviewee: "I think it is the arrow in the second simulation. I included the arrow because the arrow denotes the velocity, the magnitude and the direction of the velocity. So I needed them to see. But it did not work out well. But I needed them to see that at the maximum height, the arrow disappears, or the velocity is zero because the arrow is not facing up or down."	Learner understanding Curricular saliency Teaching strategy Representations and analogies	Good strategy that was ineffective due to simulation incorrectly used.
7. Interviewer: "If you say it did not work well, what would you improve in your next lesson?" Interviewee: "I think next year when I do teach this section again, or maybe when we do our revision for June, I will use the correct representation of vertical projectile motion, which goes straight up and goes straight down. Because I want that arrow to disappear completely, I will explain that, even though it goes straight up and down, we represent it like this, sort of mountain-shaped, but I just need the arrow to disappear. And I will play it in slow motion."	Learner understanding Curricular saliency Teaching strategy Representations and analogies	He is aware of his mistake and can correct it in future.
8. Interviewer: "Why did you start with this specific example?" Interviewee: "Give me a minute to just think about it. I think I started with this example because it is like the general vertical projectile calculation problem. It encapsulates all the concepts of general vertical projectile problems. It is going up, reaching the maximum height and going down. We can have a vertical projectile problem where the ball is shot straight down, which will be this piece here, from here to here. Or we can have a vertical projectile problem where the object is shot straight up, which would be this piece. So I think this is an entire example. It shows all the different aspects of the questions they might ask."	Curricular saliency Teaching strategy Representations and analogies	His examples could be scaffold better. Going from easy to difficult.

9. Interviewer: “What positives can you take from this example? What will learners know after you've used this example?” Interviewee: “I think the concept of the velocity being zero. Something I repeated so many times, so I am sure they knew it by now. So I don't want to mention that. But I think the positive would be that they learned that the time taken for the ball to reach the maximum height would equal the time taken for the ball to move from the maximum height to the same position. I think that's one positive. And the second positive that I'm sure or hope they take from this example is that the maximum height velocity can act as both final and initial. I think that's very important. I wish I didn't write v_f. I wish I had just written zero metres per second because we can use it as final and we can use it as initial, so I think that's positive. We can divide the entire motions into different aspects where we can use this as a final and as initial or here to here.”	Learner understanding Curricular saliency Teaching strategy	Referred to the concept of time-symmetry Good strategy to divide motion into sections. Misinterpretation in the final velocity – it is the final velocity because of chosen reference frame.
10. Interviewer: “When you explained this to learners, please take me through your thought process?” Interviewee: “Do you want me to explain based on what I did or based on what I now know.”		
11. Interviewer: “Explain what you did and what you intended for them to know.” Interviewee: “I wanted to show them how to find the total time taken for the entire motion. Because that's a common question, I needed them to know time symmetry. That the time taken from here to the maximum height, from the initial position to the maximum height, will equal the time from the maximum height back to the initial position. That was very important for them to know, for me. I also needed them to know how to calculate the time for the remaining part of the motion. I think that I wanted them to learn how to manipulate, not manipulate per se, but how to read the graph, how to read the motion, and interpret it and then calculate whatever they need to calculate or break it in different parts, and then calculate whatever they need.”	Learner understanding Curricular saliency Teaching strategy	Common teaching strategy
12. Interviewer: “What would you answer? Considering what you now know” Interviewee: “When I was at Mazwe, the teacher was teaching them vertical projectiles. I think it was during the holidays of term one. And I saw that he divided his entire vertical projectile motion using letters. When I explained it, I divided them in my mind, which is not very helpful to the learners. So I saw that he put the initial position as A, the maximum height as B, back to the initial position as C, and then the ground is D. I think that's very, very helpful, something I was reminded of that I forgot I think. And it is even easier to break	Learner understanding Curricular saliency Teaching strategy	Good teaching strategy. Explains why he did not use alphabet letters

down the motion of the graph when you have assigned letters to the different aspects of the graph.”		in his first lesson.
13. Interviewer: “During your calculation, you stopped to explain the concept to learners. Why was it important for you to emphasize this to learners?” Interviewee: “I want to say I regret putting the equal sign in because it is not true. I wish I'd said: five squared equals 25, and minus five squared is equal to minus 25. That would have worked much better than me saying this is equal to this. To answer your question, I think it was important for me to stop and remind them to put the V when they're working with this equation to put the velocities inside the brackets because a velocity can be negative or positive. And you get a different answer when you use the brackets and when you don't. So I needed them always to remember to put the brackets.”	Learner understanding	Explained a difficulty that is normally associated with mathematics
14. Interviewer: “Learners asked a few questions. I want to know what you think of the questions asked by the learners?” Interviewee: “They seem obvious. I think to someone who has finished matric and done physics, it seems like an obvious question, but I don't know if it is. It was a good question. Because if they had the misconception, they would get the entire question wrong. So it is a good question, but it seems obvious to me. But I've learned that what's obvious to me may not necessarily be obvious to them.”	Learner understanding Teaching strategy	Good remark to not take for granted what we think learners know.
15. Interviewer: “Would you keep your sequence of examples the same?” Interviewee: “I remember I did the displacement, the vertical one separating the horizontal line. I sort of, like, mashed them together. I think I would do them the same. I don't think I would change the sequences of my examples because they build on top of one another. Yeah, I would keep them the same.”	Learner understanding Curricular saliency Teaching strategy	
16. Interviewer: “Is there something you would change or do differently in your lesson?” Interviewee: “Yeah, definitely the second simulation. I would use the correct vertical projectile motion, and how it looks like correctly. Some of the misconceptions like the one of five squared and minus five squared. I would clarify that misconception better because, honestly, I doubt they heard me the way I put the equal sign in the middle. I don't like that I did that. And I would change the final velocity when I was doing the example, the maximum height velocity. I called it the final velocity, and I wish I had just written the velocity, the value of the velocity, or just v is equal to. Because I feel like if I just read that I wrote the final velocity, they must have thought it is always the final velocity, which is not true. So I would change that. What else	Learner understanding Teaching strategy Representations and analogies	Good correction made on simulation. His entry on final velocity rather entails the chosen reference frame

would I change? Now, those are the ones I remember that I would like to change.”		to be understood.
17. Interviewer: “What did you consider very difficult to teach?”		
Interviewee: “To teach not for the learners to learn, but to teach.”		
18. Interviewer: “Yes, for you to teach.”		
Interviewee: “I couldn't find an easier way to teach how to break up the motion into different segments. I wish I knew how to do it in an easier way. Teaching it was a bit difficult because I felt like I was relying mostly on my mental model rather than what I was showing on the chalkboard, and I was not confident that they were really hearing me. So I think that example was a bit challenging to simplify at the time.”	Learner understanding Teaching strategy	Asking questions could have assisted.
19. Interviewer: “What do you think was difficult for learners to learn?”		
Interviewee: “Again, the same thing. I think it was difficult to break down the motion into different segments. I say this because I've assessed them, and they struggle with calculations and separating the motions into different segments. So I think that was difficult for them to learn.”	Learner understanding	
20. Interviewer: “Why did you decide to start with this example?”		
Interviewee: “I think because, honestly, it is the simplest graph. And it gives them an idea that when you choose upwards as positive, your graph will look different than when you've chosen downwards as positive. So I just wanted them to see your graph will look differently based on your positive direction and also because it was the simplest one.”	Learner understanding Curricular saliency Teaching strategy	Addressing possible misconception
21. Interviewer: “Do you think it is important to break the motion down into smaller parts? Like you did?”		
Interviewee: Yeah, definitely. You might find that they do not have enough data to solve the problem using the entire motion, so they might need to break them down to use the given values. Like for example, let's say they require the final velocity or the velocity at C, but they only have, that's not a good example. But yeah, my answer still stands that you might need to use one segment to find the answers to another segment. So it is necessary to learn how to break the motion into different segments.”	Curricular saliency Teaching strategy	Workable strategy
22. Interviewer: “Please explain why you thought this was important for learners to know.”		
Interviewee: “First of all, I needed them to know that as the ball goes upwards, its velocity is decreasing, and then as it goes downward, its velocity is increasing. They need to know that. And I also needed them to	Learner understanding Curricular saliency	Including pre-concepts in new relevant

learn this because I know that the questions are never straightforward in the exams. They always ask questions that need you to apply what you've learned. It is never defined, you know? So I needed them to understand that the gradient of that position time graph represents the velocity. There might come a question that says to calculate the velocity of the object, and they don't have enough data to use the equation of motions, but they do have enough data to use the gradient. So it is something that I wanted to prepare them for. But mostly, I needed them to know that the velocity is increasing as you go upwards as the object goes upwards, and decreasing as it goes downwards."	Teaching strategy	concepts. Last sentence is a slip of tongue.
23. Interviewer: "Can you elaborate on that concern that you had?" Interviewee: "I can't be 100% sure if this was the concern, but at the moment, I'm thinking how the graph would look if downwards is taken as positive. And will my learners know how to draw the very same graph of a bouncing ball if they are required to draw it taking downwards as positive? I think that that is the concern that actually I still have now. Would they be able to draw the graph taking downwards as positive? Or would they be able to interpret it if we are given it downwards as positive?"	Learner understanding Teaching strategy	A bit unclear, but definitely progress made on his misinterpretation
24. Interviewer: "Would you keep your sequence of examples the same?" Interviewee: "I think I would. I would keep the sequence the same because acceleration was the easiest. The velocity one is a bit average is understandable. And then the position-time graph is really easy. But when it comes to a bouncing ball, then it becomes a bit tricky. I would keep them the same, but I think I would spend more time going through the last example. That's what I would change. The sequence I would keep the same."	Learner understanding Curricular saliency Teaching strategy	
25. Interviewer: "What was difficult for you to teach during this lesson?" Interviewee: "Definitely this example. I wish I focused on teaching them how to identify the direction of the object. This is what I mean. I wish I told them to, of course we were taking upwards as positive, to identify if the velocity is decreasing or increasing and then come to the conclusion that it is going upwards or downwards based on the change in velocity. I wish I'd done that."	Learner understanding Teaching strategy	A bit unclear, but definitely progress made on his misinterpretation.
26. Interviewer: "What do you think was difficult for learners to grasp about graphs in projectile motion?" Interviewee: "I'm not sure I can't really tell. I honestly can't tell what was difficult for them to understand. I think I made a mistake not giving them a class test on graphs alone."	Learner understanding Curricular saliency Teaching strategy	

27. Interviewer: “Do you think graphs are difficult for them?” Interviewee: “I think it is challenging for them because when we were going through some classwork, and when we were doing corrections of that classwork and homework, they were having a difficult time, and even on the test when I was making the test and doing item analysis. The vertical projectile questions were poorly answered. Mainly the graph questions. I think it was only three out of six that were able to interpret the graph. So I think graphs are challenging for them.”		
28. Interviewer: “Is there any concept you can pinpoint to say why graphs are difficult for them or their results were not good?” Interviewee: “I don't know. I can't point to any concept.”	Learner understanding Curricular saliency	

8.11 APPENDIX K: TRANSCRIBED AND CODED VSR INTERVIEW WITH MR DN

Interview 2 – Mr DN		Analysis of interview	
		Components and competences	Comments
Mr. DN			
1. Interviewer: “Is there anything you would change from your introduction to this lesson?” Interviewee: "Yes, firstly, I would give them one example of grade 10 movement in one dimension with the movement equations. To sharpen up that knowledge a bit because it can get lost sometimes since we don't do a lot of them in grade 11. And we focus a lot of them on grade 10; it is two years ago for them. After explaining that part of projectile motion, I would have looked at a quick example. This is how we use these equations. Focus less in detail on all the definitions and small detail, and rather get down to the nitty-gritty things that they usually do not get correct in exams, and in questions, and so on."		Learner understanding Curricular saliency Teaching strategy	Pre-concepts introduced at the beginning of lesson. Too soon for exam questions
2. Interviewer: “The first example that you showed to learners, please explain why you chose this specific example and why you think it was the best example to start with.” Interviewee: “I chose this example because they are used to something just going to the left or right. They are not used to something going up and down or left and right. So I think I used it to explain how I can divide it. If we take Newton's second law, I explained that we can divide it into upward and downward movements. Because in many exam questions, they like to throw a ball upwards, and then it falls past the starting point down to the ground of a building. So I didn't want to take a building example like they usually ask for in exam papers; I wanted to take one where they start with a certain height and end with a certain height. An example, they throw a ball in the air and catch it at the same place. I can also explain that the starting velocity will equal the end velocity if they are at the same point in that plane in that entire movement. So I chose that one because it is a concept that they struggle a lot with. That is the upward and downward movement. That's why I started with the upward and downward movement so that I can explain at the top, its velocity is zero, so your new starting velocity will be zero if you work with the downward movement. If you work with the upward movement, your starting velocity will be the maximum velocity in that movement.”		Learner understanding Curricular saliency Teaching strategy Representations and analogies	Linking of pre-concepts with relevant concepts Touched important relevant concepts

3. Interviewer: “In this second example you're doing with the learners, please explain or take us through your thought process in introducing these concepts to the learners.” Interviewee: “The first example I used was a ball being thrown upwards; you can't explain only the one type of movement because if they only know it is going to move upwards, now they get shown something maybe where it is the inverse. And this is just the inverse of that, where the ball gets dropped downwards and hops back up. So that bounce effect is also a concept. That is important. Because once again, now it is just the previous one turned around. So if you explain to them back to back, they can start seeing the differences between the two. When they get into the exam and have this type of example or that type of example, depending on the question, if it is a ball being thrown upwards or dropped downwards, they can for themselves go and see. Okay, so I need to go and look at this example. This is the direction of the starting velocity; this is the direction of the end velocity; that's why their starting velocity in the first one will be the maximum, and the starting velocity in this one will be zero. So it is just so that both examples can be done back to back so they can understand that it is just the inverse of the first one. And then it might be easier for them to understand both concepts if you explain them next to each other.”	Learner understanding Curricular saliency Teaching strategy Representations and analogies	Sequencing of examples
4. Interviewer: “Are you satisfied with the representation you used to explain this example to learners?” Interviewee: “Yes, I am more or less satisfied. One or two things may need to be changed, like the arrows' direction, which can confuse some learners. When they used to draw vector diagrams and those types of things, the arrows for them represent the length. They may not see the ball falling completely to the ground unless they read the questions. Sometimes you get kids that don't read that well. I would have just taken the arrow and drawn it onto the ground so that they could see it going upwards, and then it came downwards, straight down onto the ground. There's something that can confuse them, which is the arrows are next to each other. They won't go back to the vector diagrams because when we draw vector diagrams in one dimension, we draw them underneath each other if they are in opposite directions. But sometimes, they forget that knowledge and might think the ball is being thrown forward. Importantly, I would have used a person on top of that building to show that the person was not throwing it from the building. The person is holding their hand over the building. They don't understand where the person is exactly standing, all these types of things.”	Learner understanding Curricular saliency Representations and analogies	Uncommon difficulties identified

5. Interviewer: “About the acceleration of an object, one of the learners made a statement in the class that you've just listened to. What do you think of this statement made by the learner?” Interviewee: The learner understands the concept that I explained. In the real world, when we talk about somebody and say they are slowing down instead of they have a negative acceleration. But in physics and the science classroom, we talk about acceleration only. Acceleration can be positive or negative. It doesn't mean you drive in the opposite direction because it is not velocity. That statement was a good statement from her. So it bettered my lesson to the other children so they could also understand at the level she understood at that stage. Even though I have a negative acceleration or a deceleration, we talk about acceleration in the opposite direction. Even though we're talking about acceleration in the opposite direction, it doesn't mean we turned around and drove in the opposite direction, we are slowing down, but we still talk about acceleration. So she understood the concept that I explained, and the statement was also a good aid for me to explain to the children when I'm talking about this. Because they learned this in grade 10 but could have forgotten it, it helped me better explain it and further the concept knowledge I spoke about in my lesson. If you have acceleration and deceleration, deceleration is equal to acceleration in the opposite direction. And that's why you use the sign negative because it is a vector.	Learner understanding Curricular saliency Representations and analogies	Misconception identified Pre-concepts revised
6. Interviewer: “In the example of the hot-air balloon, what concepts did you want to highlight to learners?” Interviewee: The concept I wanted to explain corresponds with Newton's one of inertia. If you have a hot-air balloon moving upwards, and if you drop the ball, it is initially going to move upwards because of the concept of inertia. It is a concept I wanted to work on because the children often forget about the inertia factor, where if it moves upward, it is still continuing to move upwards even though I've dropped it. So for a split second, it is going to move upwards. And the second concept of this specific hot-air balloon is the fact that the ball is being dropped, and somebody is running to catch it, if I remember correctly. Now we're working basically with a rectangular triangle, a right triangle where one moves to the left and a hot-air balloon moves upwards. Then we need to determine the time and the speed at which this guy needs to run to catch that ball. This concept takes a lot of concepts; I wanted to give them an example. Often, they ask in an exam for an example of where they use different concepts and not only projectiles moving upwards and downwards. Force the learners to think more deeply about the concept and where they have to go and decide for themselves what they are actually asking of me. This also develops the scientific process skills they use to answer questions like this. To wake up that little part of the brain that says I need to think now. They're not saying specifically what they want; I need to search deeper into what they want.	Learner understanding Curricular saliency Teaching strategy Representations and analogies	Concepts from other topics linked to new concepts of VPM.

7. Interviewer: “Are you satisfied with the sequence you followed during this first lesson?” Interviewee: Yes, I am satisfied. Basically introduced them to this concept and gave them examples without using physical numbers and those types of things. Give them examples of the movements to understand the movement of the ball, how it would go up or down, and why it turns around and starts dropping down at the turning point. At that point, why is it zero velocity and those types of things? One thing I might want to change is fewer examples that are physically done that are already done on the board, and do more examples with them physically and maybe one or two exam questions already to throw them into the deep end so that they can have a cooperative lesson where I pair them two-two. They work on the problem together to learn from each other. Then I’m only the facilitator, so to throw them in the deep end and to see where I might have to go back to something and explain it again. Because you only diagnose those types of problems when they already wrote the test and said this question was difficult, I didn't understand why it moved that way, or I couldn't find my velocity or the acceleration confused them. At the end of the lesson, I need to put a higher-order question that comes out of a previous exam because, in the exams, they like to ask certain types of questions. They can now see this is what I'm going to get. In the book exercises, they ask a certain way, but when you get an exam question, they first ask you to give a definition. Bloom's taxonomy that they use in exam papers for the NSC exam. As soon as you see those questions, they can get used to them; this is more the type of questions I am going to get, rather than the questions I get in the exercise, which is not focused on Bloom's Taxonomy.	Teaching strategy	New strategy suggested compared to post-CoRe
8. Interviewer: “Which concepts did you find difficult to explain to the learners.” Interviewee: The most difficult concepts were the ones with up and down movement for the acceleration to explain to them that acceleration is always negative because it is always downwards. It is an unwritten rule, it is a better thought process, and you don't confuse yourself that you choose upwards as positive. Acceleration is always downwards. To explain this concept to them, if you are on the Earth, the acceleration due to the gravitational force is always downwards. And that's why we give it a negative sign. The other concept that I found difficult is the one where I throw a ball from a certain point, and I throw it upwards, and it comes down, and I catch it at that certain point. The velocity will be the same because the acceleration is constant. That concept was also a bit difficult because as soon as they started doing the questions, they told me I couldn't use that 12; why did I use that 12? This concept and why did I use that starting velocity where the person threw it up in the air and to explain to them that remember the acceleration is constant and if I throw it upwards from a certain point, the points between it that displacement point is the same as the displacement point for the downward movement because it ends at the same place, the displacement is zero. The upward and downward movement displacement is the same, and the acceleration is constant. Thus, the starting velocity and the end	Learner understanding Curricular saliency Teaching strategy	This strategy might not be the best to establish conceptual reasoning with learners.

velocity can be put as the same number; it is the same magnitude; because the acceleration is constant, that concept took time to explain.		
9. Interviewer: “Were you able to identify misconceptions from the learners?” Interviewee: Like the previous answer, the acceleration was one. Then the starting and end velocity that's the same. The other big one was one that the top student in the class had. We did an example once again with a building where they asked the time for the total movement it took. He split up the movements; he worked out a time for the upward movement and then the downward movement. He added them together, which is fine, but then told me it was impossible. I asked him; why do you say it is impossible? Give me a reason. He said he couldn't understand when the displacement for the downward movement is four points, something seconds, and the displacement that he got the total displacement is zero, but the distance travelled was less than the distance travelled from the start point. Because it was a ball that was thrown upwards and went down through the start point and dropped to the ground of the building. So he asked me why it takes more time for the ball to travel a lesser distance. So then I needed to explain to him there is acceleration. If I throw the ball upwards, there's a negative deceleration. Every second, it goes slower, and that's why it takes longer for you to complete that first movement than it takes to complete the entire movement from its amplitude or the top point down to the ground. That's why it is fewer seconds because it is going faster. They don't understand that acceleration is always negative, and if I throw it upwards, it is going slower every second until it is at zero. Then from the top point, it drops down and goes faster and faster and faster until it drops onto the ground. That was one misconception he had that the time needs to be directly proportional to the distance it is travelled. It is not because we have an acceleration that is less; it is not the fact that we have a single velocity, we have acceleration, and so velocity changes each second.	Learner understanding	Own misinterpretation evident
10. Interviewer: “Are you satisfied with the interactive board you used in your classroom?” Interviewee: Yes, I'm very satisfied with it. I underutilized it a bit; I could have utilized it more. It is much easier for the learners to see how I do these examples and my thought process. Then they can nit-pick from my thought process, and then in a second lesson, when they walk into class, I can write down an example and tell one of the learners to do the question for me. Now they can see their thought process, and it is always better to learn from other people rather than just learning from the teacher or just using one specific method. We all think differently; when I write on the smart board, I can show you this is my thought process going through this. This is the first thing I write; they can write something different, and then they can see, but this is also a way to do it. They can see the way they do it, or they can pick from me that it is easier for them to understand. Or they can see this is basically the exact same thing that I'm doing. So I could have utilized it a bit more, but	Teaching strategy	Learner-centred strategy suggested.

overall of the performance and what it does to the lesson, I think the smart board was a good resource that I used in the lesson.		
11. Interviewer: “In your second lesson on graphs, you said you consider the acceleration time graph to be the easiest. Why do you say it is the easiest graph?” Interviewee: I should have specified that it is the easiest graph when you're in grade 12 because we always work with constant acceleration. In matric, we never work with changing acceleration. So we always work with a constant acceleration that is 9.8. The only difference is we sometimes have a positive 9.8 and sometimes negative, but the acceleration is always 9.8 metres per second since we are on Earth. If we have a projectile that's on the moon, it will always be 1.6. It never changes suddenly from 9.8 to 12 metres per second. It always stays at 9.8 metres per second, no matter what. That's why the graph is the easiest. It is always just a straight line from 9.8 because as time goes on, it stays 9.8. It doesn't change all of a sudden. So it is unlike velocity or displacement-time graphs, which have to change variables.	Curricular saliency	
12. Interviewer: “In the position-time graph, you clarified some concepts to the learners. Please explain your thought process by using this example and by doing this graph with them.” Interviewee: “Let's go back to what a graph means. If you have a graph, you have two variables: one on the x-axis and one on the y-axis. So you need to know that both variables have something in common if the position and time move. That was my thinking process when I explained it to him. I can't go up and down because he asked me straight up and down; why doesn't it represent a straight up and down line? I explained to him that means his time is staying the same. He only took into consideration the displacement. He didn't consider the time for the graph. It is important to consider both variables as soon as one changes. The next question was, why is the line curved and not straight? And the answer is quite simple. It is because there is acceleration. The biggest concept that kids struggle with the graphs is that they have a position-time graph, but they need to remember there is still acceleration even though that acceleration isn't in the graph. The acceleration within the graph is the slope that it uses. Not straight lines represent that acceleration. So if it was straight lines, it meant there was no acceleration. It was a constant velocity. So it is not a constant velocity. There was acceleration, so the slope indicates to us that there was a change in velocity. It moved over a certain amount of time, and it moved slower, slower, slower, and then when it fell over one second, it moved more metres in one second. That is why it can't have straight graphs, and the important thing is, I think it was a good question from him because the learners might ask, but we working with a straight up and down movement; why can't it move straight up and down? Or why can't I use straight lines? Why is there a curved line?	Learner understanding Curricular saliency Teaching strategy	Learner difficulty addressed about graphs

13. Interviewer: “What was your intent when using the displacement-time graph, or this specific example, to do the displacement, time and velocity-time graphs with learners?” Interviewee: It is the inverse of a ball being dropped, and then secondly, I wanted to show them the fact that they need to read attentively because if it is a softball, you need to put into consideration that time of the contact period because of impulse. That ties again to previous knowledge they did on the previous topic. That's why I specifically did this one for the bouncing, and as well to see especially the velocity time graph; it is the most difficult part for them to see they need to leave a space open because there went time before it bounced back up, especially with the softball, there is a certain amount of time that elapsed before the ball bounced up. As well for them to see this is where the ball bounces, and this is where it goes up. To explain the movement, you can see a graph because usually it is confusing for the children to go from the movement and put it into the graph because the graph only sometimes represents the exact movement of what's going to happen. For instance, if you take velocity, it must go through the zero point before turning around. Some kids think if I draw the straight line upwards, and now it drops down, they think that's where it turned around. That's not where it turned around. It needs to go through the zero point before it turns around.	Learner understanding Curricular saliency Teaching strategy	Misconception on graph and object motion identified. Pre-concepts explained in terms of new topic.
14. Interviewer: “You discussed acceleration with one of the learners in this example. Please take me through your reasoning in answering the learner.” Interviewee: Firstly, I needed to identify what she was specifically struggling with, and the fact that she was struggling with was, why is the acceleration always negative? To explain to her, it is about signs. So firstly, we picked up as positive, so if we pick up as positive, then the acceleration has to be negative because it is in the opposite direction. So for her to understand the fact that it is always negative, I went back to Newton's laws with the force diagrams to explain to her if I throw a ball upwards, I have a certain force I put into it, but I have the gravitational force moving downwards as well and as soon as it is at the zero point. It turns around. The only force working on it is then the gravity. When she didn't understand, I decided to explain the concept of gravity to her. Obviously, from our perspective, we get pulled downwards. In reality, we get pulled towards the centre of the Earth. So that's why we can't say gravity is always downwards. The fact is, it moves to the middle point of the Earth. So if we have somebody standing on this side of the Earth and somebody standing on this side of the Earth, they will be pulled towards the middle. So no matter where you are, from your perspective, if you throw something upwards, it doesn't float into the sky. That's the reason we have gravity, and that was the first question that Isaac Newton asked, why don't we float into the air? Why do we stay stationary on Earth? And why, if we jump, come down? And why do we always seem to come down with the same amount of force?	Learner understanding Curricular saliency Teaching strategy	Relevant concepts are linked. Explanation on the direction of gravity can be better.

That was my thought process explaining to her the basic concept of what gravity is, then to make the connotation as to why it is negative because it is always from your perspective moving downwards or is moving downwards on Earth. That's why we give it a negative sign because we choose positive most of the time as upward.		
15. Interviewer: “Is there anything that you will change in how you presented this lesson to learners.” Interviewee: Getting the learners a bit more involved, they may draw a graph. Once again, cooperative learning puts the learners together, gives them examples and sees if they understand it. Explaining the graphs more in unison because each graph says something about something else. So giving them an example, doing the displacement-time, velocity-time and acceleration-time for that specific one, doing that a bit more so that they can see this is why the graph looks like this, this is why the graph looks like that. For an introduction, go back to grade 10 because, in grade 10, you always have the movement graphs, which are almost the same as this; the only difference is it is only one direction the whole time. So to ensure that they have that back knowledge that they can fall back to and say in grade 10, this graph will change in that direction if I change this. For example, that's why the velocity will change if I change the acceleration, and so on	Teaching strategy	

8.12 APPENDIX L: TRANSCRIBED AND CODED VSR INTERVIEW WITH MS NJ

Interview 2 – Ms NJ		Analysis of interview	
		Components and competences	Comments
Ms NJ			
1. Interviewer: “Why did you choose this specific starting point for the lesson?” Interviewee: “Firstly, I started introducing what I believe are the most important terms when teaching vertical projectiles and using these two terms. I used them as an introduction because I wanted the learners to be familiar with the term, especially free fall , and understand what we mean when we talk about projectile and the difference between projectile and free fall . Then I also used an example of a marker that I was using to write so that the learners could see that the only force acting on it during free fall is the gravitational force . Using the marker, it is something that they will be able to see , and it is something that they might relate to . So that is why I use the starting point.		Curricular saliency Teaching strategy Representations and analogies	Good representation that is different from drawings.
2. Interviewer: “Can you please explain your thought process in choosing these specific characteristics to introduce them to learners?” Interviewee: “I found it very important to make learners aware of the characteristics of a projectile. Because in understanding all those characteristics I've stated, I believe those are the most important ones. And for learners to grasp those characteristics, I even used a diagram so that they could see those characteristics being explained in a diagram because they are very important in answering any of the questions in vertical projectiles. The learner should be made aware of those characteristics. So I felt it is very important for learners to understand first the characteristics or those concepts before answering any questions because I find them very critical in this topic.		Curricular saliency Teaching strategy Representations and analogies	
3. Interviewer: "Are there any characteristics that you now would add to that list or maybe something that we take away? Are you satisfied the way it is?" Interviewee: "No, I'm satisfied the way it is."		Curricular saliency	There are characteristics that can be added

4. Interviewer: “The first example that you did with learners, it is a ball that's being thrown upwards, and you did the representation on the board. Please tell me why you decided to use this specific example?” Interviewee: “I used this specific example because I had just introduced learners to the characteristics of a projectile, and I felt that if I used this scenario, learners would be able to see most, if not all, the characteristics on that example because if a ball is thrown up, I will start talking about the sign convention, they will be able to see the time symmetry, they will be able to see the maximum height so because I had just taught learners about the characteristics of a projectile I believe that it was important that we do an example that is related to what I had just spoken about. So, that is why I use the specifically started with that example for introducing other scenarios.”	Curricular saliency Teaching strategy Representations and analogies	Good sequence of concepts.
5. Interviewer: “Are you satisfied with the example that you used?” Interviewee: “Yes, I am satisfied with my example.”	Teaching strategy	
6. Interviewer: “Is there anything that you would change or add?” Interviewee: “No”		
7. Interviewer: “You used the representation again of a ball thrown from the top of a building, and the learner fails to catch it and falls back to the ground. Why did you choose this specific representation? And why do you think this representation is helping learners understand the topic better?” Interviewee: “I used this representation specifically because I believe that with the scenario that I just gave them, a learner throwing a ball vertically upwards. Lenders had to pick very important key points out of that scenario. So in this representation, I have pointed out certain points so that learners could be aware of or can be taken back to those characteristics we have spoken about. So I made around four points on the representation, where point A represented our initial velocity, and point B showed them the maximum height. Point C was showing the point where the starting point where the learner failed to catch the ball. Tembi failed to catch the ball up until it reached the ground. So on that representation, I use those points from point A to point D so that when explaining to learners, I can go back and refer them to those points I was talking about. That is why I use this representation and label them so that when I explain to learners, they will be made aware or able to see at which point am I talking about?”	Curricular saliency Teaching strategy Representations and analogies	Dividing the motion path of the object into sections using alphabet letters. Linking of concepts

8. Interviewer: “What do you think of the question that the learner asked?” Interviewee: “I think that was a brilliant question. Because I just showed them a calculation for finding the change in displacement. So during the question, we only used one equation of motion. So I think that was a good question because it shows that the learner did understand what we're talking about because he realized that there is another equation of motion that he can use to answer the same question. So it shows that the learners are not stereotyped, or they do not just focus on only what I taught them, but they can think even on their own and see that there are still other options that they can use to find the same answer. So I think that was very good.”	Learner understanding Curricular saliency Teaching strategy	Good discussion with learner
9. Interviewer: “There was a discussion that you and some of the learners in class had regarding this example; what do you make of this discussion?” Interviewee: “I think the learner who asked the question did well because I believe this is one of the misconceptions that learners might have concerning displacement. So I think it was good that he asked. Also, I was glad that there were other learners in the class, specifically one who even attempted to answer the question, and it is very good that even the answer that he had; I was not aware that I could have used that approach to show that I can still use the displacement (35,1) if I'm taking my initial velocity as zero so I think that discussion was good. Because firstly, the first learner who asked the question made me answer the misconception that he had. Secondly, the learner who also decided to come in also made me aware of a new way that I could have also attempted to answer that question. So it was not specifically to say that we can use the displacement as 30 and the initial velocity as 10. There is also another way, which also is a way that the first learner who asked the question because the question was, why can we use 35.1? So instead of just saying we can use 30, the learner was made aware that he can still use that 35.1 But taking the maximum height as a reference where the object was through, I think it was good. That discussion”	Learner understanding Curricular saliency Teaching strategy	Teacher not aware of other options to solve problems Allowed discussions in class.
10. Interviewer: “Can you elaborate again on that misconception? What do you think the misconception is?” Interviewee: “I think the learners have to check in terms of the displacement. For example, in this case, the ball was thrown from the roof, so the learners must understand that there is displacement from the ground to the roof. And if the ball was thrown vertically upwards, that shows that there is also another displacement from the starting point up until it reaches the maximum height. So somehow, I can say that there are two displacements or positions that the learners would need to add up. So it means it is from the starting point to the maximum height, and that displacement should be added to the distance from the starting point until the ground. So a learner might use 30 metres as the displacement and forget about the distance from the starting point to the maximum height. So that's the misconception.”	Learner understanding Curricular saliency Teaching strategy	Not a documented or common misconception

11. Interviewer: “Can you describe your thought process in the method you used when discussing the equations of motion with learners? And the option of which one to choose?” Interviewee: “I used this method because I think it would be easy for learners; the learners already know the equations of motion. So the first key point that I wanted them to get out of this is that firstly, they should be able to take the data out, they should be able to take what is it that they're given, and on the equations of motion, I made them aware that we have about five variables. So on those five variables, they should be able to take out the data of what is given. So if they have two unknown variables, the learner should be able to go back to the question to check what the question wants, which is very important to know. What is it that the question asked? So if the learner has two unknown variables, they go back to the question and check what the question wants. And if the questions want the final velocity, then the learner should know that it means they must look for an equation that does not have time because, in this case, they do not have the final velocity they do not have the time. So it means if they have two variables, they check what the question asked is. And if the question wants the final velocity, they look for the equation that does not have time. So I thought it is very important for learners to use this method because I think it is easier for them to take out the data, but in cases where they have two variables, it might be difficult for them to know which equation to use. So I think it works best this way. That is why I use this method.”	Curricular saliency Teaching strategy	Strategy can fail when simultaneous equations are needed to solve problems.
12. Interviewer: “Are you satisfied with the representations used? Or is there anything that you would add or change?” Interviewee: “In these representations, I used three scenarios, which I think are very important, but if there is a scenario that I think I should have done was with the hot-air balloon because I had introduced the characteristics of the projectile. The last characteristic concerns the hot air balloon, but I have not done an example with the learners. So I think if there's one thing that I would have changed, I would do a question on hot-air balloon so that the learners could apply or see the characteristics we have spoken about. So that is what I would add, but other than that, I'm happy with the scenarios that I used.”	Teaching strategy Representations and analogies	Important example, misconception is common in this problem.
13. Interviewer: “What concepts were difficult for you to teach?” Interviewee: “I think the concept that was a bit tricky for me to explain to learners was a scenario where a ball is thrown vertically upwards, and then the person who threw the ball didn't catch it because now we have to talk about two displacements. So I think that was a question I found difficult to make learners grasp the concept of adding the distance from where the ball was thrown to the maximum height and added to the roof's displacement. So I think that is where I find it a bit challenging. I don't think it is a difficult concept to explain to learners, but I feel learners have a bit of difficulty grasping that concept.”	Learner understanding Curricular saliency	Not a documented or common difficulty

14. Interviewer: “Did you pick up some misconceptions or learning difficulties from the learners?” Interviewee: “No, I don't think up to so far.”	Learner understanding	
15. Interviewer: “Why did you decide to start with this graph?” Interviewee: “I just started with the velocity-time graph mainly because I wanted to introduce the learners to the velocity versus time graph and the displacement versus time graph. So I just chose to start with the velocity-time graph. I don't have this specific reason why I started with it.”	Curricular saliency Teaching strategy	Did not consider sequencing
16. Interviewer: “If you have to do this lesson again, would you again start with the velocity versus time graph?” Interviewee: “No, I think I would start with the displacement versus time graph because that's the easiest one because it shows the learner exactly what is happening. I think the displacement versus time graph. It is easier for learners to understand or even to draw the graph because it shows the object's motion almost as it is in the scenario or the representation. So I would start with the displacement first and the velocity versus time graph.”	Learner understanding Curricular saliency Teaching strategy	Create opportunity for misconception. Sequencing revised
17. Interviewer: “Please explain your strategy when explaining this graph to learners.” Interviewee: “I think a position-time graph, according to me, is one of the easiest graphs, and there are only two concepts that learners need to grasp from this. So from the scenario that I've just given them, I told them to always take upward as positive when drawing the position-time graph because I think it will be easy for learners to grasp the concept once taking upward as positive. It makes the learners draw a graph that seems exactly the same as what is given in the scenario. For example, the ball is thrown downward, and then the learner takes upward as positive when they draw the graph. It looks exactly the same as they would have seen or assumed from the scenario they're given. So I think that's the method that would be easy for learners because it is something that they can see or is something that they can even visualize using their minds.”	Learner understanding Curricular saliency Teaching strategy	Create opportunity for misconception. Strategy will be compromised if question stipulates direction
18. Interviewer: “You did an example of a ball being thrown off the top of the roof and then bounced. Then you did the graphs with learners. Why do you think this specific method efficiently teaches the learners?” Interviewee: “It is very important to show the references for A up to G. In that way, when drawing the graph, the learners could see all those references of the scenario being represented on the graph. To clear up the misconceptions, e.g. From point A to B, the ball is thrown vertically upward, and a learner might have a question: if it is thrown up, why is it that it is decreasing or going down on the graph? Then you could show	Learner understanding Curricular saliency	Good strategy to clarify misconception. Contradicting to information

them that point B is the maximum height, and at that maximum height, the velocity is zero. They could see or correlate point B on the scenario with point B on the graph to see zero velocity. It is very important to make references so that the learners can see the points in the scenario and those points represented on the graph. I think it clears misconceptions."	Teaching strategy Representations and analogies	above. Dividing motion into sections.
19. Interviewer: "Is there any concepts specifically that are difficult for learners?" Interviewee: "I think the velocity-time graph where a ball is thrown vertically upward and then the object falls to the ground because that is where now the learner has to draw on the graph show the start the initial velocity up until the maximum height and then from there show up until it reaches the starting point. But there is a point where now the learner, especially with a bouncing ball, there is now where a learner has to draw to start a new graph. So there is where there is a time-lapse when the ball reaches the ground. Some learners might draw the motion straight and not show the time-lapse on the velocity and displacement time graphs. So I think that is one important key point for learners to show the time lapse on both the graph, the velocity-time graph, and the position-time graph, especially with a bouncing ball. I think that is just one of the concepts that some of the learners miss. But with the displacement time graph, I think it is easier because if learners are shown that as they take the upward motion as positive, then the graph will look as if it is the same as the one that is on the scenario. So I think that difficulties could be where there is a bouncing ball for learners to show that motion both on the velocity and displacement time graphs."	Learner understanding Curricular saliency Teaching strategy Representations and analogies	Drawing of graphs for bouncing objects. Strategy could create learner difficulties if they always work with upward as positive
20. Interviewer: "Was any specific content or concept difficult to teach?" Interviewee: "I think the issue of having to explain to learners what the time-lapse means because if we are saying that a ball is thrown up and then there is a time-lapse, even though we are saying it to learners, but you might find it difficult to give the exact reason why we are saying the ball stops momentarily or even when it hits the ground. There is a momentarily stop. So if a learner were to ask me a question to say, Why do you say that? It would be difficult for me to explain why there is that time-lapse and what happens during it."	Learner understanding Curricular saliency	Teacher has difficulty regarding contact time of bouncing objects
21. Interviewer: "Would you change anything in your lesson if you were to give it again?" Interviewee: "No, regarding the graphs, I wouldn't change anything."	Curricular saliency Teaching strategy	Does not correspond to previous answer on sequence of graphs taught.

8.13 APPENDIX M: NARRATIVE AND CODED ANALYSIS OF LESSON 1 FOR MR JP

Section 1.1: He introduced the vertical projectile motion concept and the importance of gravitational force. [4 min 05 s]	
Mr JP started his lesson by explaining what vertical projectile motion is. He read from the textbook: "The motion of an object that is straight upwards or straight downwards, when the only force acting on the object is the gravitational force". Mr JP indicated to learners that when they were busy with a previous chapter on momentum, they worked with horizontal movements. However, in this chapter, they will work with vertical motions. Again he emphasized that the only force acting on a projectile is the gravitational force. He then described a scenario indicating a ball being thrown upward and coming back down again. He referred to newton's law of universal gravitation to explain the phenomena. He explained the ball's motion using the chalk he was holding. He would throw the chalk into the air and catch it again. He said: "When I throw a ball into the air, it will come back down". He asked learners: "How many forces act on the ball, and which forces are those?" a learner responded and said: "Gravitational force and normal force." Another learner said: "free-fall", and the last learner that responded said: "Gravitational force." Mr JP responded and said two forces are acting on the object, namely the gravitational force and air resistance. He indicated that they would investigate it, but for now, they are focussing on objects that are in free fall, meaning the only force acting on the object is the gravitational force. Next, Mr JP shifted to a TV screen linked to his laptop. This screen was used to demonstrate the projectile's movement/path of motion to learners. He indicated to learners that they are used to horizontal movements but will now work with vertical ones. He used the PHET simulation to fire a ball from a canon, and the motion path is shown (tracked) on the screen. His canon was set at an angle to the horizontal as he shot the ball. He referred to the trajectory of the object as vertical projectile motion.	Learner understanding Curricular saliency Teaching strategy Representations and analogies
Section 1.2: He explained the difference between the pre-concepts displacement and distance. [10 min 15 s]	
Mr JP referred to the textbook and indicated to learners that four equations of motion would be used to solve vertical projectile motion problems. He said that before starting with these problems, they need to look at displacement and velocity. He wrote displacement on the board with the following explanation: "It is the body's change in position". He then told learners that displacement is a vector and distance is a scalar. He elaborated and indicated that displacement is a vector because it has magnitude and direction. Mr JP wrote on the board: "To know displacement, you must know the straight line distance between the reference point, the new position, and the direction in which the body has moved." He emphasized that it should be a straight line distance by underlining it on	Learner understanding Curricular saliency Teaching strategy

the board. Mr JP then used the blackboard to demonstrate what he meant when talking about the straight line distance. He recorded the starting point as point A and the endpoint as point B. He drew a rectangular shape that started at point A and ended at point B and indicated the following distances on the lines: 5 km, 15 km and again 5 km. He drew a wavy line connecting points A and B, then asked the learners: "What will be the distance between points A and B." He erased the wave-like line and replaced it with a solid line saying the distance would be 15 km. Mr JP then asked learners what the distance for the whole movement would be, to which a learner indicated 25 km. He noted it down and explained that they could only write 25 km because it is a scalar. He asked the students about the displacement of the movement. He explained that they should use the symbol (Δx) for horizontal motion, and for vertical motion, (Δy) should be used. Mr JP then answered the question he initially posed and wrote down the answer as displacement = 15 km to the right. He reiterated that it is the shortest distance between two points, and direction should be noted. He indicated that he wanted to do one last example with the learners consisting of vertical motion. Again, he drew a motion path on the board, starting at point A and ending at point B. His example included up, down, left and right motions. He indicated to learners that when they add all the distances along the path length, they will get the total distance the object travelled. He then asked what the displacement (Δy) would be, to which a learner responded: "15 km". He wrote it down on the board, asking if it was the final answer. The learners said no because displacement is a vector, and direction is needed. Hence he indicated the final answer to be 15 km downwards.	Representations and analogies
Section 1.3: He revised the pre-concepts of initial and final velocity. [1 min 20 s]	
Mr JP indicated that learners remember the change in velocity from the momentum chapter. He said: "Final velocity minus initial velocity equals the change in velocity." He referred to initial velocity as the starting velocity and final velocity as the ending velocity. He did a quick recap with learners and asked them: "If an object starts from rest, it means the final or initial velocity would be zero." The learners responded: "Initial velocity". He then asked: "If an object travels at a certain velocity and should come to a stop in eight seconds, will the initial or final velocity be zero?" The learner answered: "Final velocity," and he agreed, indicating the object should come to a stop.	understanding Curricular saliency Teaching strategy

Section 1.4: Mr JP demonstrated projectile motion using a PhET simulation and attempted solving projectile problems with the class using the equations of motion and pointing out critical concepts within the topic of vertical projectile motion. [11 min 08 s]	
Mr JP showed learners again his representation of a vertical projectile movement from the PhET simulation. Again he used a canon to fire a ball. The trajectory of the object concurs with that of a negative parabola. Mr JP reset the simulation and included the option of a velocity arrow to be present during the motion, indicating the vector properties. He played the simulation a few times for learners to observe. Mr JP drew a diagram on the board representing the simulation that he just showed learners; he continued explaining the cannonball's motion. He indicated the ball was fired from the cannon, 4 meters above the ground, and reached its maximum height, after which it fell back. He indicates on his diagram that the ball's initial velocity is five $m \cdot s^{-1}$. He asked learners: "What is the velocity of the ball here at maximum height?" and a learner answered: "Zero". Mr JP alluded to learners that this (velocity being zero at maximum height) is something they will encounter a lot in the topic of vertical projectile motion, and he wrote $0 m \cdot s^{-1}$ on his diagram at maximum height. He asked his first problem-solving question to learners: "Calculate the time it takes for the ball to reach its maximum height." He indicated on the diagram that they needed to calculate Δt and pointed with his fingers at the starting point and maximum height as the two reference points. He then gave learners the following information and said: "When we deal with vertical projectile motion, the acceleration is always $9,8 m \cdot s^{-2}$ downwards". He continued and said this acceleration is constant and does not change. Furthermore, he indicated to learners that they should choose a positive direction of motion as they did on momentum. He then indicated to learners that he prefers to choose upward as positive and downward as negative; he indicated that every vector moving in a downward direction would be negative, and every vector moving upward would be positive. He then linked the gravitational acceleration to his explanation and said that because we chose upward to be positive, the gravitational acceleration would be $-9,8 m \cdot s^{-2}$. Referring to his diagram on the board with all the information added, he asked learners: "Which equation of motion will we use to find the change in time?" a learner suggested using $v_f = v_i + g\Delta t$. Mr JP started substituting the values from his diagram into the equation, referring to the vectors and the importance of the sign conventions. He also alluded that time is a scalar and will always have a positive answer. Hence he recommended that learners should be aware that when they obtain a negative answer for a time, there is a mistake in their calculations. He solved the problem with the answer writing the final answer on the board as $0,51 s = \Delta t$. He pointed with his fingers what this answer represents, indicating the time from the starting point where the ball was fired until it reached its highest point above the ground. He then explained to learners that the ball would take the same time (0,51 s) to fall from	Learner understanding Curricular saliency Teaching strategy Representations and analogies

the maximum height back to its starting point. Mr JP used the same reference points and explained that if the ball's initial velocity is five $m \cdot s^{-1}$, its final velocity at the same position upon its return will be negative five $m \cdot s^{-1}$. He explained and said if the ball starts with an initial velocity of five $m \cdot s^{-1}$ moving upwards, the velocity will decrease until it reaches its maximum height, where the velocity is 0 $m \cdot s^{-1}$; as the ball falls back down, the velocity increases and reach a velocity of five $m \cdot s^{-1}$ again when it is at the same position compared to where it started. He indicated that the ball is moving in the opposite direction, which will be considered negative. Mr JP explained to learners using the same diagram on the board, if they were to calculate the total time taken for the ball to reach the ground, they would add the time from the point of launch to maximum height and the time from the maximum height back to the point of launch, they will need to calculate the time taken from the current position to the ground and then also add it to the previous calculation to obtain the final answer. Learners indicated that they needed help understanding the solution. Mr JP used the same explanation as before. During his explanation, he pointed to the three sections on the diagram using his fingers. He then stated that by adding the time of these sections together, learners could calculate the total duration of the motion.	
Section 1.5: He did an example from the textbook of a ball dropped from a high building. [9 min 44 s]	
Mr JP quickly left the classroom to fetch his textbook from the office. Upon his return, he asked learners to open their textbooks to do an example together. He asked a learner to read the scenario from the textbook. The scenario is a ball being dropped from a 50-meter-high building. Mr JP asked a second learner to read the scenario from the textbook again; this time he made a diagram on the board and included information given in the description of the scenario. Mr JP asked a third learner to reread the scenario; he indicated it is important to read the description of the scenario a few times before attempting the questions. Mr JP indicated that they would attempt to solve the questions as they did when doing momentum, so the first thing needed is to choose a direction of motion to be positive. He indicated using arrows that the upward motion is positive and the downward motion negative. He also indicated that writing down the given values from the question is crucial. He made a list on the board consisting of $\Delta y = -50 \text{ m}$; $g = -9,8 \text{ m} \cdot \text{s}^{-2}$; $v_i = 0 \text{ m} \cdot \text{s}^{-1}$; $v_f = ?$ When he reread the question, he indicated to learners that it is essential to know what it means when the question said: "Ignore the effects of air resistance". He explained that it means: "The only force acting on the object is the gravitational force". He again referred to the chapter on momentum. He clarified that if one does not consider friction while dealing with momentum, the final momentum will be the same as the initial momentum due to the principle of conservation of momentum. Mr JP asked learners which equation they think will be suitable to calculate the final velocity of the object, to which they responded: $v_f^2 = v_i^2 + 2g\Delta y$. He agreed and substituted the values written on the board into this equation. Before calculating the	Learner understanding Curricular saliency Teaching strategy Representations and analogies

final answer, he asked learners whether the answer was positive or negative; he elaborated and indicated that because the object is moving downward, it will have a negative velocity due to its sign convention. He calculated the final answer and got two possible answers, positive and negative (because of the square root used). He advised the learners to choose the negative answer since the object moved downward. However, he stressed that the answer should always be written positively with the direction indicated. Therefore, he provided a positive answer but specified that it was moving downward.	
Section 1.6: He did another example from the textbook, a ball projected upward. [8 min 56 s]	
Mr JP again asked three learners to read the example from the textbook, and he made a diagram on the board illustrating the scenario. The scenario consisted of a ball being projected upward at 20 m.s^{-1}, and the question asked to calculate the maximum height that the ball reached; air friction should be ignored. Mr JP indicated on the board using arrows that the upward direction is positive and the downward direction is negative. He made a list of all the known variables on the board that consisted of $v_i = 20 \text{ m.s}^{-1}$; $v_f = 0 \text{ m.s}^{-1}$; $\Delta y = ?$; $= -9,8 \text{ m.s}^{-2}$ He reread the example and made two reference points on his diagram, one at the starting point and one at maximum height. He indicated to the class that this is the displacement that they need to calculate in order to find the maximum height. Referring to the reference point at maximum height, he asked learners: "What is the velocity here?" The learners responded and said: "Zero". Mr JP agreed and added it to his list of known variables. He then asked learners what the ball's velocity would be upon its return when it reached the starting point again. They answered: "Negative twenty" and he agreed with the answer. He asked learners which equation they think can be used to solve the question, and they indicated: $v_f^2 = v_i^2 + 2g\Delta y$. Mr JP wrote the equation down and substituted the known variables. He did every step with the learners to solve the equation and obtained the magnitude of the final answer. Mr JP asked the learners if their answer was final, to which they responded: "No". The answer must include direction, so Mr JP provided the final answer with magnitude, units, and direction. Mr JP then allowed time for questions. One of the learners questioned the possibility of displacement being given in kilometres instead of metres. Mr JP indicated it should be converted to metres. He elaborated that if time is given in hours, it should also be changed to seconds. The second question asked by a learner was how to convert kilometres to metres, to which Mr JP said: "Multiply by a thousand". Mr JP then gave his learners homework and ended the lesson.	Learner understanding Curricular saliency Teaching strategy Representations and analogies

8.14 APPENDIX N: NARRATIVE AND CODED ANALYSIS OF LESSON 1 FOR MR DN

Section 1.1: He began his lesson with an overview of all the components (definition of a projectile, gravitational acceleration, terminal velocity, equations of motion and problem solving) he wanted to cover and explained the term projectile. [1 min 16 s]	
Mr DN started his first lesson by displaying a layout of concepts he wanted to address. These concepts included the definition of a projectile, gravitational acceleration, terminal velocity, equations of motion and problem-solving. While these concepts were displayed on the board a learner asked: “What is terminal velocity?” Mr DN responded and said: “Terminal velocity is when the object has reached its maximum velocity. $9,8 \text{ m} \cdot \text{s}^{-2}$ is the gravitational acceleration, the object will only accelerate until a certain point and thereafter remains the same.”	Curricular saliency
He read from the textbook displayed on the SMART board what is a projectile. He immediately read the definition saying an object that is projected or launched into the air by shooting, kicking, hitting or throwing it. He said it can be any object that is thrown into the air, like a ball, or shooting a bullet.	Representations and analogies
Section 1.2: Introduced the concept of gravitational acceleration and linked it to relevant pre-concepts like mass and weight, velocity, change in velocity, Newton’s law of universal gravitation and equations of motion. [3 min 16 s]	
Mr DN indicated that gravitational acceleration gives us weight. He reminded that there is a difference between mass and weight. Furthermore, he indicated that mass is the matter you consist of and weight is the force that the earth is exerting on you. He stated that weight is the mass multiplied by the gravitational acceleration which is $9,8 \text{ m} \cdot \text{s}^{-2}$ and is a constant. Mr DN alluded to the fact that they might work with the gravitational acceleration of the moon which is $1,6 \text{ m} \cdot \text{s}^{-2}$.	Learner understanding Curricular saliency
Mr DN explained the concepts of velocity, change in velocity and gravitational acceleration by making use of two examples in table format. The first example is that of an object moving upwards and the second example is that of an object moving downwards. He explained that the velocity is upwards for an object moving up, and downwards for an object moving down. He said that when an object is thrown upwards the gravitational force will act in a downward direction on the object. He asked learners what the change in velocity is to which they responded “acceleration”, he agreed with the answer by repeating it. He said that the change in velocity which is regarded as the acceleration is slower for an object moving upwards and the gravitational acceleration remains downwards.	Teaching strategy Representations and analogies

He concluded with the last example saying it is like a ball being dropped, therefore the velocity is downwards, the change in velocity is faster and the gravitational acceleration remains downwards. He introduces the concept of Newton's law of universal gravitation in mathematical form to the learners and quickly explains to them the variables in the equation. He makes two statements; firstly that all objects experience the same constant gravitational acceleration on Earth and the mass of an object does not influence its acceleration. He concluded that the gravitational acceleration of the moon and Venus can be calculated using this formula, but using the mass and radius of the respective examples. Mr DN explained terminal velocity by referring to a drawing in the textbook. He emphasised that terminal velocity is reached when the force due to air friction (upwards) equals the gravitational force (downwards). Mr DN displayed the four equations of motion on the board. He reminded learners that these are the same four equations that they worked with during grade 10. Next to them were the unknown variables with an explanation of each and also the units of measurement for that quantity e.g. v_f: final velocity ($m \cdot s^{-1}$). He indicated these formulae will be available on the formula sheet provided in tests and examinations. He indicated to learners that it is important to write down the information available, and the information needed. Then proceed to select a suitable equation of motion to solve the problem, as they did in grade 10.	
Section 1.3: Started with problem-solving questions related to the topic of vertical projectile motion. [4 min 23 s]	
Mr DN introduced problem-solving skills to the learners by making use of the following two examples. Describe the displacement, velocity and acceleration of: a) a ball that is thrown upwards and is caught again b) a ball that is being dropped. He said there is a difference between distance and displacement. Explaining "distance is the total path length followed where displacement is the change in the position of an object." He indicated that learners should choose a positive direction of motion and the opposite direction will be negative. He asked learners if he drops a ball, what the initial velocity will be. He referred to momentum saying if a car was at rest what is the initial velocity of the car? The learners answered "zero". Mr DN agreed and said it is because the car was at rest. Describing the motion of the object in example (a) in Figure 5.1, Mr DN explained that the object being thrown (projected) upwards has a maximum initial velocity. He further explained that as the object moves upwards gravitational acceleration slows the object down since the gravitational force is acting downwards on the object. When the object reaches its maximum height it has a final	Learner understanding Curricular saliency Representations and analogies

velocity of 0 m.s^{-1}. He said if you divide the motion into two halves and considered the second half (downward motion) the initial velocity of the object is 0 m.s^{-1} and the final velocity will reach a maximum value. He indicated that this is because we can choose reference points. Once again he stated that the gravitational acceleration is still acting downwards which causes the object to accelerate with an acceleration of $9,8 \text{ m.s}^{-2}$ from a maximum height where the initial velocity was 0 m.s^{-1} to the point of launch. He ends his discussion with an example of how to determine the displacement of the object, once again referring to reference points when he indicated the total displacement of the object in example (a) (figure 5.1) would be zero, but the displacement of the object from the point of launch to maximum height is 5 metres. Mr DN briefly explained that the initial velocity of a dropped object is zero. He illustrated this to learners with his hand holding an imaginary ball. He stated the acceleration will remain at 9,8 and the displacement will be the same as the distance in this example because there is no change in direction. He indicated it is of utmost importance to be able to determine these quantities since they will be used in calculating unknown variables making use of the equations of motion. Mr DN displayed the position-time and velocity-time graphs for the above-mentioned examples on the board. He indicated that they will at a later stage focus on the graphs. He quickly explained that the position-time graphs observed are the same as the motion of the object.	
Section 1.4: Introducing new concepts of bouncing objects. [1 min 57 s]	
Mr DN displayed an example on the board of a ball that bounces one time on the ground. He shared two drawings with them, the first being that of a soft ball and the second being that of a hard ball. He represented an imaginary ball in his hand holding it up in the air as if he was about to drop it. He asked what the initial velocity of this ball will be when it is dropped. The learners responded and said zero. He then asked a second question: "What will the acceleration of the ball be when it is dropped?" And the learners responded by saying: "9,8". He agreed with the answer, adding: "only when it is dropped on the earth". Referring to the diagram on the board he asked learners why the ball doesn't bounce back to its original height (from where it was dropped). He got an answer saying it is not a closed system. Once again he agreed with the answer saying energy is converted to other forms when the ball bounced. He indicated that there can be examples where the object bounces more than once and the total displacement of the ball needs to be calculated. He moved to the second diagram, which represented a hard ball. He then referred back to the first diagram saying the soft ball can be compared with a tennis ball. When it hits the ground the concept of impulse should be kept in mind. He indicated that when this	Representations and analogies Learner understanding Curricular saliency Teaching strategy

soft ball hits the ground the ball will compress a bit, which causes the contact time with the ground to be longer than that of a hard ball which he compared to a golf ball. Mr DN displayed the two corresponding position-time graphs on the board of the before-mentioned examples and indicated to learners how the graph of a soft ball will differ from the graph of a hard ball – the focus being on the contact time. He then moved to the velocity-time graphs also displaying how to indicate the contact time on the graphs for a soft and hard ball.	
Section 1.5: Conduct problem-solving examples where the teacher explained the solution to the problems. [19 min 23 s]	
Mr DN started with an example from the textbook where a cricket ball is thrown up into the air with a velocity of $20 \text{ m} \cdot \text{s}^{-1}$. When Mr DN read the question he stopped at $20 \text{ m} \cdot \text{s}^{-1}$ and asked what they think this quantity represents. They responded with an initial velocity and he indicated they can write that on top of the $20 \text{ m} \cdot \text{s}^{-1}$. Learners are asked to calculate (1) the maximum height that the ball will reach and (2) the time it will take the ball to reach the point of launch again. The solutions and key concepts (velocity and acceleration) to the above-mentioned examples are displayed on the board with a diagram representing the motion of the ball. Mr DN indicated that the motion should be divided into parts, he referred to the first question and showed on the diagram that the question only needs information from the first part of the motion (launch to max height) and not the second part (max height to point of launch). He indicated it is important to remember that the velocity at maximum height is zero and also reminded learners that for this example the upwards motion is regarded as positive and the downward motion as negative. Mr DN wanted to make use of the drawing function of the SMART board but did not succeed. He decided to use the computer mouse when drawing on the screen. He drew a diagram of the scenario again explaining to learners where the initial velocity is. He asked if the velocity would increase or decrease as the ball is moving upwards. The learners responded and said decrease. Mr DN agreed and added that the velocity will decrease by $9,8 \text{ m} \cdot \text{s}^{-1}$ every second and that the acceleration is in the opposite direction of motion. Mr DN talked through the solution to the first question on the board explaining the answer and steps to the solution to learners. He said in the exam always write down what information is available and what information is needed. From this information, you will be able to choose one of the four equations of motion that are most suitable for calculating the unknown (asked) variable. Once you	Representations and analogies Teaching strategy Curricular saliency Learner understanding

have the equation substitute the information and solve the unknown using your mathematical skills. Mr DN again read from the textbook repeating question 2. He read that we can accept the time it takes the ball to reach its maximum height will be equal to the time it takes the ball to fall back from its maximum height to the point of launch (solution 1). He followed the instruction from the textbook choosing upwards as the positive direction and proceeded to read the solution from the textbook. In the textbook, another possible solution (solution 2) was provided. This time the whole motion is considered and not only part of the motion as in solution 1. Mr DN once again read through the second possible solution to question 2. Another example explained by Mr DN is that of a rock being thrown from the top of a building and falling past the point of launch to the ground. The following questions are displayed on the board: Calculate (1) the time it will take the rock to reach the ground (2) the maximum height reached by the rock above the ground (3) the velocity with which the ball hits the ground. Again the diagram is displayed on the board and Mr DN used it to explain the trajectory of the rock. Mr DN displayed the solutions on the board and explained the answers by talking through the steps displayed on the board When he interpreted the solution to the first question he explained there are two possible answers because the mathematical formula for quadratic equations provides two answers for time, but because time cannot be negative the positive answer is accepted. The rest of the solutions to the above-mentioned questions were also displayed on the board and Mr DN explained the solutions to the learners by reading it from the textbook.	
Section 1.6: Hot-air balloon problem addressed. [10 min 45 s]	
Mr DN indicated that this is a very popular question to ask in the exams. He referred to the grade 11 pre-concepts of forces, in particular Newton's first law of motion. He described the following example: <i>"I saw a video yesterday of a person stealing something and then jumping in the boot of a car which remains open. Once the car drives away the person falls out of the boot."</i> He asked: <i>"What can be a possible reason for this occurrence?"</i> Learner: "Inertia" He agrees with the answer and explained inertia again to learners. He referred to the fact that an object wants to remain at rest or	Representations and analogies Teaching strategy Curricular saliency Learner understanding

move at constant velocity. He linked the before-mentioned example with his hot-air balloon problem. He indicated that when the hot-air balloon moves upwards and you release a ball from it, the ball will first travel upwards before falling to the ground, and this is due to the inertia experienced by the ball. Mr DN displayed a drawing from the textbook on the SMART board indicating a hot-air balloon moving upwards and a camera being dropped from it when 200m above the ground. The description of the scenario and questions were displayed next to the drawing. Mr DN read the scenario to learners and also the questions to be answered. Mr DN emphasized the importance of using a diagram when answering vertical projectile motion questions. He alluded to the fact that a diagram allows us to link physical quantities to the path or trajectory of the object. Mr DN read important information from the textbook regarding the hot-air balloon problem they are trying to solve. He indicated that the initial velocity of the camera will be the same as the constant velocity with which the hot-air balloon is travelling. He referred to the fact that the camera is in free-fall once it was dropped and that the acceleration is a constant $9,8 \text{ m} \cdot \text{s}^{-2}$ downwards. Mr DN explained by gestures in the air how distance and displacement should be interpreted in this question. He indicated that the displacement of the camera will be 200 m (the height from which it was dropped), but the distance will be the total path length followed by the camera, hence bigger than 200 m. Mr DN continued to solve the questions with learners by displaying the solutions on the board and explaining them.	
Section 1.7: Interpreting the velocity-time graph. [3 min 36 s]	
Mr DN indicated that the graphs should be put aside for now, he then proceeded to explain an example which started with the velocity-time graph and learners had to interpret it. Mr DN briefly displayed the velocity-time graph on the board and then proceeded to the questions. He displayed the solutions to the questions on the board and talked through the steps taken to obtain the solution. Each question related to the velocity-time graph was skipped and he indicated his main focus, for now, is to explain problem-solving questions.	Teaching strategy
Section 1.8: Started with a exercise on solving projectile motion problems. [2 min 47 s]	
Mr DN attempted to draw on the SMART board but was unable to. He continued to use his computer mouse to draw on the SMART board. The end of the period arrived before they could attempt to solve any questions on this specific problem.	Teaching strategy

8.15 APPENDIX O: NARRATIVE AND CODED ANALYSIS OF LESSON 1 FOR MS NJ

Section 1.1: Ms NJ started her lesson by defining a projectile and free-fall. She introduced the concept of the gravitational force. [6 min 15 s]	
Ms NJ started her lesson by differentiating between: "What is a projectile" and "What is free-fall" She indicated that these are the two definitions learners need to know for grade 12 according to the examination guidelines. She also pointed out that one of these definitions is often asked in question papers. She wrote the two definitions on the board and indicated keywords in each definition. She explained that both, a projectile and free-fall, are under the influence of only the gravitational force. However, free-fall is the motion that occurs when a projectile is launched with an initial velocity. Ms NJ threw a pen into the air and indicated that the pen was falling back down. She asked learners: "Why when we throw an object up, it always comes back down?" The learners responded with: "Gravitational force." Ms NJ agreed and said the force of gravity is responsible for the object to return. She mentioned they are aware of other forces, namely the normal force, frictional force and tension, but the only force they will deal with in this chapter is the gravitational force.	Learner understanding Curricular saliency Teaching strategy Representations and analogies
Section 1.2: Introduced new concepts such as free-fall, the velocity of an object at maximum height, time symmetry, equal magnitude of velocity at the same position and the initial velocity of a dropped object from a moving carrier. [14 min 40 s]	
Ms NJ made a poster with concepts she regarded as important, which was put up against the wall in the classroom. The following concepts were included on the poster: (1) The only force acting on a projectile in free fall is the gravitational force (2) Gravitational acceleration is constant in its entire motion. It always acts downward whether the projectile is going up or down (3) At maximum height, the projectile's velocity is zero (4) Time taken by a projectile to reach its maximum height equals the time it takes from a maximum height back to its starting point (5) Velocity of an object as it passes through a point is equal in magnitude, but in different directions (6) When an object is dropped from a moving carrier its initial velocity is equal to the velocity of the moving carrier. Ms NJ indicated they just addressed point (1) on the poster. She explained (2) and said it does not matter whether an object travels upward or downward. The gravitational acceleration is always downward. She indicated that (4) is called time symmetry and that she will explain it later. She explained (5) using a diagram of a hot-air-balloon travelling upwards and an object dropped from the moving carrier. She indicated that if the hot-air-balloon travels upward with a velocity of $5 \text{ m} \cdot \text{s}^{-1}$, a ball is dropped from it. The ball will also	Learner understanding Curricular saliency Teaching strategy Representations and analogies

have an initial velocity of 5 m.s^{-1}. Ms NJ indicated they would keep referring to this poster while addressing problems. She then explained the concept of time-symmetry, to which she referred earlier. She used a diagram to represent the scenario of a ball thrown upward, reaching its maximum height and falling back to the point of launch. Once again, she indicated that the ball fell back due to the gravitational force. She also indicated on the diagram that the velocity at maximum height is zero. She explained that an object's velocity would decrease as it moves upwards until it reaches maximum height (zero) and then increase its velocity again as it falls to the ground. She also indicated, using the same diagram, that the velocity of an object is equal in magnitude when passing the same point but in opposite directions. Ms NJ indicated that it is essential always to choose a direction of motion to be positive when working with vertical projectile motion. She expanded and said remember; we are working with vertical projectile motion (emphasising the word vertical), which means it is up and down motions. Hence "the upward or downward direction should be selected as the positive direction, and we call this sign conversion". Ms NJ encouraged learners to use the same direction the object initially travels as the positive direction. She did mention that there is nothing wrong with choosing the opposite direction as positive. Both methods are correct. She explained this concept using the same diagram, indicating that if they chose the upward direction to be positive, the object's velocity would be positive for the first half of the motion. However, the velocity is negative upon returning due to the sign conversion. She also explained the opposite and said that if downward is chosen as positive, the object's velocity will be negative as it travels upward but will become positive once it falls back to the ground. Ms NJ explained (referring to the diagram) that the time the object reaches its maximum height will equal the time it takes the object to fall back from maximum height to the point of launch. She indicated that if it took two seconds for the object to reach its maximum height, it would take two seconds to reach its starting point again. Ms NJ quickly recapped the points on the poster with the learners.	
Section 1.3: Explaining the variables found in the equations of motion and how to select a suitable equation. [5 min 37 s]	
Ms NJ displayed a poster in front of her class with the four motion equations. She indicated that these equations are found at the back of the question paper on the information sheet, so there is no need to study them, but only to understand how to use them. She indicated this is familiar information, the same four equations used in grade 10. She explained all variables found in the four equations by writing them down, e.g. $v_f = \text{final velocity}$ and is measured in m.s^{-1}. When she reached the variable Δy, she explained that because we are dealing with vertical motions, we are using y, and when we are dealing with horizontal motions, we will use x. She referred to the Cartesian plane reminding learners of the y and x-axis and, in such a manner, related them to the movements. Ms NJ indicated that in every one of the equations of motion, there is a "missing" variable. For instance, she indicated that the equation $v_f = v_i + a\Delta t$ missed the y variable. She added all of the "missing" variables to her poster and said that when working with	Learner understanding Curricular saliency Teaching strategy

these equations, check what is asked and then look at which variable is missing. This will help to assist in choosing an equation to solve the problem.	
Section 1.4: Example discussed with the class on determining the displacement of an object thrown upward from the top of a building and falling to the ground. [22 min 24 s]	
Each learner received a copy of task one, their class exercise. Ms NJ indicated that they will now apply all the concepts they have just learned. She explained to learners that it is important to read the question and ensure they understand and interpret what is happening before they attempt the questions. The first exercise is that of a person throwing a ball upward from the top of a building, failing to catch it upon its return, and the ball falls to the ground. The question stated that air friction should be ignored, and Ms NJ reminded learners that the gravitational force acting on a projectile in free fall is the only force acting on a projectile in free fall. She proceeded to draw a diagram depicting the scenario on the board and added information to the diagram that was given in the question description. Ms NJ divided the motion into parts using alphabet letters (A→D). The alphabet letters consisted of (A) Initial position, (B) Maximum height, (C) point of launch (return), and (D) Ground. She indicated that when referring to the diagram, they have reference points that can be used. She indicated that before attempting to solve the question, they should use sign conversion and choose a positive direction for the movement. She added that it does not matter which direction (up or down) is chosen as positive. However, she recommended that the upward direction be chosen as the positive direction for this example. Ms NJ indicated that learners should stick to the same sign convention throughout the question and not change in between sub-questions. She indicated that she prefers to write the positive sign, although it is unnecessary because it reminds her of the direction of movement. She proceeded to write that the initial velocity is $+10 \text{ m} \cdot \text{s}^{-1}$. Ms NJ indicated they would work with reference points A to B to solve the first question (calculating maximum height). She listed the following quantities for these reference points: $v_i = +10 \text{ m} \cdot \text{s}^{-1}$; $v_f = 0 \text{ m} \cdot \text{s}^{-1}$; $\Delta t = ?$; $\Delta y = ?$; $a = -9,8 \text{ m} \cdot \text{s}^{-2}$. She explained that the final velocity is zero because the ball has reached maximum height, and the acceleration is negative because it acts in the downward direction, opposite to what they chose as the positive direction. She noted that in the information listed, there are two unknown variables: time and displacement. She added that they want to calculate the displacement; hence they need to choose an equation that consists of displacement, but because time is also unavailable, they should choose an equation without time. Therefore, the equation should consist of displacement but not contain time. They decided to use the following equation: $v_f^2 = v_i^2 + 2a\Delta y$. Ms NJ completed the question with the learners by substituting all values and completing all the mathematical steps to find the final answer. After they obtained the final answer, she reminded learners	Learner understanding Curricular saliency Teaching strategy Representations and analogies

that this answer applies to the reference points chosen ($A \rightarrow B$). Therefore they still need to add the height of the building to obtain the maximum height from the ground.

A learner asked if it is possible to use different equations of motion to obtain the answer. He elaborated and said if he calculated the time using the first equation and then used an equation consisting of time to solve the displacement. Ms NJ verified with the class what information was available and agreed it could be done. She then proceeded to solve the same question in the manner suggested by the learner to obtain the same answer.

Ms NJ concluded and said there is not only one correct way to solve the questions. There are other methods (solutions) that can be used. Referring to what happened in class regarding the different methods. She suggested that learners should look for what is asked and what is missing and select any suitable equation(s)

8.16 APPENDIX P: NARRATIVE AND CODED ANALYSIS OF LESSON 2 FOR MR JP

Lesson 2 narrative - Mr JP

Section 2.1: He introduced the three graphs of motion. He started to explain the acceleration-time graph. [8 min 25 s]	
Mr JP indicated to learners that they would learn about three different graphs. He started with the first one, which he described as the simplest one: the acceleration vs time graph. He then mentioned the second graph, the velocity vs time graph, and the last one, the position vs time graph. He explained to learners that many scenarios could be asked and highlighted the following scenarios when he quickly drew their diagrams on the board representing the motions. (1) Object thrown from the top of a building and falls back down to the ground (2) Object thrown upward and falls back to the starting position (3) Object dropped from the top of a building (4) Object dropped from the top of a building and bounces on the ground. He also explained to learners that they would only sometimes be required to draw the graph. They may be given a pre-drawn graph and need to interpret it. He explained to learners that they should remember that there are always dependent and independent variables when dealing with these three graphs. He started with the acceleration-time graph and indicated acceleration as the dependent variable and time as the independent variable. He elaborated and said this is also applicable to the other two graphs. Time is always the independent variable. He proceeded to draw the x and y-axis on the board. He indicated that because time is the independent variable, it will be on the x-axis, and the dependent variable will be on the y-axis. Mr JP indicated that it is always essential to choose a positive direction of motion. On the board, he drew arrows to show that moving up is positive while moving down is negative. He emphasised that this (upward as positive) is the notation they use in the classroom. It can be that a learner chooses the opposite, and it will be okay. He indicated below his arrows that the gravitational acceleration will always be $-9,8 \text{ m} \cdot \text{s}^{-2}$ for this sign convention because it is always downward. He emphasised that the gravitational acceleration is constant and always remains the same. He drew a straight horizontal line at $-9,8$ on the y-axis of his cartesian plane. He explained that the line will remain straight because the gravitational acceleration remains constant and is always $9,8$. He also indicated that learners should remember that these graphs usually stop. He used an example saying that if the motion lasted twenty seconds, the graph would stop at 20 seconds (referring to the acceleration-time graph he drew).	Learner understanding Curricular saliency Teaching strategy Representations and analogies

Section 2.2: Mr JP explained the position-time graph of an object thrown upward and fell back to the point of launch. [15 min 10 s] Mr JP wrote on the board position vs time graph but indicated to learners that it could also be called the displacement-time graph. He indicated that, unlike the acceleration-time graph, the position-time graph would differ each time depending on the scenario. He gave the first example and wrote on the board: "An object is thrown vertically upwards with a velocity of $10 \text{ m} \cdot \text{s}^{-1}$, and then it comes back down to the same position". He also made a diagram on the blackboard representing this scenario. He divided the diagram into three sections. A – The starting point of the motion; B – Maximum height and C – When the object reaches the ground again. Next to his diagram, he indicated using an arrow that the upward direction is chosen as the positive direction. He also wrote next to points A, B and C that the object's velocity is $10 \text{ m} \cdot \text{s}^{-1}$, $0 \text{ m} \cdot \text{s}^{-1}$ and $-10 \text{ m} \cdot \text{s}^{-1}$, respectively. He then asked, "The time it takes the ball from A to B will be equal to..?" a learner answered: "The time it takes the ball to move from B to C". Mr JP agreed with the answer. Mr JP quickly left the classroom to attend to a learner outside. Upon his return, he indicated they would now attempt to draw the position-time graph. Referring back to his diagram on the board, he said they would need to calculate the maximum height. He then indicated to learners that he wanted to clarify the motion of an object. Referring to his diagram, he explained that although we draw the diagram (negative parabola on the board) this way, it is not what is happening in reality. In reality, the object moves up and down. He elaborated and said we only draw it this way to make more sense. Using the equation $v_f^2 = v_i^2 + 2g\Delta y$ Mr JP calculated the maximum height the object reached as $5,10 \text{ m}$ upward. He then asked learners what the displacement from A to B is, to which a learner responded: "$5,10 \text{ m}$". Mr JP then asked what the displacement from A to C is, and the learners answered: "Zero" he agreed and indicated it is because the object is at the same position from which it started. Mr JP drew the axis for his graph on the board, indicating "P (m)" on the y-axis and "t (s)" on the x-axis. He then asked learners which formula can they use to calculate the time it took the object to reach its maximum height. The class responded with $v_f = v_i + g\Delta t$. He completed the problem with them, obtaining an answer of $1,02$ seconds. He then asked learners what the total time for the movement would be, to which they indicated $2,04$ seconds. Dividing his y and x-axis into equal intervals, he started to draw the position-time graph explaining to learners that they knew the maximum height now and the time it took the object to reach the maximum height. Hence they can draw the first part of the graph. For the second part of the graph, he said they knew the whole movement took $2,04$ seconds, so they knew where the graph should stop. He completed the graph on the board.	Learner understanding Curricular saliency Teaching strategy Representations and analogies

Section 2.3: He explained what the gradient of the position-time graph drawn in section 2.2 represents. [11 min 50 s] Mr JP then referred to the position-time graph and indicated to learners that the graph's gradient would represent the object's velocity for that time interval. He also wrote the equation $\left(\frac{y_2 - y_1}{x_2 - x_1}\right)$ on the board to calculate the gradient. He then referred to two lines that he had drawn, one having a more significant gradient than the other. He asked learners which one had the more significant gradient, and they did not answer. Mr JP then explained that the steeper the line, the greater the gradient. He asked learners: "What is a tangent?" and a learner answered a line that touches the graph in only one place. He then drew two tangents between points A and B on his graph. The tangent closer to point B was less steep than the tangent drawn around halfway. He then indicated that the gradient of the tangents is decreasing. Hence it means the velocity is decreasing. Doing the same between point B and point C, Mr JP explained that the object's velocity will increase because the tangents' gradients increase. He then wrote the statement down on the board, asking learners to copy it.	Curricular saliency Teaching strategy
Section 2.4: Mr JP interpreted a position-time graph already drawn. The graph was drawn for an object dropped from a certain height and bounced back to the same height it was dropped. [6 min 55 s] Mr JP indicated to learners that he wanted to show them a position-time graph that looked different from the motion observed in the object's path. He referred to his previous graph, saying it is obvious that the graph and the object's motion path correspond, referring to the graph's shape and the object's motion. He asked learners to open their textbooks on page 70. He drew a set of an axis on the board, indicating the y-axis is: "P(m)" and the x-axis is: "t(s)". He also indicated that the upward direction is positive and the downward direction is negative. Mr JP then drew the graph on the board, dividing it into sections A, B and C. He then said they were going to interpret the graph. His first asked learners if the gradient was increasing or decreasing between points A and B, but the class did not respond. Mr JP indicated that by using three tangent lines between points A and B, they could tell if the gradient was increasing or decreasing. He drew three tangent lines between points A and B and asked a learner whether the gradient was increasing or decreasing. The learner responded and said: "Increasing". He then indicated that the ball was thrown downward because the gradient is increasing, which means the velocity is increasing. He then read the scenario from the textbook used to draw the graph they were interpreting. A ball was dropped from a certain height and allowed to bounce back to the same height. He asked learners to look at the gradient between points B and C, and he asked whether it was increasing or decreasing. They responded and said: "decreasing". Mr JP said that the velocity is decreasing, which means the object is moving upward. He then realised he needed to include something from the graph that needed to make sense. He told learners: "There is something I am	Learner understanding Curricular saliency Teaching strategy

missing here, I will look at it and come back to you”.	
Section 2.5: He explained how to draw the velocity-time graph of an object thrown upward and falling back to the point of launch. [5 min 21 s]	
Mr JP drew an axis set on the board, indicating that the vertical axis represents velocity measured in $m \cdot s^{-1}$ and the horizontal axis represents the time measured in seconds. He wrote the answers they had previously calculated to serve as a reference. He indicated to learners that because the object's initial velocity is positive 10, the graph will start at positive 10. He then drew a straight line from 10 on the y-axis to 1,02 seconds on the x-axis. Because the final velocity is negative ten, he extended the line to where the time is 2,04 seconds, and the velocity is negative 10. He asked if there were any questions from the class, but there were none. He then ended the lesson by giving homework to the learners.	Learner understanding Curricular saliency Teaching strategy

8.17 APPENDIX Q: NARRATIVE AND CODED ANALYSIS OF LESSON 2 FOR MR DN

Section 2.1: Starts his lesson by explaining the acceleration-time graph. [2 min]	
Mr DN indicated there is always acceleration when dealing with projectile motion. He emphasised that we are working with the gravitational acceleration of the earth. He asked learners: “What is the acceleration on the earth?” they responded with: “9,8”. He agreed with the answer. He used the example of a ball that was dropped from the top of a building. Mr DN used the SMART board and drew the diagram for this scenario. He asked learners at different positions on his diagram what the acceleration would be, and each time they answered 9,8. He indicated that they should note it does not matter where on the diagram we depict the acceleration it will always be a constant value of 9,8. He drew the acceleration-time graph next to his diagram and indicated that the acceleration-time graph will have a horizontal line at +9,8. Mr DN explained if we chose downwards to be negative the graph will look the same, except the horizontal line will now be at -9,8 (indicating it on the graph).	Curricular saliency Representations and analogies Teaching strategy
Section 2.2: Explained the position-time graph of an object thrown upward and was caught again at the point of launch [6 min 06 s]	
Mr DN drew a diagram on the board of a person throwing an object into the air and catching it again at the point of launch. He indicated to learners that they should remember the diagram is only a representation of the motion and that we only consider up and down motions in vertical projectile motions. Mr DN asked learners what the displacement of the ball was while still in the person’s hand, referring to the diagram on the board. They responded with zero. He then added this information to his diagram displaying 0 metres at the point of launch. He indicated that the ball reached a maximum height of 10 m above the ground also adding this information to his diagram. He reminded learners to remember there is a difference between displacement and distance, hence when the ball reaches the point of launch again its displacement will be zero. Making use of this information Mr DN draws the position-time graph on the board. The graph that he drew corresponded to the object’s motion. There was a question from a learner asking: “Why don’t we use straight lines?”... “Going straight up and down.” Mr DN said: “Then it means time does not move.” He elaborated by indicating the lapse of time on his diagram and linking it to the graph. He also expanded his explanation to say the graph should not be drawn using straight lines because of acceleration, which means the velocity will not be constant.	Representations and analogies Curricular saliency Learner understanding Teaching strategy

Mr DN explained a second example of a ball being dropped. He indicated that the downward motion should be considered as the negative direction and indicated this on a diagram he drew on the board. He indicated that the position where the ball is being dropped from should be considered as the zero point. He drew the axis of the position-time graph on the board and also indicated the zero point. He proceeded to draw the position-time graph. This graph also corresponded to the object's motion.	
Section 2.3: Explained the velocity-time graph. [4 min 14 s]	
Mr DN referred back to the first example of the ball being thrown up in the air and being caught again at the point of launch. He said that they should take the upwards direction as positive. Mr DN asked learners what the velocity of the ball will be when it is released. The class indicated that the initial velocity will be the same as the velocity of the person's hand throwing it. Mr DN suggested they make use of the value 12 m.s^{-1}. He indicated this information on his diagram and also added that the velocity will be zero at maximum height (indicating it on the graph). Making use of this information displayed on the diagram he explained to learners that the ball is moving slower as it moves from the point of launch to the maximum height. He then indicated this on the velocity-time graph. Starting with an initial velocity of 12 m.s^{-1} and drawing a line to 0 m.s^{-1}. He asked learners what the point on the velocity-time graph means where the graph reaches the x-axis. The learners indicated it is where the ball had a velocity of zero. Mr DN agreed and added it is also the point where the object changes direction. He also indicated that because the acceleration is constant we can use straight lines when drawing velocity-time graphs. Mr DN referred back to the second example of a ball being dropped. He asked what the initial velocity is to which learners responded zero. Mr DN indicated this on his diagram. He then drew the axis of the velocity-time graph indicating the zero point on the graph. He reminded learners that the downward direction is considered to be negative. He continued to draw the graph	Representations and analogies Curricular saliency Learner understanding Teaching strategy
Section 2.4: Examples consisting of bouncing objects (explained the position-time graph). [3 min 44 s]	
Mr DN indicated that the downwards direction was considered to be positive for the coming examples, that being a soft and hard ball that bounced. He did a quick revision and asked learners if he had a flat rugby ball and one that is inflated, which one will bounce the highest when dropped? Learners responded and said the inflated one. Mr DN agreed and explained it is because the contact time between the inflated ball and the ground is less compared to the flat ball. Mr DN drew a diagram on the board indicating the motion of a dropped object. In his diagram, he indicated that the initial velocity is zero and also that the object does not reach its original position from which it was dropped after it bounced. He indicated that this is due to many reasons of which one is energy conversion.	Representations and analogies Curricular saliency Learner understanding

He then drew the axis of the position-time graph on the board in started to link the information from his diagram to the graph. They completed the position-time graph for a soft ball bouncing and he explained how to interpret the contact time on the graph as well as why the graph does not end where it started (position). On the same graph, Mr DN explained the concept of a hard ball bouncing. He indicated how the contact time will change (become less), and that the ball still does not reach the same point (position) from where it started.	Teaching strategy
Section 2.5: Provided examples involving bouncing objects by representing their motion using a velocity-time graph. [3 min 25 s]	
Mr DN made use of the same examples mentioned in section 2.4. He suggested that they divide the motion into two halves; the first being the motion from where the object has been dropped to where it bounced for the first time and the second half is from where the object bounced the first time to its maximum height after the bounce. He reminded them to remember the object is changing from direction when it bounces. He then indicated on the diagram that the velocity of the object is zero when it bounced. Mr DN related the information on his diagram to the velocity-time graph. He indicated the contact time on the graph and mentioned that this occurs when the object bounced. He proceeded to complete the graph referring to the textbook constantly. He briefly explained that when a harder object bounces the graph will move straight down because the object will bounce right back up.	Representations and analogies Curricular saliency Learner understanding Teaching strategy
Section 2.6: Examples used in his first lesson are used again to describe the graphs. [12 min 36 s]	
Mr DN made use of the drawing function on the SMART board to draw the diagrams representing the examples. The first example is that of a ball being thrown upwards from the top of a building and falling back past the point of launch to the ground. He reminded learners that they already solved the questions in their first lesson, they will now only focus on drawing the graphs. He started to draw the velocity-time graph on the board, linking the information on his diagram with the graph. Mr DN repeated this process when drawing the position-time graph and acceleration-time graph. When Mr DN completed his acceleration-time graph a learner asked him if the graph only represented the first part of the motion. He responded and said: "No, it is for the whole motion." He elaborated by drawing the force diagram of the object at different instances in the motion explaining that acceleration is always constant and downwards. The learner confirmed she understand and then made a statement and said: "If we chose the downwards motion as positive the graph would be drawn at +9,8." Mr DN agreed with her statement indicating it on the graph as well. He ended this conversation and said: "Make use of the same sign throughout	Representations and analogies Curricular saliency Learner understanding Teaching strategy

the question.”	
Section 2.7: Revision of pre-concepts and an example where learners need to interpret the graph. [5 min 51 s]	
Mr DN indicated that they are going to investigate the relationship between the three graphs of motion. He reads the scenarios from the textbook of an object experiencing a constant positive acceleration and constant negative acceleration. He copied the three graphs from the textbook illustrating the motion of an object having a constant positive acceleration. From these graphs, he indicated that the gradient of the position-time graph will represent the average velocity of the object for that time interval and that the area between the acceleration-time graph and the x-axis will also represent the average velocity for that time interval. He continued to explain the gradient of the velocity-time graph will provide the acceleration experienced by the object. He elaborated and said it will always be 9,8 when on Earth and that is why we use straight lines when drawing the velocity-time graph. He proceeded to explain the area of the velocity-time graph will provide the displacement of the object. Mr DN then copied the three graphs from the textbook illustrating the motion of an object having a constant negative acceleration. He briefly explained (while referring to the textbook) the mathematical formulas to calculate gradient and area (for different shapes).	Representations and analogies Curricular saliency Learner understanding Teaching strategy
Section 2.8: Exercise interpreting a velocity-time graph. [6 min 52 s]	
Mr DN read the scenario from the textbook and then copied the graph from the textbook on the SMART board. The scenario described is that of a rocket that accelerates (uniform) in an upward direction from rest. He interpreted the velocity-time graph on the board and explained to learners the different stages of the motion. They proceeded to answer the questions from the textbook. When answering the questions Mr DN referred to the textbook and copied the answers from the textbook. He explained that this scenario consisted of a rocket that is driven by fuel (external force) for the first part of the motion, hence the acceleration will not be 9,8 for that part of the motion. While describing the velocity-time graph he indicated that the rocket returns to the earth when the fuel has burnt out.	Curricular saliency Learner understanding Teaching strategy

8.18 APPENDIX R: NARRATIVE AND CODED ANALYSIS OF LESSON 2 FOR MS NJ

Section 2.1: Introduction of the graphs of motion (velocity-time graph) using a scenario where an object was dropped from the top of a high building. [9 min]	
Ms NJ indicated they would continue with vertical projectile motion, but the lesson's focus will be on graphs. She indicated that she would explain the motion graphs in a few scenarios. The first scenario drawn on the board by Ms NJ is that of a ball being dropped from the top of a 40-meter-high building. She indicated that it is important to investigate what information is available. This led her to ask learners: "When an object is dropped, what is it that we know?" The learners responded and said the velocity was equal to zero. Ms NJ proceeded and wrote the information next to her drawing saying the velocity for a dropped object is zero because the object is at rest. She informed learners that they were now going to draw the graphs of motion based on the information that they had. She started with the velocity-time graph. She drew the graph (x and y-axis) on the board and indicated that it is important to name them. She indicated that the x-axis represents the time, measured in seconds, and the y-axis represents the velocity, measured in $m \cdot s^{-1}$. Referring back to her diagram Ms NJ explained that learners should always choose a direction of motion to be positive. For this example, she indicated that they would select the downward motion to be positive. She asked learners what they thought would happen to the object's velocity after it was dropped. The class responded and said: "Increase". Ms NJ indicated on her x-axis set that the top half of the velocity-time graph is positive and the bottom half is negative. She also added that the x-axis is zero. Thus, everything above zero is positive, and everything below zero is negative. She explained, referring to the diagram, that the initial velocity of the object is zero. She pointed out that they will start at zero references on the axis. She reminded them to keep in mind that the velocity is increasing; hence, it should also increase on the graph. Because they have chosen downward as positive and the ball is falling downward, they used the positive end of the graph. Ms NJ revised the scenario with learners; she again indicated that we start at zero on the graph because the object was at rest. Furthermore, the object's velocity is increasing in a downward direction, and because they chose downward as positive, they should draw using the positive end of the graph. Ms NJ used the same example to explain how the graph would look if upward was chosen as positive. She indicated that they oppose the motion when choosing the upward direction to be positive. Hence as the object falls, its velocity decreases. She again explained why they are starting at the zero point on the graph – because the object is dropped. She then explained that the object was falling and its velocity was increasing. If upward is chosen as positive, the velocity graph will decrease. Ms NJ did a recap of the example. She pointed out that learners should always look for information given and what information can be determined. Then they should choose a motion of direction to be positive. This will enable them to draw the graph.	Learner understanding Curricular saliency Teaching strategy Representations and analogies

Section 2.2: Gravitational acceleration explained using the scenario mentioned in 2.1. [3 min]	
Ms NJ started talking about gravitational acceleration. She indicated that they know the gravitational acceleration is always $9,8 \text{ m} \cdot \text{s}^{-2}$. Using the same example in 2.1 above, she asked learners what the gravitational acceleration of a dropped object would be if they chose downward as positive. She provided the options of 9,8 or $-9,8$. The class responded and said positive 9, 8. Ms NJ then wrote $9,8 \text{ m} \cdot \text{s}^{-2}$ on top of the velocity-time graph she drew earlier. She did the same and wrote negative $9,8 \text{ m} \cdot \text{s}^{-2}$ on top of the velocity-time graph she drew earlier when they considered the upward motion positive. She indicated that the gradient of the velocity-time graph could be investigated. She referred to the mathematical equation of a gradient $m = \frac{\Delta y}{\Delta x}$. She noted that Δy represents the velocity and that Δx represents the time, providing the equation of $\frac{\Delta v}{\Delta t}$. She substituted the units of measurement for each physical quantity in the equation obtained $\frac{\text{m} \cdot \text{s}^{-1}}{\text{s}}$ and, using the exponent's law of mathematics, concluded that it can also be written as $\text{m} \cdot \text{s}^{-1} \text{s}^{-1}$, which in turn equals $\text{m} \cdot \text{s}^{-2}$. She concluded that the gradient of the velocity-time graph would represent the acceleration for that time interval and that it is easy to determine by only looking at the velocity-time graph whether the acceleration will be positive or negative.	Learner understanding Curricular saliency Teaching strategy
Section 2.3: Position-time graph explained using the scenario described in 2.1. [6 min 50 s]	
Ms NJ explained the position-time graph using the same scenario on the board. (She has not erased any information from the board) Ms NJ made a recommendation to learners and said it is easier if they choose upward as positive. She elaborated that when they chose upward as positive, the graph obtained would look the same as the path of motion the object travelled. She drew the axis on the board for the position-time graph indicating the position (m) on the y-axis and time (s) on the x-axis. She indicated the height of the building at +40 on the y-axis. She indicated that the ground is chosen as the zero point. Hence the ground is the reference point. She also indicated this on the graph by drawing a zero at the x-axis. She explained that the ball was dropped from 40 metres above the ground. Hence the starting point on the graph should be at +40 because the ground is used as the reference point. Ms NJ drew the graph starting at +40 and moving down to zero (x-axis). She pointed out again that the shape of the graph is the same as the object's motion path. Ms NJ did a quick recap of the graph she had just drawn, linking the path of motion of the object to the graph. A learner asked what would happen if it was a bouncing ball. Ms NJ explained that they would still get to that example, and she will explain it then.	Learner understanding Curricular saliency Teaching strategy Representations and analogies
Section 2.4: The velocity-time graph was explained to learners in terms of an object thrown upward from the top of a building and falling to the ground. [15 min 45 s]	
Ms NJ introduces a new scenario to learners. She uses the information for the first scenario, only this time, the object is thrown vertically upwards from the top of the 40m high building and falls back to the ground. Ms NJ made a diagram on the board illustrating the scenario. She labelled the object's motion path using alphabet letters ($A \rightarrow D$). She explained that this would enable them to link the motion to the graph.	Learner understanding

Again, she started to draw the x-axis on the board and labelled the x-axis as time measured in seconds. She labelled the y-axis as velocity measured in metres per second.

On the diagram (at point A), Ms NJ indicated that the object's initial velocity could be considered as five $m \cdot s^{-1}$ upward. She proceeded and asked the class: "At point B, our velocity is going to be how much?" the class responded with: "Zero". She started to write down the available information next to her diagram on the board and added that the time the object takes to move from point A to point B is two seconds.

Ms NJ indicated that they would use this information to draw the velocity-time graph of the scenario. She said: "Firstly, we are going to choose the direction to be positive". She pointed out that because the object is thrown initially upward, they should choose the upward motion to be considered positive.

She proceeded to her set of axis and indicated that the half above zero on the y-axis is positive and the half below zero on the y-axis is negative. Therefore she indicated that the graph's starting point would be positive five on the y-axis. She explained the object's motion, indicating that after it was thrown at point A, the velocity would decrease until it reached its maximum height, where the velocity would be zero and then again increase its velocity as it fell to the ground.

Ms NJ started to draw the graph on the set of an axis, starting at positive five on the y-axis and drawing a straight line (negative slope) to the x-axis. She indicated to learners that the velocity is zero on the x-axis as her label indicated and that this point represents the maximum height of the object, where we also know our velocity is zero and the time is two seconds. She further explained that the object's velocity increases as it moves from point B (maximum height) to point C (same position as initially launched). She asked learners: "What the velocity will be at point C" to which they responded: "negative 5". She agreed with the answer and added: "because we have taken upward as positive", referring to the negative sign. She went to her graph and indicated a negative five on the y-axis, then connected it to her graph using a dotted line. She asked, "Do we know the time at this point?". She did not give learners a chance to answer but immediately explained that if it took the object two seconds to move from point A to B, it would take another two seconds to move from point B to C. Therefore, she indicated that the time on the x-axis would be four seconds. She extended the graph downward (straight line), indicating the object did not stop at that point (point C). She labelled the end of her graph with point D.

Ms NJ did a quick recap of the problem explaining the whole motion to learners again and linking it to the graph she drew. She allowed learners to ask questions at the end of her explanation, and a learner asked if the velocity was decreasing between points A and B. Ms NJ responded, "Yes because it is moving upward, the velocity decreases."

Another learner needed clarification about point D. Ms NJ explained that point D represents the final velocity with which the object reaches the ground. She said that at the moment, we are not sure what the final velocity is, but if there were negative ten on the graph, we could tell from the graph what the final velocity of the object would be as it reaches the ground.

Ms NJ explained to learners that the area underneath the velocity-time graph is useful. Using her velocity-time graph on the board, she shaded the first two shapes, two triangles. She pointed out that we know the area formula for a triangle which she wrote on the board

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as $A = \frac{1}{2} b \times h$. She elaborated and said: "Our base is going to be time... and our height is going to be velocity." She substituted <i>time</i> and <i>velocity</i> into the place of <i>base</i> and <i>height</i>, respectively, giving her the equation $A = \frac{1}{2} (t) \times (v)$. She then further explained that time is measured in seconds and velocity in metres per second; hence the equation can be written as $A = \frac{1}{2} (s) \times (m \cdot s^{-1})$, which she solved mathematically to produce $A = \frac{1}{2} m$. She then asked learners what the "m" represents, to which they responded and said: "Displacement". Ms NJ indicated she wanted to show them that it is possible to use this graph's area to determine the object's displacement.	
Section 2.5: Explained the position-time graph using the scenario described in 2.4. [4 min 43 s]	
Ms NJ indicated that she would draw the position-time graph using the same scenario on the board. She erased the velocity-time graph from the board and drew a new set of axis indicating the position in metres on the y-axis and time in seconds on the x-axis. She quickly explained the object's motion again and then indicated to learners that because the object was being thrown upward, they should choose the upward motion as positive. As she mentioned, she pointed out to learners: "If you take the upward motion as positive, it gives you almost the same picture of what is happening here." She indicated positive 40 on the y-axis and the zero point, which she said is the ground. She started to draw the graph at positive 40 because it is a 40m high building. She drew the graph upwards until maximum height using curved lines and back to the ground (zero point) using a straight line. Referring back to her diagram of the scenario, she pointed out that the graph and diagram look almost similar. She allowed learners to ask questions, and a learner asked: "Why is there a straight line back to the ground?" Ms NJ was initially unsure, but upon her investigation, she indicated that she needed to improve at drawings and that the line should not be straight down. She also pointed out that using a straight line means the time is not progressing, which is not practical. She changed her graph from maximum height using a curved line to zero point. Another learner asked: "Will the graph be almost the same if we chose downward as positive?" Ms NJ indicated: "If you chose downward to be positive, your graph is going to be sort of a reflection of what is happening this side [pointing to the original graph]". She then drew a mirror image of the original graph and indicated how the graph would look when downward is chosen to be positive.	Learner understanding Curricular saliency Teaching strategy Representations and analogies
Section 2.6: Explained the acceleration-time graph using the scenario described in 2.4. [1 min 59 s]	
Using the same example and choosing upward as her positive direction Ms NJ indicated that the acceleration is $-9,8 m \cdot s^{-2}$. She proceeded and drew the y-axis and x-axis and indicated that time measured in seconds is represented by the x-axis and acceleration measured in $m \cdot s^{-2}$ is represented by the y-axis. She pointed out that this graph is much easier and that straight lines are always used. Learners only need to know which direction was chosen as positive. She indicated on her acceleration-time graph positive and negative 9,8 and drew a straight horizontal line at negative 9,8 because they chose the upward direction to be positive. She ended her discussion and said: "It is only a matter to say if it [gravitational acceleration] is going to be positive 9,8 or negative 9,8".	Curricular saliency Teaching strategy Representations and analogies

8.19 APPENDIX S: LDoE LETTER

Dear Sir/Madam.

Request to conduct research in Waterberg District schools.

I am Danie du Toit, 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 district with your staff members as participants.

The title of my study towards my Master's degree is *"Teaching vertical projectile motion: The role of teaching experience in pedagogical content knowledge development."* The aim of the study is to explore the role of teaching experience in the development of novice teachers' PCK when teaching vertical projectile motion for the first time.

I am working under the supervision of Dr. Coetzee and Dr. Mazibe from the Department of Science, Mathematics and Technology Education at the University of Pretoria.

There are three parts to this research, the completion of a content representation (CoRe) –tool in questionnaire format which is corroborated with an interview (using semi-structured interview questions) followed by a lesson presentation on vertical projectile motion which will be observed and video recorded by me.

The CoRe -tool is asking questions about the teaching of vertical projectile motion, and will also be explained to the teacher beforehand. The interviews will be scheduled with teachers when they are available and will take place at a venue convenient to them. I will not interfere with the normal running of the school. The first interview will take approximately 30 minutes. This interview is to strengthen the data obtained through the CoRe -tool, and the second interview, after the lesson presentation, is about 45 minutes where I will do a stimulated recall interview. It will be possible for both interviews to occur after the school has adjourned.

I also ask permission to observe and video record one or more of the lessons where the teacher teaches the topic, vertical projectile motion, to Grade 12 learners. I will

be a passive non-intrusive observer when recording the lesson. I will ensure that it will not be possible to recognise learners on the videos.

Participation in this study is **voluntary** and confidential. Participants have the right to withdraw at any point during the research study without any consequences or explanations. They can be assured that their decision will be respected.

Confidentiality and anonymity will always be guaranteed by using pseudonyms for the participants during the transcription phase and the writing up of the research. **No school name, teacher name, participant names or personal information will be reported in my findings.**

I will make audio recordings of the semi-structured interviews. The purpose thereof is to make the transcription of data valid and authentic. The recording will be safely kept at the University of Pretoria. Only my supervisors and I will have access to the audio recordings. All data collected will only be used for academic purposes. Questions or queries regarding participation and/or data collection can be directed to me or my supervisor.

The findings of this study may be used to understand how experience contributes to the development of an educator's pedagogical content knowledge base. 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 for professional development interventions.

I would also like to request your permission to use the collected data, confidentially and anonymously, for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

Please find attached my full research proposal.

Yours sincerely

Danie du Toit



E-mail address: ddutoit14@yahoo.com

Contact number: 064 906 1199



Supervisor: Dr. Coetzee C

E-mail address: corene.coetzee@up.ac.za



Co-supervisor: Dr. Mazibe E

E-mail address: ernest.mazibe@up.ac.za

8.20 APPENDIX T: PRINCIPAL LETTER

The Principal
XXX School
Limpopo

Request for Permission to Conduct Research

I am Danie du Toit, 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 one of your staff members.

The title of my study towards my Master's degree is *"Teaching vertical projectile motion: The role of teaching experience in pedagogical content knowledge development."* The aim of the study is to explore the role of teaching experience in the development of novice teachers' PCK when teaching vertical projectile motion for the first time.

I am working under the supervision of Dr. Coetzee and Dr. Mazibe from the Department of Science, Mathematics and Technology Education at the University of Pretoria.

There are three parts to this research, the completion of a content representation (CoRe) –tool in questionnaire format which is corroborated with an interview (using semi-structured interview questions) followed by a lesson presentation on vertical projectile motion which will be observed and video recorded by me.

The CoRe -tool consists of questions about the teaching of vertical projectile motion, and will also be explained to the teacher beforehand. The interviews will be scheduled with teachers when they are available and will take place at a venue convenient to them. I will not interfere with the normal running of the school. The first interview will take approximately 30 minutes. This interview is to strengthen the data obtained through the CoRe -tool, and the second interview after the lesson presentation, is about 45 minutes where we will do a stimulated recall interview. It will be possible for both interviews to occur after the school has adjourned.

I also ask permission to observe and video tape one or more of the lessons. The aim of the observation is to observe the teacher teaching vertical projectile motion to his/her class. I will be a passive non-intrusive observer when recording the lesson. I will ensure that it will not be possible to recognise learners on the videos.

Participation in this study is **voluntary** and confidential. Participants have the right to withdraw at any point during the research study without any consequences or explanations. They can be assured that their decision will be respected. Confidentiality and anonymity will be guaranteed always by using pseudonyms to the participants during the transcription phase. **No school name, teacher name, participant names or personal information will be reported in my findings.**

I will make audio recordings of the semi-structured interviews. The purpose thereof is to make the transcription of data valid and authentic. The recording will be safely kept at the University of Pretoria. Only my supervisors and I will have access to the audio recordings. All data collected will only be used for academic purposes. You may ask questions before or during the time of participation. If you have any concerns regarding the data collection procedures, please notify me or my supervisor.

I would also like to request your permission to use your data, confidentially and anonymously, for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

Kind Regards

Danie du Toit

E-mail address: ddutoit14@yahoo.com

Contact number: 064 906 1199

Supervisor: Dr. Coetzee C

E-mail address: corene.coetzee@up.ac.za

Co-supervisor: Dr. Mazibe E

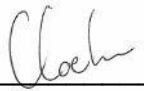
E-mail address: ernest.mazibe@up.ac.za

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 vertical projectile motion: The role of teaching experience in pedagogical content knowledge development" conducted in my school with my staff member(s) and learners. I am well aware that my staff member(s), the teacher(s), will be asked to complete the questionnaire through the CoRe tool, teach in the presence of the researcher while the lesson will be recorded and that the teacher will be interviewed.

Researcher's signature:  _____ Date: _____

Principal's signature: _____ Date: _____

Supervisor's signature:  _____ Date: _____

Co-supervisor's signature:  _____ Date: _____

8.21 APPENDIX U: TEACHER LETTER

Dear Teacher

Informed consent to participate in research

I am Danie du Toit, 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. I would like to ask if you would be willing to participate in my research project.

The title of my study towards my Master's degree is *"Teaching vertical projectile motion: The role of teaching experience in pedagogical content knowledge development."* The aim of the study is to explore the role of teaching experience in the development of novice teachers' PCK when teaching vertical projectile motion for the first time.

I am working under the supervision of Dr. Coetzee and Dr. Mazibe from the Department of Science, Mathematics and Technology Education at the University of Pretoria.

As one of the participants, I kindly invite you to participate in this study. There are three parts to this research, the completion of a content representation (CoRe) –tool in questionnaire format which is corroborated with an interview (using semi-structured interview questions) followed by a lesson presentation on vertical projectile motion which will be observed and video recorded by me.

The CoRe -tool is asking questions about your teaching of Vertical projectile motion, and will also be explained to you beforehand. The interviews will be scheduled as per your availability and will take place at a venue convenient to you. The first interview will take approximately 30 minutes this interview is to strengthen the data obtained through the CoRe -tool, and the second interview after the lesson presentation will take about 45 minutes where we will do a stimulated review interview. We will view the lesson presented together and you can stop or pause the recording at any time to elaborate on your actions.

The researcher also asks permission to observe and video record one or more of your lessons. The aim is to observe the teacher teaching vertical projectile motion to his/her class. I will be a passive non-intrusive observer when recording the lesson. I will ensure that it will not be possible to recognise learners on the videos.

Your participation in this study is **voluntary** and confidential. You have the right to withdraw at any point during the research study without any consequences or explanations. You can be assured that your decision will be respected. Confidentiality and anonymity will always be guaranteed by using pseudonyms to the participants during the transcription phase. **No participant names or personal information will be reported in my findings.**

In participating in this research study, you will be asked for permission by the researcher to make audio recordings of the semi-structured interview. The purpose thereof is to make transcription of data valid and authentic. The recording will be safely kept at the University of Pretoria. Only my supervisors and I will have access to the audio recordings. All data collected will only be used for academic purposes.

You may ask questions before or during the time of participation. If you have any concerns regarding the data collection procedures, please notify me or my supervisor. As a participant, you will have the opportunity to access and verify the recorded views and the transcriptions of interviews made in case there is a need to do so.

I would also like to request your permission to use your data, confidentially and anonymously, for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

Kind Regards



Danie du Toit

E-mail address: ddutoit14@yahoo.com

Contact number: 064 906 1199



Supervisor: Dr. Coetzee C

E-mail address: corene.coetzee@up.ac.za



Co-supervisor: Dr. Mazibe E

E-mail address: ernest.mazibe@up.ac.za

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

I, _____ (your name) hereby give permission to DR du Toit to include me as a participant in his research on teaching vertical projectile motion: The role of teaching experience in pedagogical content knowledge development.

Signature: _____

Date: _____

8.22 APPENDIX V: PARENT/GUARDIAN AND LEARNER LETTER

Dear Parent / Guardian and learner.

I am Danie du Toit, 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. The title of my study towards my Master's degree is **“Teaching vertical projectile motion: The role of teaching experience in pedagogical content knowledge development.”**

One of the data collection techniques that will be used in this study is observation, where the Physical Sciences teacher will be observed and video-recorded while teaching the topic *vertical projectile 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 learners also have the option to be seated at the back to ensure the camera would not capture them.

The lesson would take place like any other lesson as I will just be observing and recording the lesson without interrupting. I, the researcher, am not going to ask the learners or their teacher questions. Should your child turn and face the camera so that his/her face is captured the image will be blocked to protect his/her identity.

The video recorded lesson will be used to compile a dissertation which will be uploaded onto the open access repository for anyone to read. No images of the faces of learners or teachers will be displayed in the dissertation. The names of the school and teacher will be kept confidential at all times, only my supervisors and I will have access to the video.

If you are not willing to let your child participate in this study, or want to request that the learner sit behind the camera please sign this letter and sent it back to the school.

I also would like to request your permission to use your data, confidentially and anonymously, for further research purposes, as the data sets are the intellectual property of the University of Pretoria and, where relevant, project funders.

Further research may include secondary data analysis and using the data for teaching purposes. The confidentiality and privacy applicable to this study will be binding on future research studies.

I, _____ (your name), the parent/guardian of _____ (your child's name) in Grade 12 grant/do not grant (delete the one that is not applicable) my child to partake in the study entitled **“Teaching vertical projectile motion: The role of teaching experience in pedagogical content knowledge development.”** I am aware of the following:

- My child's identity will be protected.
- The video recording 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, without any adverse consequences for my child, the teacher or the school.

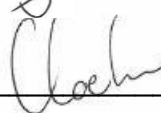
Please tick the box if you would like your child to be seated behind the camera

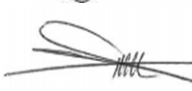
☐

Parent signature: _____ Date: _____

Learner signature: _____ Date: _____

Researcher's signature:  _____ Date: 13/12/2021

Supervisor's signature:  _____ Date: 13/12/2021

Co-supervisor's signature:  _____ Date: 13/12/2021