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EXAMINING THE CLASSROOM TEACHING OF BEGINNING PHYSICAL SCIENCE TEACHERS WHO GRADUATED FROM A TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE BASED UNDERGRADUATE PROGRAMME

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A Thesis Submitted to the Faculty of Humanities, University of Witwatersrand, Johannesburg in fulfilment of the requirements for the degree of Doctor of Philosophy

Johannesburg, South Africa

2018

DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

_____

(Signature of candidate)

19th day of October 2018

ABSTRACT

In science education, Topic Specific Pedagogical Content Knowledge (TSPCK) is attested to as a valid theoretical construct for implementation within topics in initial teacher preparation programs (Abell, 2008; Mavhunga, 2015). This study investigated the advantage brought about by the early exposure of Graduate Beginning Teachers of physical sciences, (intervention GBTs) to explicit TSPCK development at the time of their pre-service training in the quality of their classroom teaching. The study employed a qualitative comparative case study design of 7 intervention GBTs. A control sample of 3 GBTs, and 1 expert teacher were added to this sample. Data was collected and analyzed at four sampling stages. The first stage entailed fresh analysis of sets of data that were retrospectively collected from archived completed pre-versus-post TSPCK tools, which were used to measure the quality of planned TSPCK in the topics of intervention before and immediately after the intervention. The second stage comprised analysis of sets of freshly completed TSPCK tools in the same topics of intervention administered 2 years into the actual teaching practice of the intervention GBTs. The third stage involved a comparison of the freshly completed TSPCK test tools in the same topics of intervention and in new topics, collected from a sub-set sample of 3 intervention-GBTs vs. 3 control GBTs and 1 expert teacher. The new topics were different from those used during the intervention. The fourth stage included analysis of sets video-recorded lessons and pre- (post) lesson interviews, captured during the actual classroom teaching of the same sub-set of 3 GBT cohort pairs and the expert teacher. The completed TSPCK tools were analyzed and scored using the criterion based Mavhunga & Rollnick TSPCK (2013) rubric for scoring planned TSPCK. Measurement of the quality of enacted classroom teaching involved qualitative in-depth analysis for TSPCK episodes contained in the recorded lessons. This was followed by matching the identified episodes into pre-determined categories of quality in a newly developed and validated TSPCK classroom rubric, with assistance of three independent raters. The inter-rater reliability agreement in both planned and enacted TSPCK was calculated at a Cohen Kappa value of 0.80 and 0.822, respectively. The findings from the first and second sets of data confirmed a positive gain in the quality planned TSPCK at the end of the final year of the intervention GBTs training program and retention of the acquired quality two years into actual teaching practice. Findings from the third and fourth sets of data revealed that; the intervention-GBTs displayed added advantage over their control GBTs in planning and reasoning about teaching, as well as their real classroom teaching.

The above findings suggests that an early exposure to explicit TSPCK as part of teacher preparation may influence the retention of the aquired competency for planning and enactment of TSPCK across different topics in real classroom teaching among beginning physical science teachers. I acknowledge the small sample size used as a limitation to the generalization of the research findings. I however suggest that emphasis be placed on the displayed patterns, as they emerged from multiple qualitative data sources and recommend for the development of PCK in core science topics in pre-service teacher preparation programmes

Key words: Retention, Pedagogical Content Knowledge, Topic specific Pedagogical Content Knowledge; Pedagogical Transformation Competence

DEDICATION

This work is dedicated to my dear wife Flora and our children for their patience and encouragement during my studies. My late parents, tata Miheso A.A.A. and mama Agnes, who laboured hard to give us a scholarly upbringing, a big thank you. Memories of you remain fresh and inspiring.

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Abbreviations

DBE	Department of Basic Education
DHET	Department of Higher Education and Training
DoE	Department of Education
HEI	Higher Education Institutes
PCK	Pedagogical Content Knowledge
PK	Pedagogical Knowledge
SAIRR	South African Institute of Race Relations
SCK	Specialised Content Knowledge
SMK	Subject Matter Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge

CHAPTER 1

INTRODUCTION TO THE STUDY

This chapter provides an overview of the study, within the South African context. In the chapter, I provide an outline on why the study was conducted, how the research questions were conceptually devised, my positionality as a researcher, and the chronological sequence of the chapters in the thesis.

1.1 Introduction

Does an early exposure to explicit Pedagogical Content Knowledge (PCK) development in a specific topic translate to coherent and effective classroom practice by graduate beginning teachers of physical science? This constitutes the question at the heart of PCK studies in science education. Teacher education programmes across the globe generally aim to develop pedagogical competencies needed for effective teaching (Darling-Hammond, Hammerness, Grossman, Rust, & Shulman, 2005). In science education, Pedagogical Content Knowledge is considered a valuable theoretical construct for implementation within topics in initial teacher preparation programmes (Abell, 2008; Aydin, Demirdogen, Akin, Uzuntiryaki-Kondakci, & Tarkin, 2015; Kind., 2009; Mavhunga, 2015b).

Current science education researchers contend that the nexus between theory and practice is navigated through Pedagogical Content Knowledge as a theoretical construct (PCK). According to Loughran & Hamilton (2016) the construct of PCK has provided science educators with a new way of understanding teaching beyond the technical genre, opening a pathway to name and frame teachers' professional specialist knowledge of practice.

In South Africa, initial teacher education preparation is a preserve of Higher Education institutions under the Higher Education Act 101 (1997). In this context, Parker and Adler (2005) argue that the current reform climate creates space for Higher Education Institutions to have a leeway to structure their teacher education programmes as they deem fit. However, the release of qualified graduate science

teachers who qualify from the teacher Education programmes (B.Ed) across all institutions of Higher Education nationally, has not made a noticeable impact on the state of science education in the country (Spaull, 2013), as evidenced by the low performance of South African learners in recent international educational achievement studies, such as the International Trends in Mathematics and Science Study or TIMSS assessment and the local benchmark studies, the Matriculation results of science students passing with access to higher education (HE). In a study aiming to understand why some of the world's educational systems performed significantly better than others, Barber and Mourshed (2007) found that rather than the curriculum itself, another the main driver of the variation in student achievement is instead its delivery.

About five years ago, in 2011, in a response to increased calls for the implementation of PCK in pre-service teacher programmes (e.g. Abell, 2008; Nilsson, 2008), the Department of Science and Technology Education at my university, situated in South Africa initiated an intervention programme that explicitly introduced PCK in the undergraduate B.Ed teacher qualification programme. This is in line with one of the goals of the National Secondary School Curriculum in South Africa that requires the development of PCK in specific topics (DoE, 2006). The intervention programme is located in the fourth and final year of the methodology class of Physical Science[1] teachers, referred to in this study as intervention GBTs.

The aim of the intervention programme is the development of PCK at the level of teacher knowledge located at a topic level of the PCK taxonomy (Nezvalová, 2011; Veal & Makinster, 1999) as distinct from the broader PCK construct commonly defined through models such as the Magnusson, Krajcik and Borko (1999). In the intervention, PCK at a topic level was called Topic Specific Pedagogical Content Knowledge (TSPCK). The focus of the intervention studies is placed on demonstrating pedagogical transformation of content knowledge from topic to topic through planning and reasoning about teaching a topic. Each year since then, the

[1] Physical Science is a subject or area of study offered in the South African school curriculum that combines the two subject domains of physics and chemistry into one single subject area.

programme has been producing graduate teachers who have been exposed to the TSPCK-based intervention construct.

This study explores how particular cohorts of intervention GBTs exposed to an intervention that explicitly introduces TSPCK during their undergraduate programme perform in their actual classroom practice in the early years of their teaching careers. According to Luft et al. (2015), newly hired graduate teachers of science are considered beginning teachers during their first five years of teaching. The cohorts of graduate beginning teachers from the TSPCK-based undergraduate programme who participated in this study fall within this bracket of teaching experience.

1.2 Problem statement

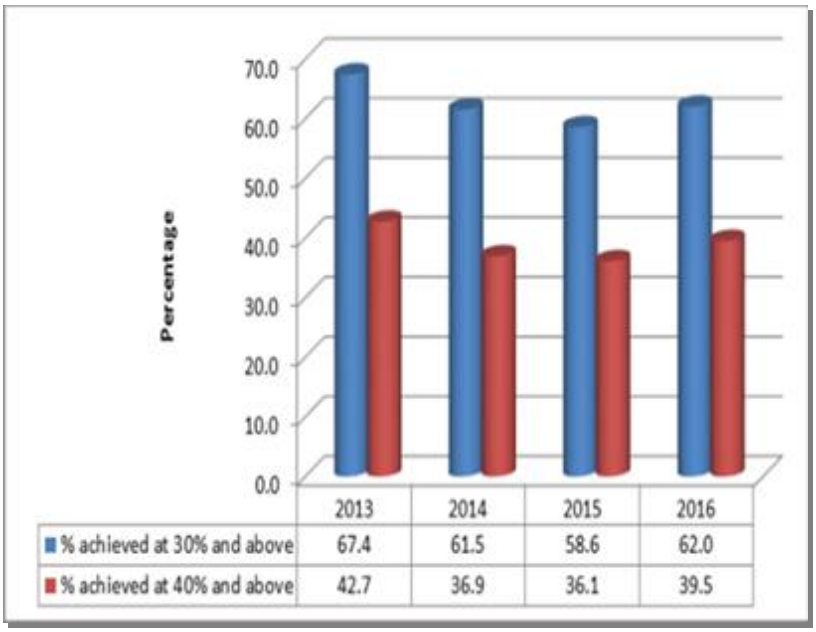
A country can be said to be as good as the quality of education afforded to its citizens. South Africa as a nation has a vision commonly referred to as *Vision 2030*. Through this vision, the national government has articulated its aspirations for basic education as:

> By 2030, South Africans should have access to education and training of the highest quality, leading to significantly improved learning outcomes. The performance of South African learners in international standardised tests should be comparable to the performance of learners from countries at a similar level of development and with similar levels of access. Education should be compulsory up to Grade 12 or equivalent levels in vocational education and training (National Development Plan, 2013 p. 296).

The latest performance by South Africa, in the international TIMSS assessment (Reddy et al., 2011) showed however that three quarters of South African learners had not acquired the minimum set of mathematics or science skills by Grade Nine. The study further categorised only one percent of learners at the advanced level of learning and one-quarter as achieving above the lowest benchmark score. This implies the number of learners at low proficiency level in Science and Mathematics to

be an indicator of not only the development of a future scientifically literate society, but also of the citizens' inability to participate fully in the knowledge economy, where expertise is becoming a critical economic resource.

Moreover, the number of candidates who enrol in and sit for Physical Science in South Africa has been dropping in the past few years. For example, between 2009 and 2013, the number of candidates who sat for Physical Science at secondary school level shows a 17% decline (DBE, 2014). Likewise, the poor performance of matriculation results of Science students passing with access to higher education (HE), attests to this concern. Figure 1.1 below shows the national performance of learners in Physical Science at Grade 12 between 2013 and 2016.



	2013	2014	2015	2016
% achieved at 30% and above	67.4	61.5	58.6	62.0
% achieved at 40% and above	42.7	36.9	36.1	39.5

Figure 1: National performance of Grade 12 Physical Science learners (DEB report 2017).

Looking at the learners' overall performance in Figure 1.1 reveals that the percentage of learners who achieved 40% and below between 2013 and 2016 constituted about 40% of the total number of all learners who sat for Physical Science in Grade 12. Those who achieved an average of 30% were between 60% and 70% of the total number of all learners. From these findings, it may not be practical for South Africa and other developing African countries in similar circumstances to expect to be able to create the critical mass of a scientifically literate workforce that can meet a projected vision centred on scientific innovation.

This scenario calls for a need for strong interventions, aimed at changing the current state of science education in the South Africa.

This study thus focuses on the PCK-based intervention programme introduced in the science methodology course at my university. In this programme, pre-service teachers are exposed to the idea of PCK broadly over their second and third years of study, and more particularly, the construct of Topic Specific Pedagogical Content Knowledge (TSPCK) in their fourth year, which is their final year of study. The unique feature of the programme is the explicit implementation of the TSPCK construct targeting the competence to pedagogically transform concepts of core topics in Physical Science. This study explored the possible advantage derived from the early exposure of intervention-GBTs to explicit PCK development in specific topics during their years of training as pre-service teachers.

1.3 Rationale

According to the Department of Basic Education (DBE), South Africa has an acute shortage of skilled educators in the areas of mathematics, science and technology. This problem is further exacerbated by the low levels in the production of qualified educators from higher institutions of learning (DEB, 2014). Moreover, research findings indicate that most of the current teaching force in the country are inadequately educated and trained whether during the apartheid era or in the recent past (Spaull, 2013). Other studies reveal that there is an uncertainty as to the content knowledge and pedagogical knowledge of physical science teachers on the new topics in the revised Physical Science National Curriculum Statement in high schools NCS (Ramnarain & Fortus, 2013). According to Edwards (2015), extant literature on content knowledge of South African teachers reveals that many teachers have not mastered the curricula they are expected to teach.

In addition, hiring more newly trained graduate teachers into the education system seems not to improve the average level of qualification of employed teachers. This is because a large portion of the teachers leave the profession within the first five years of placement in South Africa (Spaull, 2013). According to the National Academies of

Sciences (2015), opportunities for new teachers to formally enhance their understanding of science after entering the classroom are very limited. Rollnick and Mavhunga (2016), have similarly reported on the paucity of follow-up development programmes for beginning teachers. The authors argue that many of the formal experiences designed to help teachers develop science SMK are completed by the time teachers enter the classroom.

To address the critical challenge of poor content and conceptual knowledge among teachers, the South African education sector has launched several initiatives to assist beginning teachers to best implement quality classroom practice. One such programme is the Integrated Strategy Planning Framework for Teacher Education and Development -ISPFTED (DEB, 2011). The aim of this initiative is to improve the quality of teachers and teaching through expanding initial teacher training education programmes (ITE) provision at public higher education institutions (HEI); as well as the achievement of significant increase in subject content knowledge and how to teach it and the teaching practice component (Spaull, 2013). However, evidence from national evaluation state reports indicate that both public and private funded initiatives that have attempted to improve the teaching and/or learner performance in Mathematics and Science education over the past decades in South Africa have made no noticeable impact at a national level (OECD, 2008).

Research studies in teacher education suggest that the efficiency and effectiveness of teachers depends upon the nature and quality of teacher training course programmes (Arshad & Akramnaseem, 2013; Bressoux, Kramarz, & Prost, 2005). It ought to follow therefore that, if the pre-service teacher preparation has been successful, beginning teachers will have a compelling vision of good teaching, a novice repertoire of approaches to curriculum, instruction and assessment, and the tools to learn in and from their practice (Darling-Hammond & Bransford, 2005). While some research studies support the above argument (e.g. Ingersoll et al., 2014; Nilsson, 2008) other studies indicate that even with sound initial teacher certification programmes, beginning teachers' classroom practice may be repressed and need time to surface (e.g. Loughran, 1994). Beginning teachers are often said to struggle with how to represent concepts and ideas in ways that make sense to the specific

students they are teaching (Wilson, Shulman, & Richert, 1987). This observation has been shown to manifest even with beginning teachers who possess substantial subject matter knowledge (SMK) gained through advanced science degrees (Grossman, Wilson, & Shulman, 1989; Lee, Brown, Luft, & Roehrig, 2007). Therefore, by studying beginning teachers who have experienced a specific programme, that promotes pedagogical transformation of content knowledge for purposes of teaching, it is possible to understand the potential contributions of different initial certification programmes for teachers' professional practice. It is argued in the literature that teacher educators do not have the time to model lessons related to every core curriculum topic in which they may demonstrate best practices (Grossman, 2011). Hence, this study traces cohorts of GBTs, who were exposed to an intervention, which serves to dismantle PCK and the re-construction of its elements in a bid to develop requisite pedagogical knowledge in science related topics.

The distinct focus of the intervention on the construct of TSPCK (rather than on general PCK) requires additionally for the programme to succinctly articulate the knowledge components to be taught to pre-service teachers. In addition to this, it articulates the sequence according to which these components were introduced to build scenarios that promote learning of their interactive use.

It is positively noted that the intervention programme mentioned above has displayed success in developing TSPCK at the level of thinking and planning (Planned TSPCK); a level at which it is important to display reasoning about the teaching of a topic (e.g. Mavhunga, 2012). However, even so, enactment of TSPCK in real classroom teaching is still needed, since both 'Planned' PCK and 'Enacted' PCK are important (Aydeniz & Kirbulut, 2014; Park, Jang, Chen & Jung, 2011). According to Shulman (1987), reasoning about teaching involves the ability to transform content knowledge long before the actual act of teaching itself. In the case of TSPCK, a slightly different version of PCK, little is known in the literature about the success in applying the acquired ability to transform content knowledge, referred to in this study as acquired pedagogical transformation competence (or PTC), and developed in the pre-service teacher training programme with a single topic across other Physical Science topics in real classroom teaching. According to Mavhunga and Rollnick,

(2013), PTC is the ability for pre-service teachers to learn both the knowledge components of TSPCK, and their combined interactive use in formulating explanations and responses to questions in teaching a topic. This study explores how the acquired PTC developed in a planning and thinking context at the time of pre-service teacher intervention programme by observing the actual classroom practice of South African GBTs in the early years of their teaching careers.

1.4 Research questions

The study focuses on Physical Science teachers who graduated from a TSPCK based pre-service teacher intervention programme in the year 2014.

The study sought to determine whether there is enough evidence to show a visible advantage in the quality of GBTs enacted classroom practice derived from the added benefit of the early exposure to explicit TSPCK development during the early years their teaching careers.

The main research question that guided this study is: How does the early exposure of GBTs to explicit PCK development in a specific topic influence retention of the acquired TSPCK and their current classroom practice?

This research question has the following three sub-questions:

1. To what extent is the quality of PCK previously acquired from a pre-service teacher training programme retained in the topic of intervention?
2. What is the advantage, if any derived from an early exposure to explicit Topic-specific PCK development?
3. What is the nature of the GBTs' enacted classroom teaching in topics of their choice?

1.5 Conceptual framework

This study was grounded in the broader pedagogical content knowledge PCK theoretical framework, by acknowledging Shulman's statement that "comprehended ideas must be transformed in some manner if they are to be taught" (Shulman, 1987,

p. 16). The frame is defined by the level of teacher knowledge located at a topic level of PCK taxonomies (Nezvalová, 2011; Veal & Makinster, 1999). The theoretical framework for this study was thus drawn from selective aspects of two PCK models, viz. Mavhunga's (2012) Topic Specific PCK (TSPCK) model, and the consensus Teacher Professional Knowledge and Skill (TPK & S) model forwarded by Gess-Newsome (2015). Both models speak to the separation of the teacher knowledge needed for teaching specific topics from the broader teacher professional knowledge bases. In addition, the (TPK & S) model reveals how the topic specific professional knowledge of PCK, translates into classroom practice. I elaborate on these models in Chapter 2. Although many studies in PCK refer to the two models, no study has been reported to combine and use both models in a theoretical framework. I envision the report findings from this study to contribute towards a feasible understanding of how the two models support the broader discussions about PCK and the transfer of acquired pedagogical transformation competence from a planning and thinking context, into actual classroom practice.

1.6 Researcher positionality

This study was situated within a qualitative, interpretivist research paradigm (see Chapter 3). According to Henning (2004), it is important in qualitative, interpretive research for the researcher to provide a clear account of who s/he is, and how s/he influenced the research findings by engaging in the research process. The nature of qualitative research sets the researcher as the data collection instrument. It is therefore expected that the researcher's beliefs, political stance, cultural background (gender, race, class, socio-economic status, and educational background) are important variables that may affect the research process (Bourke, 2014).

In the following section, I discuss how my identity as the researcher, who interacted with the research conducted. I am a black African male, born in the early 1960s at the dawn of independence in my home country of Kenya. My early schooling was shaped by a strong Christian predisposition. This was because most learning institutions at the time were strongly linked to the different religious missionaries that initially established the learning institutions in my country. My parents having been

ardent Christians, Christianity and education were the most cherished virtues in our family. My inclination towards the field of science was however influenced by my older siblings, who were training in different fields of science and engineering at the only national university at the time. I later enrolled for a Bachelor of Science degree course, majoring in Chemistry and Biology at the same university. I however later changed from pursuing the Bachelor of Science general degree (B.Sc) to a Bachelor of education degree course (B.Ed. Sc). The reason behind changing my initial course was the fact that I would easily secure a teaching position upon graduation as a qualified teacher, compared to graduating with a general degree. I went on to graduate as a Chemistry and Biology teacher in the late 1980s, and was immediately offered employment as a teacher in one of the high schools in the country. I taught in several other schools, advancing in my profession and eventually became a school principal in the late 1990s. After about sixteen years of teaching, I enrolled for a Post-graduate Diploma course in Curriculum Development at my former university. Upon completion of this course, I was moved from classroom teaching, to start working at the country's national centre for curriculum development as a curriculum development specialist in charge of Chemistry education. With my strong background in the hard sciences and many years of teaching, my philosophical paradigm leaned more towards a realist worldview. However, my twelve years of working experience at the Centre for Curriculum Development, slightly impacted my initial view, shifting from an extreme realist orientation towards a more relativist ontology. My basic worldview as a science educator is that social science deals with direct experience of people in specific contexts, and it is therefore subjective. This is because participants in classroom contexts define their own social reality. Although I may regard myself as a 'modest realist' (Osborne, 1996), I accept the relativist position that constructivism can assist learners to learn better, where human behaviour cannot be said to be governed by general, universal laws that are characterised by underlying essential regularities.

The above values mirror the interpretation I bring to the data collection, interpretation and analysis in this thesis, as I constantly search for the factors that influence beginning teachers' decision making and instructional practices.

I thus felt it was important to search for such factors using a qualitative interpretivist research approach. This was the only way I would be able to obtain rich and detailed data about beginning teachers' classroom practices based on the very small sample size of my study. I acknowledge the many challenges I experienced during this study, some of which might be threats to the quality and trustworthiness of the study findings. It is therefore important for the reader to know some of the challenges faced in compiling this study. The first challenge was that I was a foreign student, thus some of the beginning teachers studied were initially not very willing to cooperate with me, especially when it came to video recording of the observed lessons. This challenge forced me to seek the help of a research assistant, who accompanied me throughout my initial data collection exercise. Despite this constraint, I consider that my research was able to investigate the retention of the GBTs' acquired TSPCK, and the advantage derived from the early exposure to explicit TSPCK developed at the time of the pre-service intervention teacher training. The findings provided me with insights about the transfer of learnt pedagogical transformation competence (PTC) from a planning and reasoning context into real classroom teaching.

1.7 Structure of the thesis

My thesis is comprised of nine chapters. The first chapter is introduction to the research study and research questions. Chapter 2 discusses a review of selected literature, relevant to pedagogical content knowledge (PCK), with reference to beginning physical science teachers' transition from teacher education institutions to life in a real classroom teaching. In addition, I reviewed literature on expert teachers' classroom practice. I then acknowledge previous studies that have reported promising improvements in the development of Topic Specific PCK, after some interventions, noting the dearth of empirical studies that report on the retention of the quality of acquired TSPCK and the actual classroom practice of graduate beginning teachers from a PCK based pre-service teacher intervention programme in real classroom teaching. Chapter 3 describes the research methodology followed in this study, specifically the qualitative research approach, according to a multiple comparative case study design, outlining the research instruments used and how the

data was collected and analysed. I have also addressed issues of ethics and rigour in the same chapter. In Chapter 4, I report on the rationale, development and validation of a TSPCK classroom rubric that was used to evaluate and grade enacted TSPCK displayed in the video lessons in this study. Chapter 5 is my first chapter on the research findings of this study. The chapter reports on the analysis and findings on data that were used to confirm the acquisition of TSPCK as a direct result of the pre-service teacher intervention programmes. This is followed by analysis of the findings that were used to determine the GBTs' retention of the quality of acquired level of TSPCK in the respective topics of intervention in Chapter 6. In this chapter, qualitative data sets are quantitatively analysed and the findings compared. In Chapter 7, the findings on the analysis of data sets that were used to establish the advantage derived from the early exposure to explicit PCK development in specific topics in reasoning and planning to teach a topic are presented. Similarly, sets of qualitative data were quantitatively analysed and the finding compared. Chapter 8 reports on the findings of the possible advantage derived from the early exposure to explicit PCK development in specific topics, focusing on the nature of the quality of enacted TSPCK in real classroom teaching of the GBTs in topics of their own choice. The qualitative data sets collected from video recorded classroom lessons, pre-(post) lesson interviews and researcher's think notes were analysed and the findings triangulated. Chapter 9 summarises the thesis with discussions on the main findings with respect to the research questions asked in this study. The chapter closes with discussions, implications and recommendations of the findings for science education teacher professional programmes within the South African context, as well as the science education research community.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews a selection of literature related to the development of pedagogical content knowledge (PCK) among science teachers in general and specifically pre-service and beginning teachers. It reviews literature on the pedagogical transformation of content knowledge through the five content components of topic-specific PCK (TSPCK). Thereafter it isolates the generic competence that is transferable for the development of PCK in new topics as pedagogical transformation competence (PTC). The chapter closes by proposing a theoretical framework that translates planned TSPCK from a planning and thinking context into real classroom practice.

2.1 Introduction

The starting point of this study is the acknowledgement of Shulman's (1987) theoretical argument that the process leading to classroom teaching begins long before the act of teaching itself, starting with teachers' sound pedagogical reasoning about the content they are to teach.

Beginning teachers coming into the profession are generally expected to critically examine, reflect upon, and perfect their own practice as they continually seek to acquire new knowledge and expertise. However, the transition of newly qualified teachers from teacher education institutions to life in a real classroom practice is generally characterised as a type of unexpected reality. Often, beginning science teachers realise that the ideals they formed while training may not be appropriate for the realism they are faced with during their first years of teaching. Their view of the profession and the role they play in it is shaped by many factors, which may include handling heavy workloads, maintaining discipline, different school contexts, etc. (Helms-Lorenz, van de Grift & Maulana, 2016). These challenges are often exasperated by insufficient training.

In preparing new teachers, teacher educators tend to follow local, state, or regional standards, which may not necessarily be influenced by research (Luft et al., 2015). According to Bekalo and Welford (1999), PCK is not seriously considered and given the comparable credit and attention in teacher training programmes, required to assist pre-service teachers translate the training course programs into school-based activities. For example, in a study that examined the association between beginning teachers' pre-service education preparation and their attrition in mathematics and science subjects, Ingersol et al., (2014) found out that Mathematics and Science teachers tend to have more subject matter knowledge education and less pedagogical preparation than teachers in other subjects.

In this literature review, I acknowledge the general agreement among scholars to consider the development of PCK in teacher education (Kind, 2009). I begin this literature review with a discussion on the importance of initial teacher preparation programmes. I then underscore literature from previous research studies, regarding the experiences of expert teachers' classroom practice. I extend my discussion to findings on the nature of PCK and TSPCK among beginning science teachers' classroom teaching, with particular interest in the knowledge components that enable pedagogical transformation of content knowledge for teaching specific science topics. I build on this conception of transformation to single out the competence needed to carry out the act of pedagogical transformation for purposes of teaching across related topics among graduate beginning teachers. I then use the above conceptions to design a theoretical framework that translates planned PCK at a topic level (TSPCK) from a planning and reasoning context into real classroom teaching.

2.2 The nature of the initial Science teachers' professional preparation

Learning to teach is a developmental process during which teachers progressively refine their beliefs and practices. The process begins with pre-service education, continues through the induction years, advancing to the early and midcareer stage and culminates in expert teacher or late career phase. According Feiman-Nemser (2010) an induction programme is a phase in learning to teach, a process of

enculturation, and a formal programme, which involves learning to work within new cultural settings of school communities with colleagues. Some research studies, however, suggest that most beginning teachers do not experience induction programmes that emphasise learning to teach Science (Wang, Odell, & Schwille, 2008). Such findings point to the need for initial teacher preparation programmes that can produce beginning teachers with highly desirable teaching qualities, including PCK on arrival.

Initial teacher education preparation programmes play a crucial role in enhancing not only the teachers' understanding and skill development, but also in increasing the likelihood of them staying in the profession (Darling-Hammond, 2000). According to Darling-Hammond, Wise, and Klein (1999) teacher preparation programmes generally include the following knowledge bases for learning and shaping teachers' professional practice.

1) Knowledge about learners and learning which include; knowledge about human growth and development, motivation and behaviour, learning theories, learning differences, and cognitive psychology.
2) Knowledge about curriculum and teaching; This knowledge base comprises general and topic specific pedagogical content knowledge, curriculum theory, assessment and evaluation, counselling as well as knowledge of scientific inquiry, epistemology, communication, and language as they relate to pedagogy.
3) Knowledge about contexts and foundations of education. This is the knowledge about schools and society, cultures, educational history and philosophy, principles from sociology and anthropology, legal responsibilities of teachers and ethics (1999, pp. 35-38).

The authors contend that although the above-listed elements maybe emphasised to different extents in different pre-service teacher preparation programmes, they are common elements across most programmes.

It is argued in the literature that the ability to prepare effective science teachers is directly related to the quality of teacher education programs offered (Darling-Hammond, Chung, & Frelow, 2002). This ability, according to Arshad and Akramnaseem (2013), is determined by the quality of the courses offered by science

teacher educators. For example, in a study that examines the association between beginning teachers' pre-service teacher education preparation and their attrition in mathematics and science subjects, Ingersoll et al., (2014) found that teachers with more pedagogical preparation were less likely to leave teaching after their first year on the job. However, other studies claim that classroom practice of beginning teachers may be repressed, and need time to surface. For example, Windschitl, Thompson, and Braaten (2009) posit that, although teacher preparation programmes provide conceptual tools that assist pre-service teachers to learn about teaching, they do not solve the problem of what to do next in the classroom for beginning teachers. In a similar study with beginning secondary science teachers, different induction programmes in their first year of teaching, Luft (2009) found that the teachers appeared to struggle in considering the use of inquiry and their teaching approach tended to be characterised by few instructional approaches and subject matter representations. The authors further found out that although the teachers' PCK was strengthened as they worked with students; it was difficult to determine whether the induction programmes contributed to the changes in PCK.

Moreover, it has been observed that even those beginning teachers with high qualifications, at a degree level still find it difficult to conceptualise key ideas behind science and technology (Gess-Newsome, 1999; Loughran , Milroy, Berry, Gunstone, & Mulhall, 2008).

Researchers in teacher education argue that school-based components of initial teacher education (ITE) are often plagued with "the preoccupation with immediate issues of practical performance, rather than inquiry into or expansion of a rationale for that performance" (Mathewson-Mitchell & Reid, 2017). According to the National Academies of Sciences (2015) (NASEM), professional teacher preparation programmes are often, not designed to help teachers develop their science SMK, but tend to focus on general pedagogy. Teacher preparation programmers therefore appear to lack attention of core disciplinary aspects of student thinking (Coffey, Hammer, Levin, & Grant, 2011).

In the same vein, Kosnik and Beck (2009) argue that pre-service education programmes often model a coverage mentality of trying to touch on almost every

aspect of educational theory and practice. The authors contend that frequently, “on the one hand, because coverage of educational theory and practice is so extensive, it is necessarily superficial and so student teachers do not gain a clear grasp of what the theories and practices mean, as the breadth of coverage militates against depth of understanding” (2009, pp.3). Many education researchers (e.g. Hagger & Mclntyre, 2006) support the argument for a sharper focus in teacher preparation programmes. This is because teacher educators do not have the time to model lessons related to every core curriculum topic in which they could demonstrate best practice (Grossman., 2011).

For instance, Darling-Hammond and Bransford (2005) advocate attending to knowledge deemed essential for beginning teachers that highlights core areas such as learning development, assessment and classroom management. Other education scholars (e.g. McDonald, Kazemi, & Kavanagh, 2013; Windschitl , Thompson, Braaten, & Stroupe, 2012) propose the agreement over a set of criteria for identifying, naming, and selecting core practices and pedagogies that are limited in number; but representative of broad applicable instructional strategies that are known to foster important student engagement and learning. Lotter, Harwood, and Bonner (2007) identified a set of four core conceptions that guide the teachers’ use of inquiry-based practices in high school classrooms, viz.: the teachers’ conceptions of science; their students; effective teaching practices; and the purpose of education. For their part, Sickel and Friedrichsen (2018) advocate for programmes that are explicit about the role of content knowledge in shaping knowledge for teaching specific topics that could be potentially useful in teacher education courses.

Importantly, ‘core practices’ require deep consideration and analysis, for their articulation, re-presentation and enactment, which according to Grossman et al. (2008) provides a framework involving the use of representations, decompositions and approximations of practice. Similar to that expressed by Sickel and Friedrichsen (2018)**,** the rationale for exposing pre-service teachers to learning about such core-practices in shaping knowledge for teaching specific topics in the context of this study include mastering the competence for transformation of content knowledge by

interactively engaging the content of core science topics with the five content components of TSPCK.

In summary, it is important that initial teacher education programmes, produce the sort of accomplished teachers, who have carefully studied teaching and reflected on how and why expert teachers relate to the socio-material elements that trigger good teaching/learning process.

According to Ausubel (2012) acquisition and retention of knowledge lies in the formal instructional practices of schooling. As pointed out by Mathewson-Mitchell and Reid (2017) beginning teachers who have had a chance of explicit coaching and critique, manifest enhanced and deepened knowledge of teaching. This study, therefore sought to find out if there is enough evidence to show a visible advantage derived from the GBTs early exposure to explicit TSPCK development in the quality of their actual teaching during the early years their teaching careers.

In the following section, I review literature on the nature and development of PCK, as teachers' professional knowledge for teaching, commencing with a brief reflection on the theoretical propositions that underpin experienced teachers' classroom practice. This is followed by discussions on the nature of PCK and how it relates to Topic Specific PCK, and an outline of the theoretical framework used in this study.

2.3 Expert teachers' classroom practice

According toVan Es and Sherin (2002), the difference between expert and novice teachers is the aspect of *noticing*, which the authors describe as the component of expert practice. Kaiser, Busse, and Hoth (2015) argue that teacher "expertise is characterised by a high degree of integration of knowledge with multiple links". The authors contend that the three situated facets linked to the concept of *noticing,* which make up a strong action-oriented point of view, are embedded in the PID-model. The model represents: (a) *perceiving* particular events in an instructional setting; (b) *interpreting* the perceived activities; and (c) *decision*-making, either as anticipating a response to students' activities and/or proposing alternative instructional strategies. According to a key assumption of the psychology of perception, activities such as perceiving, interpreting, evaluating and proposing alternatives are knowledge driven

processes (Grodin., 2016). In mathematics, Jacobs, Lamb, and Philipp (2010) argue that professional noticing includes attending to children's strategies, interpreting their understandings and deciding how to respond based on this understanding.

Van Es (2011) similarly points out that "expert teachers have heightened sensitivities to particular aspects of their work, as well as techniques for analysing and inquiring into features of their practices". The author describes this expertise as attention-dependent knowledge that includes the different skills that expert teachers use while dealing with cognitive and affective aspects of teaching, which become available to them during instruction in response to classroom activities and interactions with learners.

This context-specific knowledge that teachers activate when reflecting on their practice is what expert teachers draw upon as triggers for transformation of content knowledge for learners' understanding. According to Schön (1995), the process of reflection in-action begins when a spontaneous performance such as teaching a lesson is interrupted by surprise. The author posits that, the "surprise triggers reflection directed to both the surprising outcome and the knowing-in-action that led to the surprise" (1995, p. 30), when the teacher asks, questions such as what understandings and strategies of her/his teaching led to such an outcome. Reflection in-action therefore entails the thinking that occurs in action or stretch of time within which it is possible to make a difference to the outcomes of action. The ability to reflect on such a process displays reflection-on-action, where questions such as why the strategy employed worked or did not work, what the teacher should try next time etc., are probed.

Psychological and sociocultural understandings of teacher learning emphasises the value of 'reflective practice' in assisting new teachers as they begin to develop the 'tacit knowledge' that expert teachers gain from experience (Berliner, 2004). According to Mathewson-Mitchell and Reid (2017), this tacit practical knowledge is often difficult to make explicit because it is situated and contextualised, as it resides in the body and practice of teaching itself. In his pedagogical reasoning and action model, Shulman posits that reflection is what teachers do when they "look back at

the teaching and learning that occurred and reconstructs, re-enacts, and/or recaptures the events, the emotions, and their accomplishments" (1987, p. 17).
Many benefits have been associated with classroom reflective practice. For example, Nilsson (2008) found that engaging student teachers in projects with a focus on reflection on their teaching of Science brings about insightful shifts in their thinking and orientations towards Science teaching and learning, hence initiating PCK development prior to practice.

According to Krepf, Plöger, Scholl, and Seifert (2018), expert teachers differ significantly from novice teachers in that they activate both content knowledge (CK) and pedagogical knowledge (PK) intensively, by combining both kinds of knowledge, not in isolation but together in line with Shulman's (1987) amalgam thesis. Shulman (1987) derived the idea of transformation of content knowledge from what expert teachers do in classrooms. In Shulman's view, (1987, p. 8) this special amalgam of content and pedagogy – which is uniquely the province of teaching as a profession – constitutes PCK. Expertise in teaching is therefore associated with outstanding understanding of content knowledge as well as the nuances of knowledge for teaching a topic (Loughran., Berry., & Mulhall., 2012).

This study investigated retention of the quality of the GBTs' acquired TSPCK and their current classroom practice, as a direct result of an explicit TSPCK based intervention at the time of their pre-service teacher training programmes. Therefore, the findings from this study provide a glimpse on the opportunities that could help fast track prospective science teachers' Topic Specific PCK long before the actual act of teaching.

2.4 Nature of PCK

The concept of PCK as professional knowledge germane to teachers was introduced by Shulman, (1986). Shulman has argued that developing general pedagogical skills was insufficient for preparing content teachers as was education that stressed only content knowledge. In his view, the key to distinguishing the knowledge base for teaching resided at the intersection of content and pedagogy (Shulman, 1987, p. 15). According to Shulman (1986), teaching requires transformation of knowledge from a

variety of teacher knowledge domains. In order to articulate the knowledge enabling transformation of content knowledge, Shulman (1987) presented seven categories of professional knowledge bases as a foundation for teaching. These include: content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of the learners, knowledge of educational contexts and knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. Of these seven categories, Shulman identified Pedagogical Content Knowledge (PCK) to be of special interest because "it represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized [sic], represented and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8).

Below is a summary of descriptions of Shulman's seven categories of the teachers' professional knowledge bases.

(i) Content knowledge

According to Shulman, content knowledge refers to the amount and organisation of knowledge per se in the mind of the teacher (Shulman, 1986,). In his description of Content Knowledge (CK), Shulman refers to "going beyond knowledge of the facts or concepts of a domain and requiring understanding of the structures of the subject matter" (Shulman, 1986, p. 9). However, when describing the categories of knowledge needed by a teacher, Shulman separates each of the categories and discusses them as stand-alone categories. In this set of categories, content knowledge is used as an entity equivalent to subject matter knowledge only. SMK is generally agreed to be an overarching term, comprising a number of components, each of which influences teaching. Abell (2007) notes that Shulman's view of SMK was derived from Schwab (1964), who identified two types of SMK, viz. substantive and syntactic. Substantive knowledge includes the organisation of concepts, facts, principles, and theories, while syntactic knowledge is the rules of evidence and proof used in making claims about new knowledge in the subject. Shulman and co-workers added two more components, by suggesting that content knowledge

represents understanding the facts and concepts of the science discipline(s) that teachers teach and the big ideas (Grossman, Wilson, & Shulman, 1989).
Later workers such as Cochran and Jones (1998, p. 708) adopted a similar four-component structure, where they list content knowledge (facts and concepts), substantive knowledge (explanatory structures or paradigms), syntactic knowledge (methods and processes by which new knowledge is generated) and beliefs about the subject matter. In this regard, both the quality of the connections and the structure of those connections are important aspects of SMK (Nixon., Hill., & Luft, 2016).

(ii) General pedagogical knowledge

General pedagogical knowledge is defined as the "broad principles and strategies of classroom management and organization that appear to transcend subject matter" and is applicable across the grades (Shulman, 1986, p. 92). According to Shulman, such knowledge includes ways of maintaining appropriate classroom discipline, using class time efficiently, and communicating instructions/expectations clearly.

(iii) Curriculum knowledge

Shulman (1986) maintains that curriculum knowledge and its associated materials provide the "pharmacopoeia from which the teacher draws those tools of teaching that present or exemplify particular content and remediate or evaluate the adequacy of student accomplishments" (p. 10). It represents the full range of programmes designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programmes. Shulman adds that teachers should possess both the vertical understanding of the curriculum of their discipline, as well as lateral curriculum. He identifies vertical curriculum knowledge as familiarity with the topics and issues that have been and will be taught in the same subject area during the preceding and later years in school, and the materials that embody them. Lateral curriculum on the other hand embodies understanding of what is taught in other disciplines for a particular grade level in a given year, and it underlies the teacher's ability to relate the content of a given

course or lesson to topics, or issues being discussed simultaneously in other classes.

((iv) Pedagogical content knowledge (PCK)

Shulman (1986) describes pedagogical content knowledge (PCK) as “subject matter knowledge for teaching” (p. 203). He defines PCK as the “blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized [sic], represented, and adapted to the diverse interests and abilities of learners and presented for instruction” (Shulman, 1987, p. 8). The author argues that knowledge of subject matter alone does not make one a teacher. He goes on to describe PCK as the kind of knowledge that goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching (Shulman, 1986, p. 9). According to Shulman, PCK represents a transformation of all the knowledge needed to be a teacher, including subject matter, pedagogical and contextual knowledge into a unique form of knowledge that impacts teaching practice (Shulman, 1987, p. 98).

Pedagogical content knowledge (PCK) is therefore an idea rooted in the belief that teaching requires considerably more than delivering subject matter knowledge to students, and that student learning is considerably more than absorbing information for later accurate regurgitation. It is the knowledge that teachers develop over time, and through experience, about how to teach particular content in particular ways in order to lead to enhanced student understanding. Loughran et al. (2012) point out that PCK involves a particular expertise with individual idiosyncrasies and important differences that are influenced by the teaching context, content, and experience, but remains the corner stone of teachers’ professional knowledge and expertise’ (p. 7).

(v) Knowledge of the learners

This category of knowledge enables a teacher to relate his/her teaching to the prior knowledge of the learners, formulate representations that link with their interests, and possess an understanding of their diverse abilities and ways of learning. Teachers

require a strong knowledge base of learners in science, without which learning may not be attained. According to Novak (2011), teachers are ideally also learners and they "negotiate meanings" with their students. In Ausubel's (1968) words, the most important single factor that influences learning is what the learner already knows, which according to the author, teachers must first ascertain and then teach accordingly.

(vi) Knowledge of educational contexts

Shulman (1987) suggests that educational contexts range from "the workings of the group or classroom, the governance and financing of school districts, to the character and communities of culture" (p. 93). This knowledge base explores the relationship between schooling and a better environment for learning.

(vii) Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds

According to Shulman (1986), this knowledge base draws on the values and purposes of education that communities may have. It also acknowledges the effect of the historical background of the school or learning (p.14).

Among the seven categories of teacher professional knowledge bases used for teaching stated above, pedagogical content knowledge (PCK) is of special interest to this study, because it identifies the distinctive bodies of knowledge for teaching (Shulman 1986, p. 8). While researchers have differed in their characterisation of the relationship between the various sub-domains of the teacher knowledge bases identified by Shulman above, the four commonalities that have consistently appeared include: pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context.

Figure 2.1 shows the modified form of Grossman (1990) model that illustrates an overview of the four commonalities, which is richly contextualised in practice from which further attempts to represent all domains of teacher knowledge are embedded.

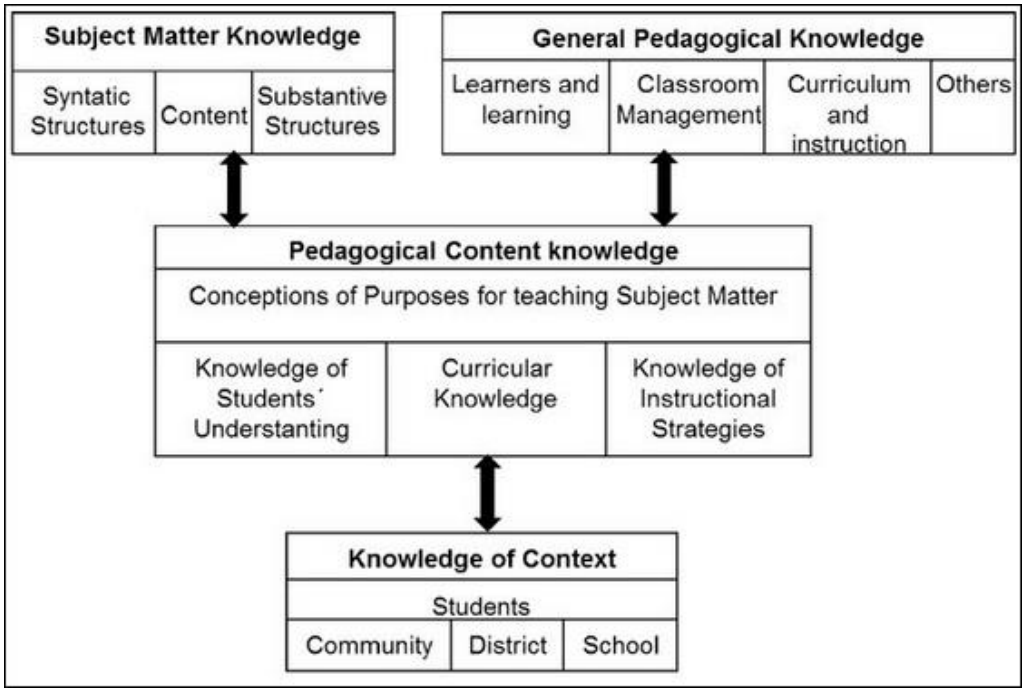


Figure 2.1: Model of teacher knowledge (Grossman 1990)

The preceding discussion has attempted to demonstrate that there is no universally accepted conceptualisation of PCK. Therefore, between scholars, differences occur with respect to the elements they include or integrate in PCK, and the specific labels or descriptions of these elements. All scholars, however, agree on Shulman's two key elements that are central to PCK, that is: knowledge of representations of subject matter, and understanding of specific learning difficulties and student (mis)conceptions. In addition, there appears to be agreement regarding the nature of PCK among different scholars as at first, referring to particular topics it is to be discerned from knowledge of pedagogy of educational purposes, and learner characteristics in the general sense. Secondly, because PCK concerns the teaching of particular topics, it may turn out to differ considerably from subject matter knowledge per se. Finally, PCK is developed through an integrative process rooted in classroom practice, through experience over time (Loughran. et al., 2012). This implies that beginning teachers usually have little or no PCK at their disposal. In the

following section, I highlight the main sources of knowledge that describes good teaching.

2.5 The knowledge needed for preparation of Science teachers

According to Shulman,(1987), the four major knowledge sources for teaching that defines, describes and reproduces good teaching include: *scholarship in content disciplines, educational materials and structures, formal educational scholarships,* and *wisdom of practice*. A brief elaboration of each knowledge source is provided below.

i. Scholarship in content disciplines: Shulman deconstructs this knowledge source into content knowledge, which comprises the knowledge, understanding, skill and disposition that are to be learned by school children.
ii. The second source of knowledge for teaching is the materials and settings of the institutionalised educational process that comprises: curriculum, textbooks, school organisations and finance, the structure of the teaching profession, research on schooling, social organisations, human learning, teaching and development, and the other social and cultural phenomena that affect what teachers can do.
iii. The third source of knowledge for teaching is formal educational scholarship, which Shulman identifies as the growing body of scholarly knowledge that is not only part of empirical research findings on teaching and learning, but what enriches teachers' images of what is possible for teachers, their visions of what constitutes good education, or what a well-educated youngster might look like if provided with appropriate opportunities and stimulation, in a word what good education constitutes.
iv. The final source of knowledge for teaching is the wisdom of practice, which, according to Shulman, although the least codified of the four sources, guides or provides reflective rationalisation for practices of able teachers. Shulman argues that one of the most important tasks of the research community is to work with practitioners and develop codified representations of the practical pedagogical wisdom of able teachers, by collecting, examining, and beginning to codify the emerging wisdom of practice among experienced teachers. This,

> according to Ethel and McMeniman (2000), involves unlocking the knowledge in action of expert practitioners. In the words of Warde (2004) any established practice is a collective and historic achievement, developed over time by groups of practitioners who are engaged in that practice. The author contends that generally, as an integrated practice begins to diffuse, institutions emerge to make it more widely known, to teach novices, to improve performance, to promote and legitimate it, and its virtues (Warde, 2004, p. 4).

Shulman's argument about the major knowledge sources for teaching foregrounds the realisation for understanding and thinking about identifying distinctive bodies of knowledge components needed to improve classroom teaching of beginning science teachers, which is central to this study. In the section below, I briefly discuss beginning teachers' PCK classroom practice.

2.6 PCK and Beginning teachers' classroom practice

As alluded to above, PCK among beginning teachers is said to be generally slow and incremental. It is related to time required for the teachers to plan, gather resources, teach, reflect and re-teach specific topics with increased effectiveness and fluency (Clermont, Borko, and Krajcik 1994). Many studies allude to the importance of classroom experience in the development of PCK (e.g. Geddis, Onslow, & Oesch, 1993; Nilsson, 2008). For instance, Park & Oliver (2008) argue that the most powerful changes in a teacher's knowledge result from experiences in practice.

In science education, effective classroom practice has increasingly been described in terms of PCK (e.g. Bertram & Loughran, 2012; Nilsson 2014). According to Shulman, PCK is a special knowledge combination of content and pedagogy that is uniquely constructed by teachers. Shulman points out that, this is the knowledge base that provides teachers with answers to questions like, what analogies, metaphors, examples, laboratory experiments, demonstrations, simulations, that are the most effective ways to communicate the appropriate understanding or attitudes of specific topics to students with particular backgrounds (Shulman, & Sykes, 1986, p. 9). In addition, it also includes comprehension of what facilitates or hinders specific content and the conceptions and pre-conceptions that students of different

backgrounds and ages have access to learning the topics most frequently taught in the lesson. PCK is therefore important for enhancing both pre-service as well as in-service teachers' performance (Bertram & Loughran, 2012; Hume & Berry, 2010).

In line with Shulman's argument, Garritz (2013) posits that classroom preparation requires beginning teachers to structure specific topics for a particular group of students, as well as to think of reasons for and ways of teaching it, and may include: thinking of teaching objectives; knowledge of students alternative conceptions of topic difficulties; appropriate scope and sequencing of topics; correct use of analogies and examples; ways of addressing the central or big ideas in the topic, experiments, projects and problems. The teachers are also required to think about ingenious ways of evaluating students' progress and understanding. According to the author, thinking along these aspects, completes class preparation. The understanding of which topics are more crucial and which ones are tangential thus helps teachers to decide how deep a topic should be covered and what further preparations are required (Davis, Petish, & Smithey, 2006). More recently, effective classroom practice has been described on the basis of teachers professional knowledge (PCK) of teaching topic-specific content (Gess-Newsome, 2015; Daehler, Heller and Wong, 2015), as well as using a refined version of PCK to describe the competencies of pedagogical transformation of content knowledge topic by topic (Mavhunga & Rollnick, 2013).

For example, in a study that compared three kinds of induction programmes for science teachers, Luft et al. (2011) found out that an induction programme with a direct link to a science topic had more impact in supporting PCK development of beginning teachers.

2.7 Planned and enacted PCK

According to Shulman (1987) the process leading to classroom teaching begins long before the actual act of teaching, starting with teachers' sound pedagogical reasoning about the content they are to teach. The author argues that PCK involves teachers' actions "from being able to comprehend subject matter for themselves, to

becoming able to expose subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be understood by students" (Shulman, 1987, p. 13). The above descriptions imply that PCK must be understood and explored at two levels: (i) planned PCK; and (ii) enacted PCK. The knowledge to be taught and the knowledge actually taught undergo complex transformation processes at various stages of selection and teaching. This fundamentally distinguishes this knowledge from its origins in academic knowledge, as what is eventually observed in the actual classroom practice is a product of the transformation process that takes place at the planning stage. According to Park and Oliver, (2008) teachers' PCK in the planning context is called Planned or espoused PCK, and is comprised of an amalgam of science teachers' knowledge of subject matter and their understanding of pedagogical strategies necessary to make a specific science topic comprehensible to their students. Similarly, beginning teachers' PCK learned in a specific core science topic during the planning and reasoning context at the time of the pre-service programme is referred to here as TSPCK. Planned TSPCK is therefore linked to reasoning about teaching, and can be used to guide science teachers in making instructional decisions regarding the use of particular reinforcement materials and instructional strategies and assessment modes, while providing for student learning (Park & Oliver, 2008). Beginning teachers must therefore be in a position to ascertain what their students know about a topic and areas of likely difficulty to employ PCK effectively. This means that beginning teachers have to understand the knowledge of learners' conceptions and misconceptions of particular topics, their learning difficulties, motivation and diversity in their abilities, learning styles, interests, developmental level, and language proficiency (Park & Oliver, 2008).

Teachers' knowledge of planned PCK, and by extension planned TSPCK, does not however, necessarily mean that they will practice that knowledge in their teaching of science (Aydeniz and Kirbulut, 2011). It is only when such knowledge becomes enacted in the teachers' actual classroom, that it is called enacted PCK, or enacted TSPCK, when it is considered within a topic. PCK is therefore not limited to only that which teachers know, but it is embedded in "what a teacher does, and the reasons for the types of actions they take in relation to teaching a specific topic" (Baxter &

Lederman, 1999, p. 158). This may imply that while planned PCK can help science teachers to design a lesson that reflects best practice, enacted PCK; and by extension, TSPCK is responsive to the students' learning needs as they present themselves during teaching. As described by Nilsson and Loughran (2012), PCK is a widely accepted and unique form of teacher knowledge that expands on constant basis as teachers plan, carry out, and reflect upon their science teaching and learning.

Given the above discussion, studies reporting on a glimpse of success in the development of PCK of science pre-service teachers while under training in a pre-service programme were taken to be of interest, as they maybe a springboard for a new breed of graduate beginning teachers who are enabled enough to deliver quality science lessons on arrival. Several studies have reported success in this context. For example, Bertram and Loughran (2012) applied content representations (CoRes) as a learning tool with pre-service science teachers and found that participating teachers developed rich understanding of their professional knowledge, student learning and content of science teaching. Similar studies (e.g.Hume & Berry, 2010; Nilsson & Loughran, 2012) have established that with appropriate and timely scaffolding, the (CoRe) based methodology to teaching has the potential of promoting PCK development among beginning teachers.

A study byMavhunga and Rollnick, (2013) targeting Topic Specific PCK shows a slightly different version of PCK exclusively focusing on a topic at a time. In their study, the authors explored the strategies that would enhance the quality PCK within the topic of chemical equilibrium among physical science pre-service teachers. The researchers found that the quality of Topic-Specific PCK as a theoretical construct located within a topic may be improved significantly through explicit discussions of a set of five content-specific components of TSPCK. After Geddis and Wood (1997) the authors identify the specific content components of TSPCK to be: (i) students' prior knowledge; (ii) what the most important concepts in the topic are, their sequence and knowledge being needed prior to teaching the topic referred to as 'curricular saliency'; (iii) what makes the topic easy or difficult to understand; (iv) representations; and (v) effective conceptual teaching strategies.

However, none of the studies mentioned above have conducted follow-up studies to track the retention of a GBTs' acquired competence in pedagogically transforming content knowledge (PTC) from a planning and reasoning context across related topics in actual classroom practice.

This created a gap in the PCK literature, which this study sought to explore. Furthermore, this study was of interest in the context of South Africa, particularly considering the critical challenge of poor content knowledge among practicing science teachers, and the lack of nationally coordinated induction programmes for beginning teachers, as mentioned earlier.

In the following sub-section I briefly highlight the link between Topic Specific PCK and PCK.

2.8 How PCK is related to TSPCK

Research studies on PCK indicate that teaching may require a specialised form of pure subject matter knowledge (Ball & Bass, 2000; Ball, Thames, & Phelps, 2008). According to Ball and Forzani (2011), teaching is 'unnatural' work that involves specialised expertise and knowledge, and thus demands particular skills, along with the capacity to take these skills apart so that others can learn them.

In Mathematics, Ball and her colleagues have termed this special expertise Specialised Content Knowledge (SCK). In Science education, this understanding is linked to Geddis and Wood's (1997) idea of creating a pedagogical encounter of interactions, among the components of PCK. Both authors in Mathematics and Science agree that teaching may require a set of knowledge components considered collectively to enable pedagogical transformation of content knowledge for teaching. The science education community is, however, yet to agree on what constitutes knowledge for teaching science (Luft, Hill, Nixon and Dubois, 2015).

For example, Kind and Osborn (2017) argue that learning science requires the development of not just content knowledge, but in addition, procedural and epistemic knowledge. The authors contend that scientific reasoning lacks a coherent account of these three critical aspects in science education.

Nonetheless, Geddis & Wood (1997) argue that as a consequence of focusing on teaching as transformation of subject matter knowledge (SMK), a variety of different kinds of knowledge from which subject matter transformation emerge, are able to be observed (p.612). These different kinds of knowledge comprise the five content specific knowledge components mentioned in 2.6 above. While Geddis and Wood (1997) did not give an overall term for these different kinds of content specific components, I argue that it is important that these components that bring out the topic specific nature of PCK be identified empirically in a way that extends the work of Mavhunga and Rollnick, (2013). Once supporting evidence is brought to the table, such content-specific components ought to be regarded as knowledge needed to teach science topics.

In the discussion below, I explore supporting evidence in the literature regarding the components of TSPCK as a set of knowledge that science educators might explicitly reveal to pre-service teachers as that knowledge needed whenever a science topic is to be taught. This study becomes important as it provides empirical evidence for modelling the implementation of Topic-specific PCK as a version of PCK at a topic level, and also extends what is known about the interactive nature of the components of TSPCK in planning (Mavhunga, 2015b) to understanding the interactions importantly in actual classroom practice. It was also of interest to observe whether – as for PCK – the extent of the interactions of the components of TSPCK in practice reflects sophistication in the quality of teaching.

2.9 Pedagogical components considered to reveal the topic-specific nature of PCK

As alluded to above, Ball and her colleagues (Ball & Bass, 2000; Ball et al., 2008) spearheaded the notion of knowledge for teaching mathematics through a collection of empirical studies. What surfaces from Ball and colleagues' argument is evidence that teaching may require a specialised form of pure subject matter knowledge. The authors go further to identify the concept of insightful understanding, and deliberate on the skills that mathematics knowledge may entail, for example: error analysis; mathematical reasoning; choice of strategic examples; and teacher understanding of the distinction between mathematical jargon and the ordinary language from which it

may borrow. For example, teachers need to recognise the advantages and disadvantages of using rectangles or circles to compare fractions, and how to explain and justify one's mathematical ideas, such as why one ought to invert and multiply so as to divide fractions. The common students' conceptions and misconceptions about mathematical content, mathematical knowledge of the design of instruction, about sequencing particular content for instruction, choosing examples that take students deeper into the content, as well as the awareness a teacher possesses of how mathematical topics are related over the mathematics included in the curriculum. All of these are examples of the ways in which teachers work to unpack mathematics knowledge. Ball and colleagues have called this collection of components Specialised Content Knowledge (SCK).

The same vision of SCK in mathematics mirrors the TSPCK construct in science education that was exposed to the beginning science teachers who participated in this study. The two constructs speak to an understanding and unpacking of specific content knowledge needed only for the purposes of teaching.

In Science education, for example, Ayidin, Friendrichsen, Boz, and Hanucin (2014), conducted a study to determine how the teaching of two experienced teachers teaching the topics of electrochemistry and nuclear reactions influenced their PCK in either a topic or discipline-specific way, based on the PCK model presented by Magnusson, Krajcik, and Borko (1999).

Their findings revealed that teachers' knowledge of: (i) instructional strategies; (ii) learners; and (iii) curriculum were topic-specific, whereas their knowledge of assessment, instructional sequence, and orientations were not topic-specific. The similarity of the knowledge components identified as topic specific with some of those suggested in the studies on TSPCK (Geddis & Wood, 1997: Mavhunga & Rollnick, 2013) is noted. In a related study on the PCK development of four experienced Science teachers in their first-time teaching of a new Biology topic in light of a curriculum change, Chan and Yung (2015) found that the teachers' knowledge of representations and teaching strategies as components played an important role in the development of the teachers PCK on site.

In another study that investigated the integration among PCK components for two different biology topics of photosynthesis and heredity, Park and Chen (2012) used their PCK pentagon model to determine that the PCK components of knowledge of learners and knowledge of instructional strategies had the strongest interactions and were more explicit in the teachers' PCK for both topics. On the contrary, knowledge of curriculum, and orientation towards science had little influence on teachers' practice. A sequel study on chemistry topics using the PCK pentagon model conducted by (Ayidin & Boz, 2013) observed the interaction of the PCK components for two experienced chemistry teachers' teaching of electrochemical cells and redox reactions, confirming the observations by Park and Chen (2012) elsewhere that the PCK components of knowledge of learner and knowledge of instructional strategies played a more prominent role in the PCK of the teachers in both topics.

The realisation that the topic-specific nature of PCK emerges from components that are content-specific is common across the studies mentioned above. This understanding point to the emergence of content-specific components for the development of PCK in a given topic, similar to the TSPCK construct.

The above findings provide empirical evidence for the idea that PCK is experienced at different levels, as argued in the PCK taxonomies models (Nezvalová, 2011; Veal & Makinster, 1999). The findings bring to light the proposition of taxonomies of PCK which point to the kind of knowledge components associated with its topic specificity, a version of PCK, located at the topic level of teacher knowledge. For instance, in the model forwarded by Veal and MaKinster (1999) shown in Figure 2.2 below, the general taxonomy of PCK shows the specificity of PCK levels, which demonstrates that science teachers develop PCK hierarchically.

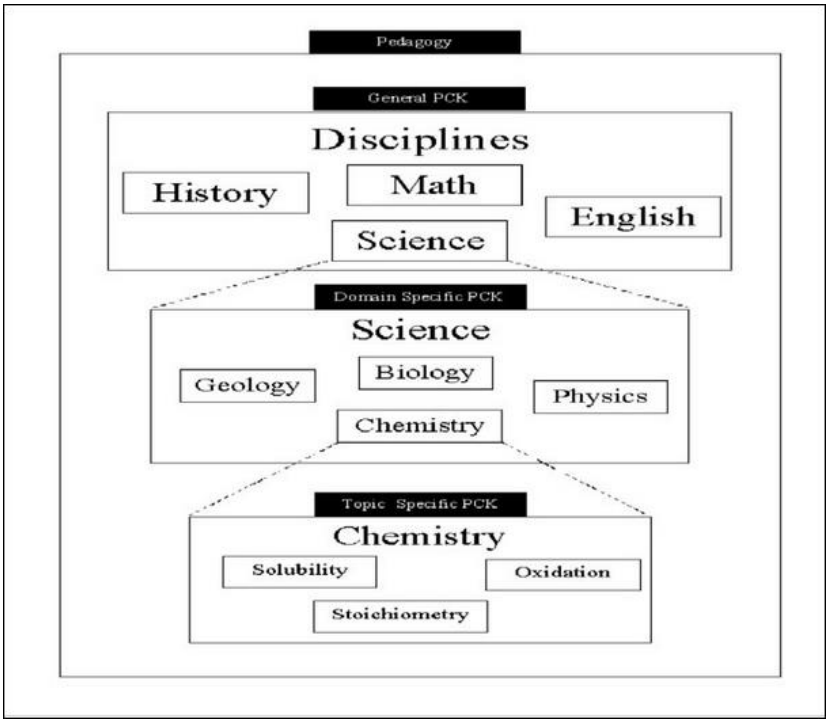


Figure 2.2: General taxonomy of PCK proposed by Veal and MaKinster (1999)

In the model, pedagogy exits outside of the general taxonomy, which means pedagogy is independent from the content areas. In the taxonomy, general PCK is placed between pedagogy and domain-specific PCK in terms of specificity. At this level, the focus is on enactment of pedagogical knowledge for specific disciplines such as science, history or mathematics. The implication here is that teachers from different disciplines may use the same orientations in their classroom practice. However, the reasons as to why and how they use them may differ. Domain-specific PCK is related to different domains under specific disciplines, such as Chemistry or Physics. Finally, topic-specific PCK is for different topics under a specific domain, for example, chemical equilibrium, radio activity etc. in Chemistry. Content knowledge might thus be general, domain-specific or topic specific. According to the authors, the latter, is the most specific and novel level of the general taxonomy of PCK (p. 9).

The notion of teacher knowledge has thus formed the basis of an evolving theoretical model that can be used to explain the nature of teachers' knowledge of teaching topic content (Jüttner, Boone, Park, & Neuhaus, 2013; Mavhunga & Rollnick, 2013; Park & Oliver, 2008)**.**

Flowing from the empirical studies described above, the common components that reveal the topic-specific nature of PCK speak to transformation of subject matter knowledge in specific topics. These are the components that frequently interact with each other for teaching purposes. This in my view discloses a construct that recognises the topic specificity of PCK. According to Shulman, (1987, p. 16) "comprehended ideas must be transformed in some manner if they are to be taught". Based on this notion, the TSPCK model forwarded by Mavhunga (2012) after Geddis and Wood (1997), which is drawn from a teacher's ability to transform content knowledge of a specific topic into teachable forms (Figure 2.3) considers that content knowledge is transformed through the five content specific components of TSPCK.

Following below is a brief description of the five content specific components of TSPCK.

(i) The first component is students' prior knowledge. This component comprises learners' preconceptions, misconceptions and alternative conceptions about a topic. With an understanding of the prior knowledge of a class of learners, the teacher can select specific instructional approaches, which ensures that learners examine and share knowledge that will support their learning and provide opportunities for them to confront and modify their existing knowledge.

(ii) The second component of curricular saliency defines the most important concepts in the topic, concept sequence and knowledge. This component refers to the learning of the various topics relative to the curriculum as a whole. It describes the understanding of which topics are the most central and which are more peripheral. According to Rollnick et al. (2008) curricular saliency "refers to the teacher's understanding of the place of a topic in the curriculum and the purpose(s) for teaching it" (p. 1367). As such, this understanding enables teachers to judge the depth to which a topic should be covered and hence the amount of time to spend on it (Geddis & Wood, 1997; Shulman, 1987).

(iii) The third component is what makes a topic difficult to understand. This component incorporates possible difficulties with each Big Idea of a topic or

known points of confusion. It does not, however, necessarily refer to misconceptions, but aspects of concepts that maybe difficult to understand because they are either an exception to a general rule or seem to contradict a particular convention.

(iv) The forth component refers to a range of subject matter representations that include: examples, illustrations, analogies, metaphors, models, and simulations, etc. in teaching a specific topic/concept. Physical science teachers in particular make extensive use of a variety of representations to explain their subject matter knowledge, at macroscopic, sub-microscopic, and symbolic levels.

(v) The final component is conceptual teaching strategies. This component constitutes pulling all the thoughts from the other four components and providing a description of how a lesson would unfold sequentially. For example, it may encompass the use of effective instructional strategies for misconceptions, known areas of difficulty, or the known importance of concepts. It also refers to the use of a combination of conceptual principles and rules of a topic as tools to confront potential misconceptions. The component does not however refer to general pedagogical strategies.

The synergistic interactions of these five content components demonstrate the quality of PCK in a given topic (Park & Chen 2012). Mavhunga and Rollnick (2013) have called these components content-specific due to their orientation to subject matter knowledge, (SMK) requiring specific considerations to be made about SMK. The link between the broader PCK and TSPCK in the TSPCK model forwarded by Mavhunga (2012) (see Figure 2.3 below) is through the content knowledge domain, which is one of the four generic knowledge domains suggested by Cochran, DeRuiter, and King (1993) to influence the development of the broader PCK. The possible influence of the knowledge bases of students and pedagogical knowledge is acknowledged through their correspondence with two of the content specific components of students' prior knowledge and conceptual teaching strategies, respectively.

The four knowledge domains are influenced by the teachers' beliefs about teaching science (Davidowitz & Rollnick, 2011).

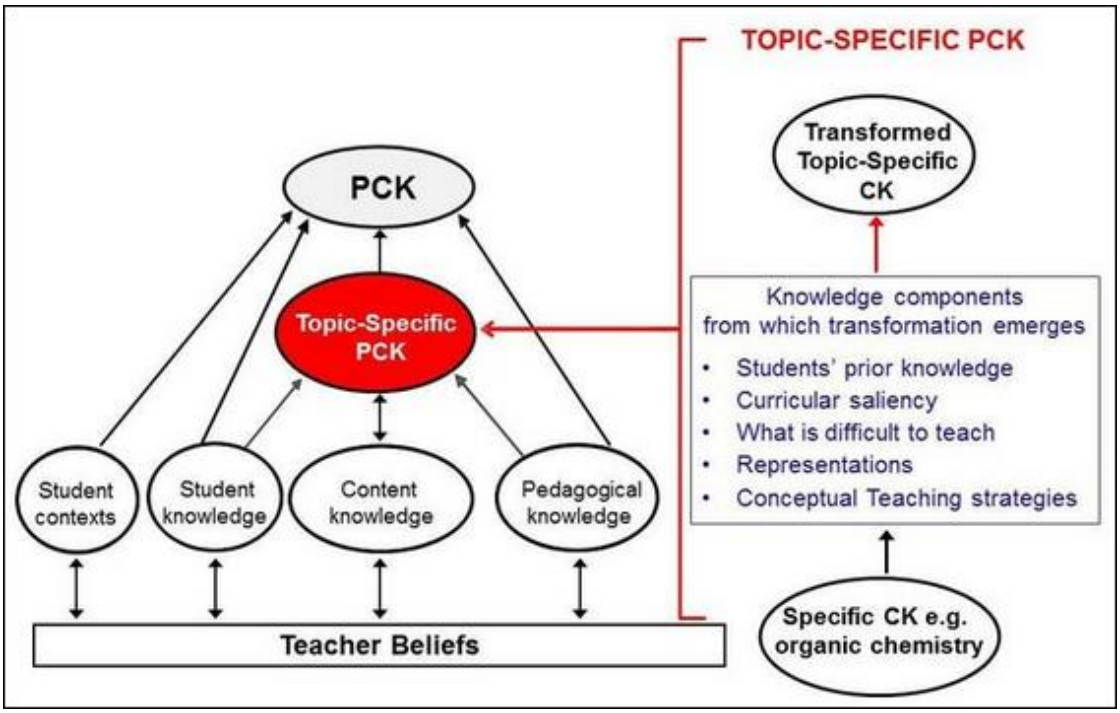


Figure 2.3: TSPCK Model by Mavhunga (2012

The topic-specific perspective on PCK differentiates the TSPCK construct from the broader considerations for PCK at a subject or domain level, as suggested in the PCK taxonomies (Nezvalová, 2011; Veal & Makinster, 1999). The TSPCK model focuses on topic specificity of PCK. The quality of PCK is thus influenced by both the knowledge of the five content components and their interactive use in bringing forth the understanding of a specific concept or pair of related concepts. For instance, when a particular element of SMK is thought about and reasoned through these content-specific components, understanding for teaching is generated that is specific to that topic. This implies that core concepts within a topic are transformed to a version that is suitable for understanding by learners (SMK'). This process of thinking about concepts topic-by-topic is considered to transform that specific topic, and therefore constitutes topic-specific PCK (TSPCK). TSPCK is therefore defined as the knowledge of the teacher that enables transformation of comprehended content knowledge, but which is limited to a specific topic. The model is therefore based on the assumption that content knowledge is a necessary pre-requisite for

development of PCK and by inference TSPCK (Rollnick, et al., 2008; Halim and Meerah, 2002).

Parallel to the TSPCK model is the consensus Teacher Professional Knowledge and Skill (TPK & S) model forwarded by (Gess-Newsome, 2015).

The TPK & S model (Figure 2.4) which was developed by a worldwide group of PCK researchers as a way of reaching some level of agreement regarding various conceptualisations of PCK, similarly reveals the understanding of the topic specific nature of PCK.

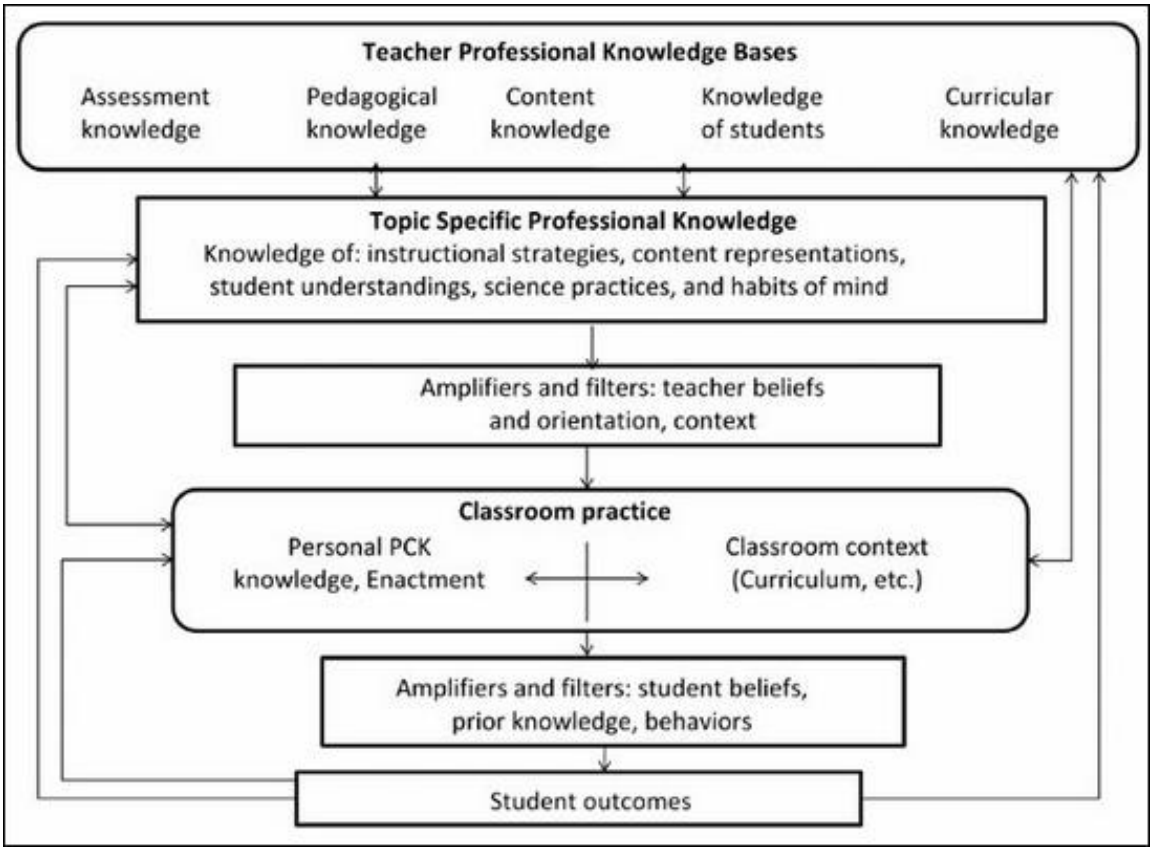


Figure 2.4: Model of teacher professional knowledge and skill including PCK (Gess-Newsome, 2015).

The model foregrounds two knowledge bases: the first is the generic knowledge bases for teaching (Shulman, 1986-87) labelled Teacher Professional Knowledge Bases (TPKB). The TPKB comprises: assessment knowledge; pedagogical knowledge; content knowledge; knowledge of students; and curricular knowledge.

The second knowledge base is the “Topic Specific Professional Knowledge base” (TSPK), which comprises knowledge of instructional strategies, content representations, student understandings, science practices, and habits of mind” (Gess-Newsome, 2015, p.31).

In this model, Knowledge from the (TPKB) informs and is informed by Topic Specific Professional Knowledge (TSPK). The TSPK separates the teacher knowledge needed for teaching specific topics from the broader teacher professional knowledge bases, by indicating the connection between teacher knowledge for teaching as a profession, actual classroom teaching, and the student outcomes. The model therefore refines the understanding of PCK to refer mainly to PCK within a topic with components similar to those of the TSPCK theoretical framework guiding this study.

The consensus model Figure 2.4, is thus aligned to the Mavhunga TSPCK model depicted in Figure 2.3, which speaks to the topic-specificity of PCK. The two topic-specific knowledge bases, which have been equated in this study, make explicit that:

- the content for teaching occurs at a topic level and not at a discipline level;
- the knowledge blends subject matter, pedagogy and context; and
- It is recognised as public knowledge or knowledge held by the profession, allowing it to assume a nomadic role.

TSPK, and by equation TSPCK is thus construed as canonical knowledge, generated by research and best practice, and can have a normative function in terms of what teachers know about a topic.

In the proposed framework, TSPK is then linked to classroom practice through a series of teachers’ filters and amplifiers that include teachers’ orientations, beliefs, and context. The teachers’ filters and amplifiers are in turn linked to a second set of students’ contextual filters and amplifiers that include: students’ prior knowledge, beliefs and behaviours, etc. Both the teachers’ and students’ filters and amplifiers act as the ‘lenses’ that mediate transformation of content knowledge from a planning context into actual enacted TSPCK classroom practice, and hence impact what occurs in actual classroom teaching.

In the Refined Consensus model (RCM) of PCK, which was published towards the end of this study, the position of topic-specificity is found within the three realms of PCK, namely ePCK, pPCK, and ePCK. In the RCM model, the general Teacher

Professional Knowledge Bases can be equated to that of collective PCK (cPCK), which is shared professional understanding about PCK. The developed personal (pPCK), in specific topics or planned Topic Specific PCK is then enacted in real teaching as (ePCK), or enacted TSPCK, permissible through a layer of individual teacher's personal beliefs, context and other affective factors that act as filters and enhances for the transfer of the developed personal (pPCK) across different physical science topics. The three constructs then feed back into one another, accounting for teacher/student interactions in the co-construction of teaching and learning experiences.

2.10 The link between TSPCK and pedagogical transformation competence (PTC)

PCK developed in a planning context through the topic-specific model is exclusively located in the topic and not transferable to other topics (Ayidin et al., 2014). This accounts for the use of the term Topic-specific PCK; that is, to distinguish the situationality of the acquired PCK whilst avoiding tautology (Mavhunga, 2016). It is important at this point to clarify between the understanding of the components that make PCK topic-specific and linking such knowledge to pedagogical transformation of the content for the development of Pedagogical Transformation Competence (PTC). Shulman and his colleagues noted that PCK is not limited to a representational repertoire of the subject matter to be taught. It is, rather, characterised by a way of thinking that allows teachers to transform their subject matter knowledge into forms that students can understand. This way of thinking was labelled 'pedagogical reasoning' (Wilson et al., 1987) and was presented as central to Shulman's (1987) model of teaching. Shulman's "view of pedagogical reasoning is from the point of view of the teacher, who is presented with the challenge of taking his or her already comprehended understanding and making it ready for effective instruction" (Shulman, 1987, p. 14).

Shulman ascribed six teacher actions or aspects to the process of pedagogical reasoning and action, which he indicated as being cyclic in nature, although not always in a given sequence, as shown in Figure 2.5 below.

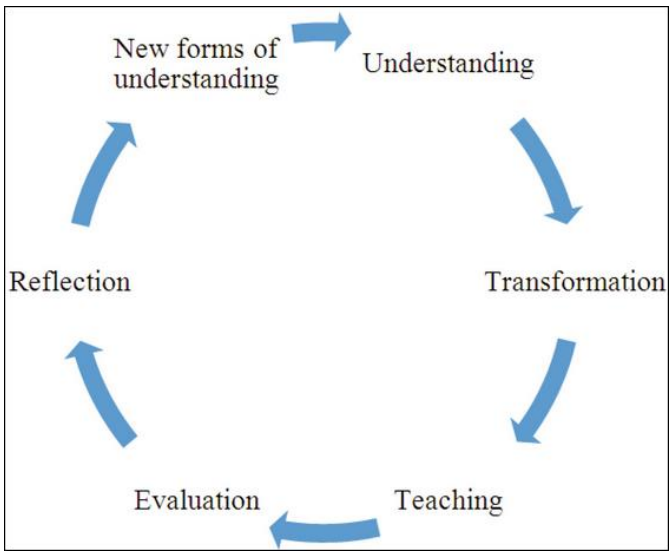


Figure 2.5: Shulman's Pedagogical reasoning and action model

These teacher activities or aspects include: *comprehension, transformation, instruction, evaluation, reflection,* and *new comprehension*. The summarised descriptions of the six categories of teacher actions below have been extracted and adapted from Smart, Sim, and Finger (2013).

i) Comprehension: Shulman noted that gaining new comprehensions was part of the process of pedagogical reasoning of purposes, subject matter, students, teaching, and self-consolidation of new understandings, and learnings from experience. This aspect is based on the idea that teachers need to understand what they are going to teach, as one cannot teach what she/he does not know.

ii) Transformation is about transforming the content or what needs to be taught into a format that will motivate the learner. Shulman suggested four processes that comprise transformation thus: preparation, representation, selection, and adaptation.

iii) Instruction is the third aspect, which refers to the act of teaching and includes the many aspects of pedagogy, such as "organizing [sic] and managing the classroom, presenting clear explanations and vivid descriptions, assigning and checking work, and interacting effectively with students through questions, probes, answers and reactions, praise and criticism" (Shulman 1987, p. 117).

iv) Evaluation occurs as teachers check for student understanding, both during and after a teaching and learning event.
v) Reflection is what teachers do when they "look back at the teaching and learning that has occurred, and reconstructs, re-enacts, and/or recaptures the events, the emotions, and the accomplishments" (Shulman 1987, p. 17); and lastly,
vi) New comprehension represents what the teachers have learnt after completing all the previous processes. It is their new understanding of what works and what doesn't work. In addition, Shulman, (1987 p. 19), specified that "pedagogical reasoning involves teacher self-evaluation directed at one's own teaching and the lessons and the materials employed in those activities, that lead directly to reflection and may involve the use of particular kinds of analytic knowledge brought to bear on one's work". This process of evaluation and reflection in pedagogical reasoning can lead to "new comprehension," which can encourage teachers to develop a new repertoire of activities for teaching.

In this study, particular interest was placed on the teacher's act of pedagogical transformation of content knowledge from a planning and reasoning context into actual classroom teaching. Pedagogical transformation, which is one of the steps within the pedagogical reasoning process, is considered to be "the essence of the act of pedagogical reasoning of teaching and starts way before the actual teaching and continues into the lesson" (Shulman, 1987, p. 16). In other words, the process of pedagogical reasoning constitutes pulling together all the five knowledge components of TSPCK in planning and reasoning about teaching a specific topic.

According to Oh and Oh (2011, p. 1124), pedagogical transformation is conceptualised as "the instructional principle in which scientific ideas are simplified and reconstructed into what can be readily accessible to and understood by students without distorting the essential features of the ideas". Thus, in Shulman's words, the key to distinguishing the knowledge base for teaching lies at the intersection of content and pedagogy in the teacher's capacity to transform content knowledge into forms that are pedagogically powerful and yet adaptive to the variety of student abilities and backgrounds (Shulman, 1987, p. 15). Hence, by engaging in the

process of pedagogical reasoning and action, beginning teachers can shift from their initial understandings of content to developing pedagogical content knowledge. As mentioned above, transformation of subject knowledge into teachable content involves some sort of a combination or ordering of the processes of preparation, representation, selection and adaptation to student characteristics as a group and for individual students (Shulman, 1987). These processes are briefly elaborated below.

a) Preparation of the given text material, includes the process of critical interpretation and analysis of the texts, structuring and segmenting. It also includes development of a curricular repertoire and clarification of purposes to ascertain whether the resources will fit the teaching and learning purpose.
b) Representation of the ideas on the other hand involves use of representational repertoire in the form of new analogies, metaphors, examples, demonstrations, explanations, and so forth. According to Glatthorn (1990), representations include the presentation of the materials using figurative language and metaphors.
c) An instructional selection includes selecting instructional resources or materials from among an array of instructional repertoire, which includes modes of teaching, organising, managing, and arranging.
d) Adaptation involves adjusting of learning materials and activities, that reflect students' characteristics and learning styles, in consideration of their conceptions, pre-conceptions, misconceptions, and difficulties, language, culture, and motivations, social class, gender, age, ability, aptitude, interests, self-concepts, and attention; and lastly
e) Tailoring the adaptations to the specific students for specific classrooms.

According to Park and Oliver (2008) "PCK can only be expressed when teachers deal with transformation of subject matter for a specific group of students in a specific classroom, and in this regard, it is closely linked to teachers' actual teaching performances and student learning" (Park and Oliver 2008, p. 813). In support of this view, Geddis and Wood (1997) argue that a focus on transformation of subject matter directs attention simultaneously towards subject matter, learners and educational purposes, as well as to the interactions among these different kinds of teacher knowledge in a pedagogical encounter. Likewise, Mavhunga and Rollnick

(2013) have demonstrated that an explicit discussion of pedagogical transformation of content knowledge as a teaching strategy in a pre-service programme leads to significant improvement in the quality of Topic Specific PCK. In this study, the competence needed to carry out the act of pedagogical transformation is singled out, for purposes of teaching among graduate beginning teachers of Physical Science. This competence, which is referred to as PTC in this study (Mavhunga, 2016), constitutes the understanding of the relevant kinds of knowledge, the components of TSPCK, and the ability to create 'interactions' that need to be drawn into a pedagogical encounter, as argued by Geddis and Wood (1997). Pedagogical Transformation Competence (PTC) is thus learnt and applied to a specific content knowledge to result in PCK for the topic of concern. This process would subsequently need to be repeated for the development of PCK in each topic.

While I acknowledge the findings on improvement in the quality of TSPCK among pre-service teachers during the intervention–based initiatives, (e.g. Mavhunga & Rollnick, 2013) and the ability to interactively use the five components of TSPCK successfully with concepts of new topics (Mavhunga, 2014), I argue that little is known of empirical studies on the transfer of the acquired PTC from a planning and reasoning context into real classroom teaching with concepts of new topics. This created the gap for this study.

This study therefore explored the ability of GBTs, who were exposed to explicit PCK development in specific topics at the time of their pre-service teacher training, to decipher their acquired PTC across new topics in real classroom teaching during the early stages of their teaching careers.

2.11 Theoretical framework

This study was grounded in the broader pedagogical content knowledge theoretical framework, by acknowledging Shulman's argument that "comprehended ideas must be transformed in some manner if they are to be taught" (1987, p.16). The framework however places a particular focus on the level of teacher knowledge located at a topic level of the PCK taxonomies (Nezvalová, 2011; Veal & Makinster, 1999). The theoretical framework for this study is therefore drawn from selective

aspects of the Mavhunga (2012), TSPCK model, and the consensus Teacher Professional Knowledge and Skill (TPK & S) model in Gess-Newsome (2015).

In the discussion that follows, I explain the resulting theoretical framework, emphasising the links between and across the two models. As alluded to above, the Mavhunga (2012) TSPCK model drawn from a teacher's ability to transform the content knowledge of specific topics into teachable forms, considers after Geddis and Wood (1997) that; content knowledge is transformed through the five content specific components of TSPCK.

The model therefore separates the teacher knowledge needed for teaching specific topics from the broader teacher professional knowledge bases. The topic specific nature of this model allowed me to explore the transfer of planned TSPCK, developed with specific topics, at the time of pre-service teacher training intervention into actual classroom teaching.

On the other hand, the consensus Teacher Professional Knowledge and Skill (TPK & S) model in Gess-Newsome (2015), similarly separates the teacher knowledge needed for teaching specific topics from the broader teacher professional knowledge bases, but goes further to reveal how the topic specific professional knowledge of PCK, which has been equated to TSPCK in this study, translates into real classroom practice. The TPK & S model therefore allowed for the exploration of those factors that enhance or filter the translation of the acquired pedagogical transformation competence (PTC) learnt from a planning and reasoning context, at the time of the pre-service training across physical science topics in the real classroom teaching of GBTs.

The integrated theoretical model (Figure 2.6) shows the interrelationships between the two models, depicting the translation of planned TSPCK, from a planning and reasoning context, during the pre-service intervention programme across different topics in real classroom teaching as enacted TSPCK indicated by the thick black arrow.

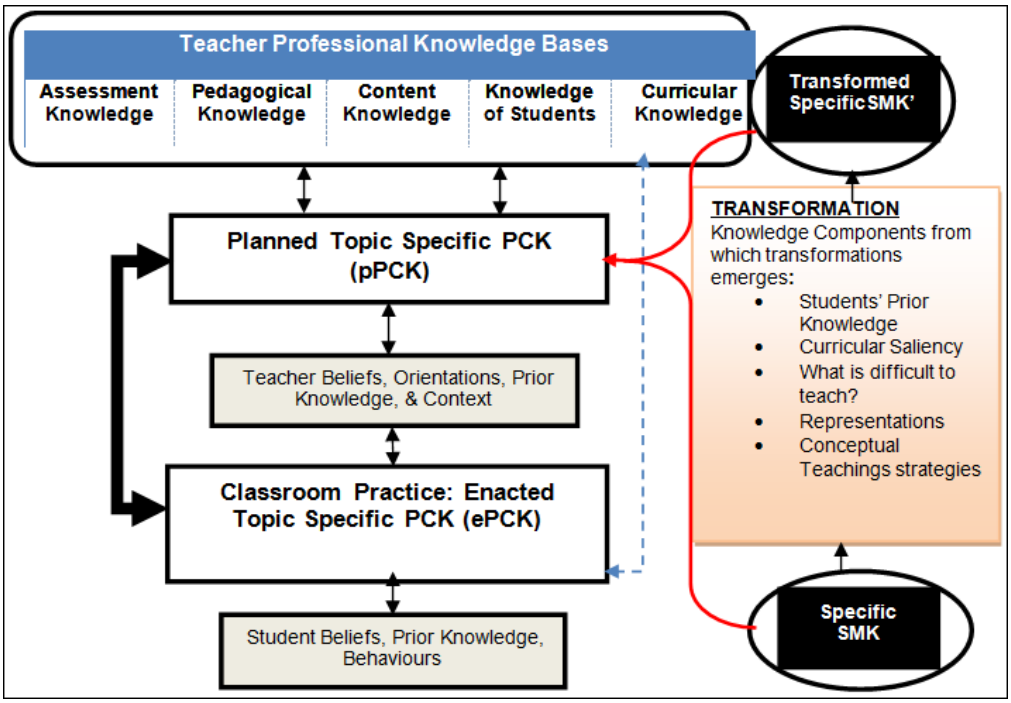


Figure 2.6: Planned TSPCK translated into classroom practice

The relationship between planned and enacted TSPCK in Figure 2.6 above is reflected in the three developmental realms of the Refined Model of PCK as collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK) (Carlson and Daehler 2018). In the framework, the GBTs early exposure to explicit TSPCK development, at the time of the pre-service intervention programme is located in the realm of collective PCK (cPCK). The acquired TSPCK developed with specific topics can be equated to personal PCK (pPCK). Finally, the enacted TSPCK by individual beginning teachers across different topics in real classroom teaching is paralleled to enacted PCK (ePCK). The dotted double-pointed arrow linking the broader TPKB and classroom practice acknowledges that generally, classroom practice can directly inform and be informed by the broader generic teacher professional knowledge bases. I have called this model 'Planned TSPCK translated into classroom practice'.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

In this chapter, I present the justification and rationale that underpins this study's research design. I begin by discussing the research methodology followed during the study. Described also are the instruments used for data collection, techniques and the procedures followed in analysing the collected data. I conclude this chapter with a reflection on issues of validity, credibility and ethics. I finally close the chapter by discussing the limitations inherent in the study.

3.0 Research Design

According to Denzin and Lincoln (2000) a research design is "a flexible set of guidelines that connect theoretical paradigms first to strategies of inquiry and second to methods of collecting empirical material" (p.22). A research design therefore situates researchers in the empirical world and connects them to specific sites, persons, groups, and bodies of relevant interpretive material, including documents and archives. Social reality can be approached in different ways and researchers must understand the philosophical worldview or paradigm on which various approaches to research are based before selecting which approach to use. Kuhn (1972) is well known for the proposition that paradigms are broad and loose sets of logically related assumptions, concepts or propositions about truth.

Therefore, underlying any research design are ontological and epistemological assumptions. Ontological assumptions are concerned with what constitutes reality, while epistemological assumptions are concerned with how knowledge can be created, acquired and communicated (Scotland, 2012). Different paradigms inherently contain differing ontological and epistemological views that lead to different assumptions of reality and knowledge, which underpin particular research approaches, as is reflected in the methodology and methods used in research. The

nature and forms of knowledge can be conceptualised along a continuum with two extreme views; the realism and relativism views (Jwan & Ong'ondo, 2011).

Realism or positivism can be regarded as a research approach rooted on the ontological principle and doctrine that truth and reality is free and independent of the viewer (Aliyu, Bello, Kasin, & Martin, 2014). This approach provides us with a clear and possible ideal of knowledge (Cohen, 2011). Positivists aim to formulate rules and regulations that govern behaviour, hence the existence of an objective truth out there to be studied that yield the basis for prediction and generalisation. The realist view, however, falls short in its application where it faces studies of complex human nature and the quality of social phenomena, like in classroom or school contexts, whose problems of teaching are internal to and dependent on the individuals' perceptions, interpretations and experiences (Jwan & Ong'ondo, 2011).

Relativists or interpretivists, also referred to as constructivist researchers, on the other hand, argue that there is no worldwide or universal truth, arguing that our realities are mediated by our senses (Aliyu et al., 2014). The interpretive epistemology is thus one of subjectivism, based on real world phenomena and the notion of the self-reflexive. Interpretivists argue that reality exits independently of those who observe it, but is only accessible through the perceptions and interpretations of individuals (Ormston, Spencer , Barnard, & Snape, 2013). In a constructivist epistemological approach, individuals' interpretations of experiences are always mediated by the researcher's interpretations (Sandelowski, 2010).

The purpose of realism in research is therefore to discover objective reality, while relativism, takes a subjective approach to reality. The two schools of thought are, however, united in their rejection of the belief that human behaviour is governed by general, universal laws and characterised by underlying regularities**.**

Social science, including science education as is the case in this study, is seen as a subjective rather than an objective undertaking, as a means of dealing with direct experience of people in specific contexts. This is because the participants themselves define their social reality.

3.1 Methodology

The purpose of this study, as described in Chapter 1, was to explore how the early exposure of GBTs to explicit PCK development in specific topics influence retention of the quality of acquired TSPCK and their actual classroom practice.

This study was situated within the interpretivist philosophical research paradigm, where a qualitative research approach was employed to determine the sampling methods, data generation techniques, analysis and interpretation of the findings. According to Merriam and Tisdell (2015), the central characteristic of qualitative research is that individuals construct reality by interacting with their social worlds. This view reflects Bourke (2014)'s description of qualitative research as a method that seeks to provide an understanding of a problem through the experiences of individuals, and the particular details of their lived experiences.

This research study was based on the above-mentioned purpose, and followed an interpretivist research approach to exploring social reality, through descriptions of the lived classroom experiences of GBTs who participated in this study.

Qualitative research is generally used as a broad umbrella term for a range of research methodologies, with differing epistemological assumptions. In relation to ontology, most qualitative research approaches operate within the relativist tradition, while quantitative research approaches operate within the realist tradition. Qualitative research is thus seen as a field in its own right, that cuts across disciplines, fields and subject matter (Denzin, 2008).

There are a variety of qualitative research designs or strategies for doing qualitative research. Merriam and Tisdell (2015) present eight of the most commonly used approaches to doing qualitative research as: basic interpretive, phenomenological, grounded theory, case study, ethnography, narrative analysis, critical and postmodernist or post-structural. These research designs have some common attributes that make them fall under the same umbrella concept of qualitative research. The designs however, each present a different focus, resulting in the

different methods and procedures followed for the type of study undertaken. According to Ormston et al. (2013, p. 4), the key elements that commonly characterises qualitative research include:

- Having aims and objectives that are directed at providing an in-depth and interpreted understanding of the social world of research participants by learning about the sense they make of their social and material circumstances, their experiences, perspectives and histories;
- The use of non-standardized [sic] methods of data generation that are sensitive to the social context of the study, which can be adapted for each participant or case to allow for the exploration of emergent issues;
- Data that are detailed, rich and complex, but varies between different studies;
- Analysis that retains complexity and nuances, and respects the uniqueness of each participant or case as well as recurrent, cross-cutting themes;
- Openness to emergent categories and theories at the analysis and interpretation stage;
- Outputs that include detailed descriptions of the phenomena being researched, grounded in the perspectives and accounts of participants; and
- A reflective approach, where the role and the perspectives of the researcher in the research process is acknowledged, and that for some researchers, reflexivity also means reporting their personal experiences of the "field".

3.2 Research strategy: A case of a comparative case study

This study was centred on determining how the early exposure of GBTs to explicit PCK development in specific topics influence the retention of the quality of acquired TSPCK. In addition, the study searched for evidence of the GBTs added advantage, if any, with respect to planned TSPCK and the nature of the quality of enacted TSPCK in their real classroom teaching. The study employed a qualitative comparative multiple case study research design. This design was used to first capture retention of the quality of the GBTs' planned TSPCK, acquired from a planning and reasoning context during the pre-service intervention teacher training. This was followed by investigating the nature of enacted TSPCK in the complex

contexts of GBTs real classroom teaching in the early years of their teaching careers. To confirm for retention of the quality of acquired TSPCK, a collection of qualitative data that were quantitatively analysed to show evidence of improved TSPCK in specific topics in which TSPCK development was targeted was found most appropriate. Likewise, capturing and qualitatively analysing the quality of TSPCK displayed in the actual classroom teaching of the GBTs was found to be most appropriate in determining the quality of the GBTs enacted TSPCK. Merriam (2009) considers a case study as an in-depth description and analysis of a bounded system. The author identifies a case study as a "bounded system when the boundaries have common sense obviousness, for example an individual teacher, a single school, or an innovatory programme" (p. 42). On the other hand, Goodrick (2014) posits that comparative case studies cover two or more cases undertaken over time, emphasising comparison within and across contexts; and which may be used to illustrate similarities and differences in outcomes across contexts in which a programme or policy is implemented (p. 9). Goodrich (2014) points out that "comparative case studies often integrate qualitative and quantitative data, with the intention of gaining in-depth understanding of the cases" (Goodrick, 2014, p. 5)**.** The author further argues that the numbers of cases included are usually limited, since a deep understanding of each case is needed, which requires intensive data collection and analysis.

According to Song and Chung (2010), case studies can be investigated as cohort studies. The authors define a "cohort" as a set of people with common traits and characteristics, who are followed over a period, and may be identified both retrospectively and prospectively. In this study, the cohorts included (7) GBTs, who were sampled from a total class of N=24, in four groups of pre-service teachers, who attended similar intervention studies targeting the development of PCK in different chemistry topics during their final year (4th year) as pre-service teachers in 2014.

The studies were structured in a similar way, but with different topics used in the discussion as the topic of intervention. The different cohorts are thus distinguished from each other by referring to the different topic of intervention used. The seven GBTs were subjected to retrospective exploration of retention of the quality of

planned TSPCK in the topic of intervention developed at the time of their training as pre-service teachers, as well as their current status as beginning teachers.

The individual GBTs sampled to participate in this study can firstly be considered as individual cases. Secondly, as a sample, the bigger group of seven GBTs can all together still fit the criteria of a case. This is because all the GBT cohorts were exposed to similar TSPCK intervention programmes and share common characteristics. The comparison element refers to the fact that a sub-set of three GBTs, were selected from the bigger sample of the seven GBTs and compared with an equivalent control sample of three marching GBTs from a sister university not exposed to the TSPCK construct. It was also found necessary to include one experienced Physical Science teacher to this samplein order to provide additional soft insight into the likely quality of expert/experienced teachers at the time. This is consistent with Hattie (2003) arguement that “apart from content knowledge, expert teachers exhibit more pedagogical content knowledge that is important in teaching situations (pg.10).

The three corresponding pairs of GBTs and the expert teacher describe multiple comparative cases, (explained in detail under the sampling section). According to Yin (2009), comparative case studies are multiple case-study designs within an overall piece of research, either of which may have a single or multiple unit of analysis.

This study therefore fits a multiple comparative case study design in a sense that it had multiple single cohorts, where the cohorts presented the same period of experience undertaken over time in teaching and measured at the same defined time. Moreover, the methods used in the study were generally inductive, and included in-depth qualitative analysis of GBTs’ planned and enacted TSPCK, as well as comparisons across the different cases with the intention of gaining in-depth understanding of similarities and differences among the cases.

Furthermore, incorporation of a component of mixed methods was found important for this study because, although the study was situated largely in the qualitative research approach, it borrowed and blended to a lesser extent, aspects used in quantitative research approach. This feature was evident during the analyses stage,

where descriptive qualitative data collected from the TSPCK tools were quantitatively analysed and reported on a categorical scale using the criterion based Mavhunga and Rollnick (2013) rubric for scoring planned TSPCK (discussed under data collection in this chapter). In this manner, the quantitative aspect of the comparative case study research complemented the information gained through examination of primary qualitative data sets. Figure 3.1 below is a pictorial representation showing features of the multiple comparative case study design.

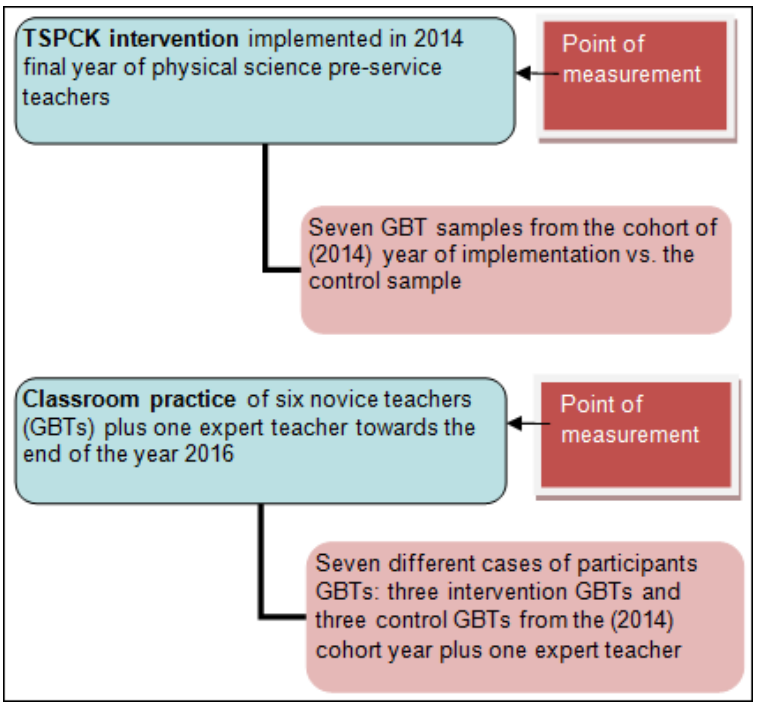


Figure 31: CCSD with multiple sample cohorts measured at same time points

It is important to expand on the similarities across the seven GBT cohorts used in the study. In addition to sharing a common feature of having been exposed to a TSPCK based intervention in their pre-service teacher programme; the seven GBT cohorts were largely from previously disadvantaged communities, historically associated with poor quality of basic education. At the time of the intervention the age range of the participants in the cohort was 22-24 years old. This similarity fits a case study criterion of a bounded system (Merriam, 2009) as the sample of cohorts, which is a case, makes my overall sample a case for the purpose of the study. The interventions conducted for the cohorts had a similar structure of sequence in which the construct of TSPCK was explicitly discussed. The pre-service teachers learnt

about transformation of content knowledge using the five content components of TSPCK interactively and were facilitated by the same instructor. The only difference across the cohorts was the different topic of exposure in the TSPCK intervention.

The main advantage of comparative case studies is that:

- the design is particularly useful for understanding and explaining how context influences the success of an intervention, as was the case for this study;
- the studies usually utilise both qualitative and quantitative methods, which allow for triangulation of information that contributes to the rigor of research, thus enhancing the validity and reliability of the research findings whilst helping to gain a deeper understanding of the phenomenon under study (Yin, 2009); and
- the studies can be used to answer questions about causal attribution and contribution when it is not feasible or desirable to create a comparison or control group (Goodrick, 2014).

In science education, there is a lacuna of comparative case studies specifically those exploring constructs such as the TSPCK (Wunsch, Russo, & Mouchart, 2010), hence this study offered me an opportunity to gain new insights about the construct from both conceptual and methodological views.

Comparative case studies however have the disadvantage of being time and resource-intensive. Equally, case study designs have been identified with weaknesses in terms of objectivity and the possibility of being influenced by the researcher's interests and perspectives (Becker & Bryman, 2004). In addition, case study research strategies have the general disadvantage of the limitation of focusing on a particular group, exclusive to others, hence restricting generalisation of the research findings.
To address the above concerns, I consciously tried to retain an objective perspective throughout the study. I have similarly acknowledged the limitations in the findings and discussion chapters.

Furthermore, the study took place in the presence of other factors, which made it difficult to account for the causal effect of a single factor over time. I acknowledge,

as pointed out by Wunsch et al. (2010) that there are a number of factors that operate over time, due to changes in behaviour and modifications of the environment or context. For example, while the GBTs had been exposed to the same TSPCK based intervention programme, other factors such as starting a new profession as a beginning teacher, and their different school contexts could have affected the full implementation of the intentions of the pre-service intervention programme, hence my findings. Additionally, the possibility of the exposure of the GBT cohorts to experiences in the interventions that, while the objectives, the intervention structure, the instructor and the sequence of the intervention were similar, other possible factors to consider were the different topics used. The literature alludes to "PCK improving with experience, through developing complex contextualized [sic] sets of knowledge needed to apply to specific problems of practice" (Abell, 2008, p. 1414).
It was therefore not practically possible to completely eliminate all the intervening factors, and isolate the single effect of the intervention programme. However, a few research techniques were implemented to reduce the 'impact' of these factors. These are outlined in detail in the sampling and data collection discussions below. It is important to note that the study was centred on the TSPCK intervention conducted in the final year of the GBT cohorts, where a description of the intervention is warranted.

3.3 Overview of the TSPCK Intervention in Pre-Service Teacher Programme

The TSPCK intervention programme is pivotal to understanding the impact explored in this study. A brief recollection of the intervention is thus herein given. The TSPCK intervention started in the academic year 2011 at our university and was repeated from the year 2013 to the present. It is located in the 4th year methodology class of the pre-service teachers majoring in physical science. These are pre-service teachers who would graduate as secondary school physical sciences teachers. As alluded to in Chapter 1, Physical Sciences is a school subject area offered in the South African secondary school education curriculum that combines selected topics from both Physics and Chemistry subject domains into one single subject area of study. The subject is thus offered in several higher education institutions as part of the Bachelor of Education (B.Ed). As mentioned above, the intervention studies had

a common purpose of fast-tracking the development of pre-service teachers' PCK in core topics of physical science. Core topics are important in understanding other related topics within the same discipline. For example, in 2014, the similarly structured intervention studies targeted the development of TSPCK in the topics of chemical equilibrium, organic chemistry, electrochemistry and stoichiometry as the topics used in the discussions. The GBTs were given the choice of an intervention with any topic of their own interest.

The components of TSPCK, as described in the theoretical framework section in the literature review (Chapter 2) consists of: (i) the common learner misconceptions; (ii) establishing understanding of the so-called Big Ideas, without which an understanding of the topic would be compromised; (iii) identification of what is difficult to understand that pose potential learner understanding; (iv) representations appropriate for various concepts of the topic; and (v) conceptual teaching strategies that take into account the effect of the above considerations. These components were discussed one at a time and in the sequence given in Table 3.1. The discussions on each content component were located to fit three teaching periods of 50 minutes each. They constituted a single period early in the week, where the introductions and explicit discussions of each component would be made, and a double period set aside for tutorial exercises at the end of the week. Tutorial exercises were used to allow pre-service teachers to work in groups of four to five learners, to explore the topic of intervention from the perspective of the TSPCK component under discussion and present their thoughts to the whole class for interactive discussions.

Table 3.1 below presents a brief description of the intervention study on the development of PCK among pre-service science teachers with the topic of chemical equilibrium adopted from the Mavhunga (2012) intervention study. The Table describes the sequence in which the TSPCK components were presented, as well as the specific concepts used in the discussions of each component during the intervention.

Table 3.1: Description of a typical TSPCK intervention in Chemical Equilibrium

Component (week)	Intervention	Specific concepts of SMK used
1) Learners' prior knowledge	• Discussions on widely researched common misconceptions in the topic of chemical equilibrium • Teaching instructions to deal with the misconceptions.	Specific SMK concepts used • Closed vs Open system • Meaning of chemical Equilibrium • Equilibrium constant
2) Curricular saliency	• Big Ideas of Chemical Equilibrium, • Sequencing the order of teaching • Awareness of the foregrounding topics/concepts needed prior to teaching Chemical equilibrium • Topics/concepts to avoid while dealing with chemical equilibrium	Specific SMK concepts used • Dynamic Equilibrium • Closed and open system • Equilibrium constant • Le Chatelier's principle and limitations
3) What is difficult to teach	• Exploration of concepts considered difficult to teach • Identifying the actual issues that make them difficult to teach. • Strategies of handling the difficult concepts.	Specific SMK concepts used • Dynamic nature of Chemical Equilibrium • Equilibrium constant • Disturbance of Chemical Equilibrium
4) Knowledge of representations	• Introduction of the three levels of explanations in Chemistry at macroscopic, symbolic and sub-microscopic levels. • Emphasis is placed on the power of using all three representations side by side in explaining a phenomenon.	Specific SMK concepts used • Meaning of chemical system at equilibrium • Meaning of dynamic Chemical Equilibrium: • Meaning of chemical equilibrium constant.
5) Conceptual Teaching strategies	• Recommended strategies for misconceptions • Use of more than one theory/principle to confirm prediction for change in the system as result of disturbance of the chemical equilibrium • Simultaneous use of macroscopic, symbolic and sub-microscopic representations.	Specific SMK concepts used • Listed misconceptions • Listed difficult concepts to teach • Le Chatelier's principle and its limitations. • Equilibrium law
6) Pulling it together	• Introduction of Content Representations (CoRe) as a tool to capture thoughts as one thinks about content knowledge of a topic through the knowledge components of TSPCK. • The CoRe was modified to explicitly include the five TSPCK components	Specific SMK concepts used • Dynamic Equilibrium • Equilibrium constant • Extent of reactions • Chemical Equilibrium and their disturbances
7) Summary	Practicing reasoning through the five content components of Topic Specific PCK • Class Activity: Planning explanation of chemical equilibrium disturbance through reasoning on the five TSPCK components.	Specific SMK concepts used • Laboratory Practical demonstration of disturbance equilibrium NO_2 /N_2O_4 chemical system

The TSPCK component of learners' prior knowledge is typically introduced in the first week. Discussions are centred on widely researched common misconceptions on the topic found in the literature. Participants are encouraged to identify misconceptions that they know of within the topic. These discussions are then followed by a presentation on recommended teaching strategies to confront the identified misconceptions. Where a strategy naturally draws on other components, such as with representations, such moments are explicitly highlighted.

In the second week, discussions are geared towards establishing curricular saliency. Curricular saliency is understood as the component of TSPCK that helps in structuring the topic to identify the most important meaning to be established in a topic. This is done through identifying the so-called big ideas, and the corresponding subordinate concepts in a topic. The idea of structuring the content of a topic through big ideas is derived from Loughran, Berry and Mulhall (2006), who define big ideas to be statements that depict the most important meaning to be understood by learners on key concepts in a topic. This session is followed by discussions on logical sequencing of the identified big ideas for scaffolding learning followed by a discussion on awareness of the foregrounding concepts needed prior to teaching.

In the third week, focus is placed on exploration of concepts considered difficult to learn and identifying the actual issues that make understanding difficult. Discussions on the component of what is difficult to understand moves beyond the abstractness of concepts, by pin-pointing the actual difficulty in teaching a topic. An example of a specific aspect of content that is difficult to understand is the fact that both forward and reverse reactions happen at the same time in a state of chemical equilibrium. Part of the reasons for this difficulty is that learners are typically first introduced to chemical reactions as one-way reactions where balancing of equations is emphasised. Also, even when the reverse reaction is discussed, such as in electrochemistry, often it is represented as a stand alone half-reaction.

The TSPCK component of representations is introduced in the fourth week. Discussions in this component point to introduction of the three different levels of explanations in chemistry that include: the macroscopic, symbolic, and sub-microscopic levels. The emphasis of the discussions is placed in the power of using all the three representations side-by-side in explaining a phenomenon. Emphasis is

further placed on making explicit the specific parts of the representations that exemplify particular aspects of content, as recommended by Klafki (1958). The TSPCK component of conceptual teaching strategies is introduced last. This is because a conceptual teaching strategy often considers the knowledge generated by the other four TSPCK components. Emphasis is placed on conceptual teaching strategies rather than general pedagogy and logistics. For example, in order to determine the direction in which a disturbance will cause a chemical reaction at equilibrium to move in the intervention with the topic of chemical equilibrium, the discussions were explicitly channelled through both the Le Chaterlier's principle and the equilibrium constant equation to verify correctness of a prediction. This strategy was based on the understanding of misconceptions learners commonly have on using the Le-Chaterlier's equation blindly.

The sixth week is reserved for pulling all the components together. During this week, the idea of Content Representations (CoRes) is introduced as a tool to capture the teachers' thoughts as one thinks about content knowledge of a topic through the five knowledge components of TSPCK. The prompts of the original (CoRe) are modified in Figure 3.2 below, to highlight explicit correspondence to the five knowledge components of TSPCK discussed in the intervention shown in 3.1 above.

Curricular saliency	What do you intend the learners to know about this idea? *(original CoRe item – geared to capture subordinate concepts)*
	Why is it important for learners to know this big idea? *(original CoRe item – a potential window to observe any consideration of the other TSPCK components in the provided reasons)*
	What concepts need to be taught before teaching this big idea? *(original CoRe item – captures pre-concepts)*
	What else do you know about this idea (that you do not intend learners to know yet)? *(original CoRe item – captures what is considered peripheral)*
What is difficult to understand	What do you consider easy or difficult in teaching this big idea? Explain. *(new question added)*
Learner Prior Knowledge	What are the typical learners' misconceptions on this big idea? *(new question added)*
Representations	What representations will you use in your teaching? *(new question added)*
Conceptual teaching strategies	What conceptual strategies would you use in teaching this big idea? *(new question added)* What questions would you consider important to ask in your teaching strategy? *(adapted from original: captures teaching procedures)*
Reflections	What ways would you ascertain students' understanding *(adapted from original: captures specific ways to ascertain students' understanding)*
	What aspects of planning and teaching this big idea would you like to reflect on *(original CoRe item)?*

Figure 3.2: An adapted CoRe highlighting the five components of TSPCK (Mavhunga, 2016)

When the discussions on components of TSPCK were completed, emphasis was placed on using the knowledge generated from the other TSPCK components interactively. For example, a teacher would construct an explanation of a concept such as dynamic equilibrium by emphasising the conditions in which such a state happens, by drawing multiple representations on the board showing a closed system. He/she would then explicitly indicate what is equal and what is not equal at chemical equilibrium, while acknowledging common learner misconceptions.

As mentioned earlier, the present study explored the impact of this intervention on the retention of the quality of planned TSPCK attained at the time of the pre-service intervention programme and the current classroom practice of the 2014 intervention GBT cohorts. The section below outlines the sampling techniques used to explore both the retention of quality of planned TSPCK and the enacted classroom practice of the intervention GBTs studied.

3.4 Sampling and selection of participants

I have alluded to the difficulty of systematically isolating the single factor impact resulting from an intervention performed a few years ago. A control group was therefore introduced in the sampling, as a research strategy to help in mitigating the research findings of this study. In this study, a control group refers to participants who did not receive the TSPCK intervention, but serve to exercise control over the nuisance variables (Welman, Kruger, & Mitchell., 2009). When working with one group only, there is the possibility that considerable changes in the dependent variable, in this case the retention of planned TSPCK in practice, could have occurred without the intervention. It is not possible to be certain that the intervention or the independent variable alone would be responsible for any changes observed. There was thus a need for a control group that had not been exposed to the intervention, to help screen off other intervening factors.

In this regard, the use of a control group, matching most of the features of the GBTs other than the exposure to the TSPCK construct was found useful. It is therefore

important to provide the background of the control group used in order to establish equivalence and describe the sampling technique more efficiently.

3.4.1 Brief description of the control group

The control group was drawn from a sister university in the vicinity. Figure 3.3 below shows the relative location of the two universities.



Figure 3.3: Distance between the sister university and my university

To establish equivalence at both universities, brief descriptions of some similarities at both institutions are herein provided.

(i) Profiles of science educators

At my university, the 4th year Physical Science Methodology class is taught by a qualified teacher educator who is a professor in science education (Chemistry), with many years of teaching experience at both undergraduate and post graduate degree levels, coupled with conducting extensive research and supervision, specifically in PCK science education. Similarly, at the sister university, the 4th year Methodology class is taught by experienced professional teacher educators. The specific teacher educator who tutors the Physical Science Methodology class at the sister university is a professor with many years of teaching, supervision and conducting research in

science education at both undergraduate and post graduate degree levels. The science teacher educators were thus seen to be equivalent in their qualifications.

(ii) Student profile

Historically, the sister university was exclusively an Afrikaans university, while my university was an English-medium university in the Open University model. Currently, most of the pre-service students at the sister university, similar to those at my university are mostly black and predominantly from previously disadvantaged communities historically associated with poor quality of school education, in particular Science education (Zhang, Parker, Koehler, & Eberhardt, 2015).

(iii) Physical Science Methodology course

The Physical Science Methodology course programmes offered at both institutes have marked similarities, with a few minor differences in terms of the aims and objectives, stipulated in their respective learning outcomes.

For example, in both institutions, the undergraduate teacher preparation programme is structured in such a way that the content and the methodology components are delivered separately, but as parallel courses in the same department. The topics for the content and the methodology components are taught simultaneously, using the concurrent (CC) Initial Teacher Education (ITE) model. The aim of the CC model is to encourage integration of the academic and professional components of the programmes. According to Sedereviciute-Paciauskiene and Vainoryte (2015) the academic component in ITE course programme, is where pre-service teachers study content subjects (SMK) of one or more academic subjects, while in the professional component, students study educational theory and knowledge for teaching the content. In the concurrent (CC) model, the academic component is studied alongside the professional component throughout the four years of the course programme. Pre-service teachers who complete this programme successfully graduate with a Bachelor of Education degree (B.Ed). The same teacher educators teach both the professional and the content components. The aim of the Physical

Sciences Methodology course programme at my university is to deepen the knowledge and conceptual understanding of pre-service teachers' content knowledge of the difficulties of learning science and broadening their classroom repertoire. The pre-service teachers are taught the professional component in close alignment with the academic component. This approach is meant to enable the pre-service teachers make informed choices in the teaching of Physical Science. At the sister university, the philosophy that guides the teaching of the physical sciences methodology course programme is a commitment to prepare caring, accountable and critical-reflective educational practitioners, who are able to support and nurture learning and development in diverse educational contexts.

In addition, both institutions offer general pedagogy and discipline specific methodology courses in their professional components. The focus of the discipline-specific methodology courses is on how to teach a specific academic discipline or subject. The topics taught include, planning for lessons, doing practical work and the different forms of assessment. Table 3.2 below shows a summary of a comparison of the broad learning outcomes offered at the two institutions. The full course outlines for the physical science methodology course programmes offered at my university and the sister university are provided as Appendices Q and R respectively

Table 3.2: The Physical Science Methodology Learning outcomes offered at my university versus the Sister university

Learning outcomes offered at my University	Learning outcomes offered at the sister University
• Demonstrate competence in planning, designing, and reflecting on learning programmes appropriate to the learners and their learning context, • Demonstrate competence in selecting, using and adjusting teaching strategies in ways which meet the needs of the learners and their contexts. • Demonstrate competence in monitoring and assessing of learner progress and achievement in physical science. • Demonstrate respect for and commitment to the educator profession. • Under general pedagogy, PCK is introduced as a version of the teacher knowledge located at a topic level of the PCK taxonomy (TSPCK) • At the topic level of the PCK taxonomy, a topic is selected, and then interrogated through the five components of TSPCK, to identify common misconceptions, core conceptual pillars that make up the content knowledge of the topic, representations specific to the topic, key concepts considered difficult to learn and conceptual teaching strategies. • The five knowledge components of TSPCK are then listed as a set of knowledge that work together to transform content knowledge of a specific topic (Shulman., 1987)	• Demonstrate competence about the knowledge base underpinning the physical sciences and be able to discuss curriculum terminology and principles. • Demonstrate competence in selecting, using and adjusting teaching and learning strategies that meet the needs of learners. • Explain the concepts associated with school science learner performance assessment processes and procedures • List the important features associated with assessing learner performance in school science and use them to design an effective ongoing assessment approach • Show creativity in making apparatus/media and follow a science-on-a-shoestring approach. • Incorporate indigenous knowledge in lessons. • Plan and execute action-research in the classroom. • Under the general pedagogy, PCK is introduced as a version of the teacher knowledge located at the general version of PCK taxonomy, with emphasis on; i) Knowledge of the learners ii) Knowledge of the learning context iii) Knowledge of curriculum and the school policies, and • Incorporation of Technological Pedagogical Content Knowledge framework in teaching ((TPACK)

Looking at the learning outcomes in Table 3.2 above, one observes that most of the features prescribed in the two methodology course programmes are similar. There are however, some slight differences noted. For example, at the sister university the course programme incorporates creativity in making apparatus/media and follow a science-on-a-shoestring approach, indigenous knowledge, and planning and executing action-research in the classroom. Furthermore, PCK is introduced as an important concept to be understood by pre-service teachers, where the prospective

teachers learn about a number of factors in order to teach certain topics/concepts effectively.

The factors emphasised include:

- knowledge of learners, their diverse backgrounds and possible naïve pre-conceptions that they may hold as a result of their experiences;
- knowledge of learning context, such as the teaching and learning resources available to teach a topic; and
- knowledge of curriculum and the school policies

The version of PCK emphasised at the sister university is however at the level of general taxonomy of PCK, (Nezvalová, 2011; Veal & Makinster, 1999). In addition, there is incorporation of the Technological Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2009). According to the authors, "TPACK builds on Shulman's idea of PCK, with a focus on the three core components of content, pedagogy, and technology, and the relationships among them" (2009, p. 62).

This is unlike the learning outcomes offered at my university, where PCK is introduced as a version of teacher knowledge located at a topic level of the taxonomy of PCK mentioned above. The TSPCK version incorporates research in science education, where the idea of PCK is introduced through stages of pedagogical reasoning (Wilson et al., 1987). This is followed by an explicit exposure to the Topic Specific PCK construct, focusing on the topic specificity of PCK, where, a specific core science topic is selected and used as an example to introduce the five content components of TSPCK in an intervention. Therefore, while the two pre-service teacher programmes are not the same item-for-item, I argue that they are equivalent in the sense that they share the same location space, draw their students from the same catchment areas, offer their programmes in English as the medium of instruction, offer the same teacher qualification degree, share similarities in the targeted objectives but different in the actual coverage and implementation of PCK. The only difference being the version of PCK, offered, i.e. the TSPCK as an intervention programme, which is a distinct difference between the two courses. Therefore, it is reasonable to regard graduates from the sister university as a comparable control group in this study.

3.4.2 Sampling Structure

The main research question asked in this study required an exploration of three sub-questions on retention of the quality planned TSPCK, and the advantage, derived from the early exposure to explicit TSPCK development. Thus, the design to solicit responses to these questions required slightly different sampling techniques. These are outlined respectively below.

(i) For exploring retention of the quality of planned TSPCK (Research Question1)

In order to measure retention of the quality of planned TSPCK acquired through the intervention, two sets of data samples were collected in 2016, from four groups of pre-service teachers, as pre-and post-intervention-TSPCK tests. The pre- (post-intervention-TSPCK tests collected at this sampling point were drawn from a sample of seven GBTs, who were purposefully sampled from the four groups (N=24).

The first sets of data were retrospectively collected from archived completed TSPCK test tools that measured the quality of planned TSPCK from the seven-sampled intervention GBTs in the topics of intervention before and immediately after the intervention in 2014. The second sets of data were comprised of freshly administered TSPCK tests, to the same seven-sampled intervention GBTs in the same topics of intervention, two years after graduation and in teaching practice as beginning teachers in 2016. At the time of the of intervention programme, pre-service teachers had the choice to attend parallel but similarly structured intervention programmes with one of the following topics for discussion: chemical equilibrium, organic chemistry, electrochemistry, or stoichiometry. The samples of participants in the retrieved data were all from my institute and are referred to in this study as intervention-GBTs. The freshly administered tests are labelled in this study as in-practice TSPCK tests.

(ii) Exploring for the advantage derived from an early exposure to PCK (Research Question 2)

The 2nd research question sought a response regarding whether there is any added advantage, derived from the GBTs' early exposure to explicit PCK development in specific topics that could be seen in their early years of practice. This question provides a response to the first component of the question on planned TSPCK as it seeks to determine the possible existence of an added advantage in the GBTs' reasoning and planning context. The second component on enacted TSPCK is discussed in the next research Question 3.

To measure for any added advantage on planned TSPCK, that determined the quality of pedagogical transformation in reasoning and planning for teaching a topic, two sets of data samples were collected in 2016. The first sets of data were comprised of freshly administered TSPCK tests collected from a sub-set of a sample of three intervention GBTs randomly selected from the original seven intervention GBTs used to explore for retention of the quality of planned TSPCK for the first question above. This sample of GBTs was compared with a comparable control sample of three GBTs who did not experience the TSPCK intervention programme, in the same topics used during in the intervention studies. The second sets of data were comprised of TSPCK test tools administered to the same three GBT cohort pairs in new topics. The new topics in this study refer to different topics from those used during the intervention studies, where the intervention-GBTs were allowed to apply the interactive use of the five content components of TSPCK learnt during the pre-service intervention programme to develop PCK in new topics.

The control-GBTs, were drawn as comparable pairs marching each of the three-sampled intervention GBTs, from a sister university. The three comparable-GBTs were also sampled from the cohort year of 2014 as the year of their respective graduation and qualifying as teachers.

The study also found it necessary to include one experienced Physical Science teacher, with a teaching experience of (10) years to this sample. The reason for incorporating the experienced teacher in the sample was to have a glimpse of additional insights on the likely improvement in TSPCK of a typical example of expert practice at the time, by reflecting on the current teacher expertise in a similar context as the GBTs. The sample structure for exploring Research Question 2 is shown in Figure 3.4 below.

Topic	**Structure for exploring research question 2 (in 2016)**		
	Intervention-GBTs	**Comparable-GBTs**	**Expert teacher**
Topics of intervention	(3x beginning teachers)	(3x beginning teachers)	
New topic	(3x beginning teachers)	(3x beginning teachers)	(1 x expert teacher)

Figure 3.4: Structure for exploring research Question 2

(iii) Sample for exploring nature of the quality of enacted TSPCK (Research Question 3)

As mentioned above, the second part of Research Question 2 explored the potential added advantage on the nature of the quality of enacted TSPCK in real classroom teaching of the GBTs, who were exposed to explicit TSPCK development during their pre-service teacher training programme.

To measure for any added advantage on the GBTs enacted TSPCK in real classroom teaching, two sets of data were collected in 2016. The first sets of data were collected from 2 consecutive video recorded lessons, lasing 45 minutes each. These were lessons captured from the classroom teaching of the same sub-set of the two groups of GBTs and one expert teacher in topics of their own choice, described in Figure 3.4 above. All the GBTs and the expert teacher taught Grade 11 classes in schools that were considered comparable.

The second set of data was collected from pre-and post-lesson interviews and researcher field notes. Only three GBT cohort pairs and one expert teacher were

followed into their actual classroom teaching, due to the need for deep understanding of each case, which required intensive data collection and analysis (Goodrick, 2014).

In total, the sample used to determine the nature of enacted TSPCK was comprised of six GBTs drawn from the 2014 intervention year and one expert teacher shown pictorially in Figure 3.5 below. This structure fits a multiple comparative case study design, specified in the research strategy.

Year of graduation and experience	Number of intervention GBTs	Number of comparable-GBTs	Expert teacher
2014(2 years' experience)	3	3	
2006 (10 years)			1

Figure 3.5: Sample for exploring quality of enacted TSPCK in classrooms

3.4.3 Criteria for selecting the participants

The first criteria for selecting the participants involved identifying only those intervention-GBTs from the 2014 cohort year who were in active employment as fulltime beginning teachers for two years within the Johannesburg region in Gauteng Province. For instance, those beginning teachers employed outside the Johannesburg region (7) were not suitable, due to accessibility and distance to their schools. The second criterion used was the willingness of the teachers to participate in the study. The participants were thus chosen based on accessibility, being within 60 km radius of Gauteng Province from the two universities, and their willingness to participate in the study. The academic performance in the intervention class was preferable for selection, but not the main criteria used. For instance, some of the teachers (10), who had already enrolled into their post graduate studies, were considered unsuitable, as they were seen to be receiving extra coaching as post graduate students, which may have resulted in undue advantage.

Likewise, the criteria for choosing the participants in the control group beyond equivalence, was practicing within the Johannesburg region and ethical willingness to participate in the study.

A period of two years was decided upon as a measure of time in practice based on an understanding that the first year of practice is commonly challenging as the

beginning teachers experience many changes in their new environment. The challenges experienced include adjusting to the culture of schools and learning about the needs of their students among others (Luft et al., 2015)**.** Furthermore, the GBTs were considered still settling down into their new assignments.

On the other hand, allowing an additional year before conducting the study had a high risk of working with a more reduced sample of GBTs from this specific cohort due to the high teacher attrition in the region, a concept prevalent in Gauteng schools (Spaull, 2013). These are beginning teachers who leave the teaching profession for other careers, or are shifted to teach other subjects within the same school, often shifting from teaching science to teaching Mathematics. Fraley and Hudson (2014) argue that a high dropout rate is a common challenge with longitudinal study designs, where participants may drop out of the study or fail to respond to one or more rounds of surveys over time, both of which may skew the results.

In this study, the sampling techniques employed to come up with a representative sample therefore included purposive sampling, convenience sampling, and the willing participant sampling techniques. Fraenkel, Wallen, and Hyun (2012, p. 100), argue that "purposive sampling is different from convenience sampling in that for purposive sampling, researchers do not simply study whoever is available, but rather use their judgement to select a sample that they believe will provide the data for use, based on prior information." According to Bryman (2015), the units of analysis in purposive sampling are strategically chosen to best march the subject of inquiry. On the other hand, convenience sampling refers to the idea of a group of individuals who (conveniently) are available for participant selection of a case that illustrates some feature or process in which the researcher is interested (Silverman, 2014). In the case of this study, the focal feature of interest, which formed the subject of inquiry, was the impact of the early exposure to explicit PCK development in specific topics on retention of the quality of GBTs acquired TSPCK and their actual classroom practice.

The three forms of sampling techniques enabled me to have a fair chance of evaluating salient features critical to both planned and enacted TSPCK, across the different GBT cohorts targeted in this study. In addition, the comparable-GBTs and

the expert teacher were found to be useful as a research technique in helping to account for the natural and uncontrollable factors such as the environment, and improving performance with experience in practice. Cooper and Loughran (2015) argue that although experience influences PCK proficiency in practice, the nature of such experience matters.

It was however not possible to eliminate all factors and isolate the single effect of the intervention, especially the expected general improvement in the quality of TSPCK as a result of starting a new career as a beginning teacher. Furthermore, I found it very difficult to trace and sustain the beginning teachers, who were willing to participate in this study.

Table 3.3 below gives a summary of the bio-demographical information of the teachers who participated in this study, the topics they were exposed to during the intervention studies, and their respective sample schools.

Table 3.3: Bio-demographical Information of the teacher participants

Name of teacher	Qualification	Teaching experience	Main Teaching subject	2ND teaching subject	Topic of intervention	University Attended	Type of teaching School
Intervention GBTs							
Ntombi	B.Ed.	2	Physical science	Natural Science	Organic Chemistry	My University	Township
Kgomotso	B.Ed.	2	Physical science	Mathematics	Stoichiometry	My University	Township
Sharon	B.Ed.	2	Physical science	Mathematics	Stoichiometry	My University	Township
Michael	B.Ed.	2	Physical science	Mathematics	Organic Chemistry	My University	Township
Menjo	B.Ed.	2	Physical science	Mathematics	Chemical equilibrium	My University	Township
Jaba	B.Ed.	2	Physical science	Natural Science	Organic Chemistry	My University	Former model C School
Tzepo	B.Ed.	2	Physical science	Mathematics	Electrochemistry	My University	Township
Comparable-GBTs							
Dido	B.Ed.	2	Physical science	Mathematics and Statistics	-	The sister university	Township
Mpho	B.Ed.	2	Physical science	Mathematics	-	The sister university	Township
Thembu	B.Ed.	2	Physical science	Mathematics	-	sister university	Township
The expert							
Chetu	UDES ACE diploma	10	Physical science	Mathematics	-	University of NW	Township

Note: pseudonyms have been used for confidentiality purposes.

In the South African context, the term “township” refers to the often underdeveloped urban residential areas that, under the apartheid rule, were reserved for non-whites (Africans, coloureds and Indians) who lived near or worked in areas that were designated “white” only. The township schools were thus meant to exclusively serve students from these communities. On the other hand, the former so-called ‘Model C’ schools are secondary schools that were previously reserved for white learners only. Both categories of schools have admitted learners across all races and backgrounds. In the following section, I present brief profiles of the schools where the seven participants who were followed into their actual classroom teaching, shown in Table 3.3 above, were teaching by the time of the data collection exercise.

3.4.4 Profiles of participant teachers’ schools

All the Physical Science teachers who participated in the classroom observation sessions were male. One of them, Jaba, is a white South African, while the other six were black South Africans. Other than the expert teacher, who had ten years of teaching experience, all the other GBTs graduated from different cohort classes in 2014 and had a two years teaching experience. Secondly, apart from teacher Jaba’s school, which was classified under the former ‘Model C’ schools, all the other participants were teaching in township secondary schools. Table 3.4 beow gives a summary of profiles of the participants teaching schools.

Table 3.4: Summary of profiles of Participants schools

Name of teacher	Physical size of classrooms	Availability of teaching/ learning resources for teaching	Mentor teacher guidance	Laboratory support	Average student population per class
Intervention GBTs					
Menjo	Ample space for effective classroom instruction	Adequate teaching/ learning resources/facilities	No teacher mentor, support	Dedicated laboratory support with a fulltime laboratory technician	25 learners
Jaba	Ample space for effective classroom instruction	Adequate teaching/learning resources.	Support from a qualified teacher mentor	Dedicated laboratory support, with a fulltime laboratory technician	20 learners
Tzepo	Small and crowded	Lack of the necessary teaching/learning resources	No teacher mentor, support	No laboratory assistance	45 learners
Comparable GBTs					
Dido	Ample space for effective classroom instruction	Lack of the required teaching/learning resources	No teacher mentor, support	No laboratory assistance	45-50 learners
Mpho	sufficient room for science teaching/learning	Adequate teaching/learning resources/facilities	No teacher mentor, support	No laboratory assistance	35-40 learners
Thembu	Ample space for effective classroom instruction	Adequate teaching/ learning resources/facilities	No teacher mentor, support	No laboratory assistance	40-45 learners
Expert Teacher					
Chetu	Ample space for effective classroom instruction	Adequate teaching/learning resources/facilities for classroom teaching	No teacher mentor, support	No laboratory assistance	35-40 learners

As indicated in Table 3.3 above, all the GBTs taught in township secondary schools, apart from teacher Jaba, whose school was classified under the former 'Model C' schools. In addition, teacher Jaba's school was the only one that enjoyed the support of a teacher mentor, dedicated to supporting beginning Physical Science teachers during their early years of classroom teaching. The teacher mentor assigned to teacher Jaba was the head of the Physical Science Department. During the class sessions, the teacher mentor sat quietly behind the classroom and observed all the lessons taught by the GBT without interfering with the lesson. In the post-lesson interview, teacher Jaba explained that *"the school policy required that all teacher mentors attend all lessons taught by beginning teachers in person, without fail."* The teacher mentor would thereafter discuss her observations with the

beginning teacher after the lesson, in a separate room, where often it would be in the preparation room. The discussions between the teacher mentor and the beginning teacher would be centred on encouraging and guiding the teacher in areas, which she felt the teacher had performed exceptionally well, and/or give guidance in arears that required specific improvements for better lesson delivery, as a form of internal teacher induction. This observation agrees withDarling-Hammond., Weiz, Andree, Richardson, and Orphanos (2009), who argue that closely related school-based coaching is an increasingly common practice of providing mentoring and other forms of formal induction to beginning teachers.

On the other hand, teacher Dido's school was a unique township school in a sense that it enrolled only those learners that were making a second attempt at matric qualification examinations, having either not succeeded in their previous qualifying examinations and/or targeting to qualify for entry into specific course programmes at the university or other tertiary learning institutions.

The learners in teacher Dido's school were, however, equivalent and similar in age (16-18 years) to the other Grade 12 learners in the formal schools, but had prior experience in the topics of instruction. The school, however, fell into a category called Adult Learning Centres, which opened for the "adult learners" in the evenings. The lessons were often conducted in the late afternoons or in the evenings.

Table 3.4 further indicates that the number of learners per class in teachers Tzepo and Thembus' schools (40-45) were observed to far exceed the recommended average class populated of 35. This aspect appeared to be a limitation for the teachers to carry out any meaningful class demonstrations as well as provide for individual learner attention.

In establishing school equivalence, slight variations were therefore noted across the schools. For instance, teacher Jaba's school was the only school with a teacher mentor. Moreover, the process did not capture all factors, for example, factors related to diversity of learners in the classrooms, or even their own personality, were not considered among others. However, accepting these factors as noise that will always be there, the patterns that emerged from the observed lessons were discussed within this context.

From the above discussions, I acknowledge the different contexts in which the GBTs were teaching as the reality in different schools out there. I therefore remained conscious of those factors arising from the school contexts that became visible in the observed classroom lessons during the analysis of the current study's findings.
One of the aspects mentioned that distinguishes the intervention GBTs from the comparable-GBTs is that the intervention GBTs were exposed to a component of PCK during their pre-service teacher intervention programme.

In the following section, I describe the tools used to collect data in this study.

3.5 Research instruments

As mentioned earlier, this study explored the development of GBTs' TSPCK from a TSPCK-based intervention pre-service teacher preparation programme into their actual classroom teaching. The instruments used in this study could thus be organised in two parts. First, those used to measure the shifts in the quality of planned TSPCK during the pre-service TSPCK based intervention programme. Second, those used to capture the quality of enacted TSPCK displayed in actual classroom teaching. These are discussed separately below.

3.5.1 Instrument used during the intervention

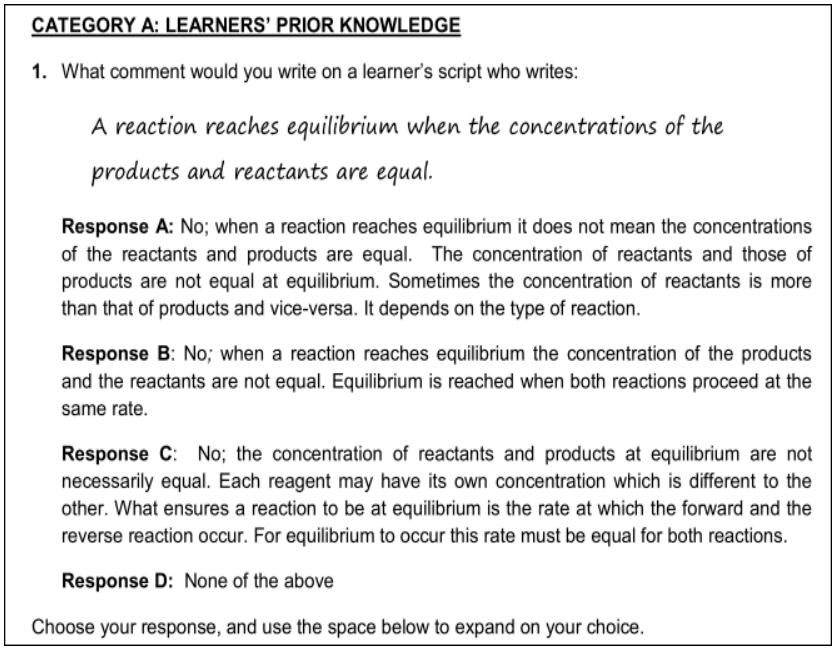
(i) Tool used to measure TSPCK in planning

The TSPCK test items used in this study were designed to match into the five categories, corresponding to the five content components of TSPCK. Each category in the test tools comprises 2-4 test items, which are teacher tasks seeking teacher responses.

For example, Category A (TSPCK component 'of Learner Prior Knowledge') consists of two questions, each of which has four typical multiple choice objective test items that students have answered incorrectly or correctly, but which require further clarification for understanding. To each set of the multiple-choice items, four possible responses are provided. For the responses that provide conceptually correct answers, the appropriate reasoning provides a difference to the course of

action for the specified contexts. The option to develop the best answer, rather than the correct-answer, is required in this case (Rohaan, Taconis, & Jachems, 2009). Examples of extracts lifted from test items in the category of learner prior knowledge in the topics of chemical equilibrium and organic chemistry are shown in Figures 3.6 and 3.7, respectively. The full copies of the TSPCK test tools used in the intervention studies are given in appendices (E& F).

All the other category items were constructed in a similar format, except for the category of conceptual teaching strategies, which retained an open-ended question format. In this category, the participants were required to choose teaching strategies they would most likely use in their teaching to help correct learner's held misconceptions, and at the same time explain the reasons for the selected choices. This category is discussed further at the end of this section.



CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. What comment would you write on a learner's script who writes:

A reaction reaches equilibrium when the concentrations of the products and reactants are equal.

Response A: No; when a reaction reaches equilibrium it does not mean the concentrations of the reactants and products are equal. The concentration of reactants and those of products are not equal at equilibrium. Sometimes the concentration of reactants is more than that of products and vice-versa. It depends on the type of reaction.

Response B: No; when a reaction reaches equilibrium the concentration of the products and the reactants are not equal. Equilibrium is reached when both reactions proceed at the same rate.

Response C: No; the concentration of reactants and products at equilibrium are not necessarily equal. Each reagent may have its own concentration which is different to the other. What ensures a reaction to be at equilibrium is the rate at which the forward and the reverse reaction occur. For equilibrium to occur this rate must be equal for both reactions.

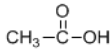
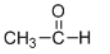
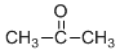
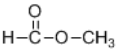
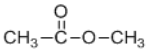
Response D: None of the above

Choose your response, and use the space below to expand on your choice.

Figure 3.6: TSPCK tool used in the topic of chemical equilibrium

Section A: STUDENT'S PRIOR KNOWLEDGE

1. You hand out a worksheet to be used in a classroom activity and ask students to select compounds that are alcohols from the table below:

1	**2** 	**3** 	**4**
5 	**6** 	**7** NaOH	**8** 

Sipho selects compounds 1, 2, 4 and 7. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds?

Figure 3.7: TSPCK tool used in the topic of Organic Chemistry

Category B (TSPCK component of 'Curricular saliency') is related to planning and sequencing of concepts. The then pre-service teachers were required to select and rank three main ideas or concepts to be taught, regarded as key or basic to teaching of the specific topics they were exposed from a list of provided options. In addition, they were required to make a concept map showing how the corresponding subordinate ideas are interrelated and linked with the main ideas. The test items further required the respondents to list topics that need to be covered, prior to teaching the topic under discussion and briefly explain why they think the topics are important for learners to study.

Category C (TSPCK component of 'What is difficult to teach') demanded that the respondents select topics/concepts, from a list of topics/concepts that they consider difficult to teach, in order to explain why they consider the selected topics/concepts difficult to teach for understanding by learners.

For Category D (TSPCK component of 'Representations'), the test items provided lists of different types of representations and/or analogies, that could be used to explain various concepts in the topics administered. The respondents were required to think about the representations they would find useful in teaching various concepts of the topics under discussion and then complete a table, giving details related to the effectiveness of the representation (s) and/or analogies provided for

teaching in their different classroom contexts. They were further required to select one of the representations or analogies that they like most and explain how they would use this in classroom teaching.

The last category, Category E (TSPCK component of 'Conceptual teaching strategies') presented a scenario, of leaners' responses in a classroom test or an informal classroom task that displays common learner misconceptions related to understanding of specific concepts. The constructed test items required the teachers to think about how they would teach a lesson, drawing on different ways of confronting the suggested learners' misconceptions, and assist them in developing conceptual understanding that would lead to correct understanding.

The ability to conceptually respond to a Topic Specific PCK test item therefore required the understanding of the content of a specific topic, as well as reasoning through the five content components of TSPCK in enabling transformation of content knowledge for learners' understanding. According to Mavhunga (2012), responding to a TSPCK test item requires a teacher to demonstrate the grasp of the content knowledge of the topic in question, reasoned through the five components of TSPCK in which transformation of content knowledge emerges.

To express the shift in the quality of TSPCK during the TSPCK-based intervention programmes, the raw scores generated from the TSPCK test tools were quantitatively analysed and reported on a categorical scale, using the Mavhunga & Rollnick (2013) TSPCK rubric for scoring the quality of planned TSPCK, as described later in this chapter.

The TSPCK test tools used in this study were previously developed in separate studies and are considered well-vetted. For example, the tool by Mavhunga (2012) in the topic of chemical equilibrium, as well as that by Vokwana (2013) in the topic of organic chemistry and Ndlovu (2014) in the topic of electrochemistry, respectively.

3.5.2 Instrument used in classroom practice

Teachers' classroom practice and activities provided the main platform for witnessing and capturing enacted TSPCK. Lesson observations provided the primary access to enacted TSPCK. To capture the displayed TSPCK for evaluation of quality, a video recorder was used to capture and record the observations as the lessons unfolded.

According to Star and Strickland (2008), viewing videotaped class lessons leads to significant increase in the ability to notice features of the classroom environment, content of a lesson, and teacher/student communication during a lesson. Furthermore, the use of video recordings has the added benefit of offering rich data that captures the complexity of non-verbal interactions, which can allow two observers to watch the same video independently, (Stingler, Gallimore, & Hiebert, 2000, p. 90). This advantage helped me to share the recorded video lessons with the enlisted reference team of independent raters for analyses and scoring purposes, thereby increasing the credibility of these research findings.

Secondly, a content representation (CoRe) interview protocol guide developed by Loughran, Mulhall and Berry (2004) was adapted and used to conduct sets of pre- and post-lesson interviews. The pre- (post-) interview protocol guide was used to collect primary data, on teachers' preparations, preparedness and reflections on action. According to Nilsson & Loughran (2012), "CoRes can adequately capture, portray and codify science teachers' PCK in ways that are accessible to and useable by other teachers"(p.701). This technique captures teachers' PCK by engaging portrayals, that is, individual profiles based on data from interviews and observations (Loughran., Milroy, Berry, Gunstone, & Mulhall, 2001b). The adapted content representation (CoRe) interview protocol guide was, however, revised to probe for in-depth instructional decision-making processes of the GBTs. According to Loughran. et al. (2012) CoRe(s), can help discuss how communities of teachers think about the knowledge needed to teach a particular topic at a given grade level. In addition, CoRe (s) can be developed across a range of science topics, since each new topic brings new demands with different expectations of understanding the complexity of content and pedagogy under consideration (Loughran. et al., 2004).

In this study, two different types of interview tools were used to collect data. These were a pre-lesson interview guide and a post-lesson video-stimulated recall interview guide. The pre-lesson interview guide was comprised of standardised unstructured open-ended question items (Webb, 2015) that were used to elicit for general views on the intended learning about specific SMK concepts and how they relate to the big ideas of the topic; the importance of learning the listed intentions and reasons for related teaching strategies applied; and lastly, the possible difficulties when it came to student thinking that influence the teaching of the particular lesson being taught.

A copy of the pre-lesson interview protocol guide is provided as (Appendix C). Likewise, the post lesson interview guide was comprised of unstructured open-ended question items, which sought to capture the understanding of the teachers' thinking about; achievement of the set lesson purposes; instances the teachers could recall that assisted them to explain particular concepts; challenges they experienced during the lesson delivery; and what they would do differently next time, given similar contexts. A copy of the post lesson interview protocol is provided in (Appendix D).

3.6 Data collection

The data collection was organised in response to the three research sub-questions of the study.

3.6.1 Data to confirm improvement of the quality of planned TSPCK

To evaluate for retention of planned TSPCK, improvement in the quality of TSPCK as a direct result of the intervention was first to be confirmed. To measure this, two sets of secondary data were retrospectively collected from the archives of the methodology courses in the respective topics used during the intervention programmes and freshly scored. The two sets of data were captured from the seven-sampled intervention GBTs mentioned Table 3.3 above.

Prior to retrieving the test tools, permission for access and use of data was sought from the teacher educators who delivered the intervention programmes, as well as other relevant authorities. These sets of data reflected evidence of developed

TSPCK, while the GBTs were under development in the methodology class of the Physical Science pre-service teacher preparation programmes. The data collected, at this stage, was meant to confirm the reported improvement of TSPCK from a planning context (e.g. Mavhunga & Rollnick, 2013). The data collected was secondary, in a sense that it was retrieved from the archives of the data collected by the teacher educators who delivered the interventions. The collected data were sorted to correspond to two sampling points of the intervention: (i) beginning of the intervention, as pre-intervention tests; and (ii) at the end of intervention, as post-intervention tests. The data collected at each of these sampling points were comprised of completed TSPCK pencil and paper test tools, submitted responses to short class activities, and stimulated recall evidence-based interviews. The data found most comprehensive were completed pre- (post-) TSPCK test tools that measured the quality of TSPCK in the topics of intervention in 2014.

The nature of the data collected largely reflected planned TSPCK developed during the pre-service teacher training programmes in the respective topics used during the intervention studies. The purpose of collecting and analysing raw secondary data was to verify the value of TSPCK reported in the secondary data, by comparing with the freshly re-administered TSPCK tests during the GBTs' actual classroom practice as beginning teachers.

The data collected at this sampling point were therefore used as a trustworthy baseline for determination of retention of the quality of planned TSPCK. Figure 3.8 below shows the structure of data that was used to confirm the quality of planned TSPCK acquired from the pre-service teacher preparation programme.

Cohort year: 2014	**Data collected in 2016 from the archives of the 2014 intervention GBTs studies**
Completed TSPCK tools	
Beginning of intervention: Pre-TSPCK tests	7x teachers) ✓
End of intervention: Post TSPCK tests	7x teachers) ✓

Figure 3.8: Data for confirmation of quality of GBTs planned TSPCK

3.6.2 Data for evaluating retention of planned TSPCK in practice

To evaluate for retention of the quality of planned TSPCK in practice, two sets of data were similarly collected at two different sampling points in 2016. The first sets of data were the same data collected at the end of each intervention programme, as post-TSPCK test scores that measured the quality of TSPCK in the respective topics of intervention at the end of the intervention studies in 2014, as shown in Figure 3.8. The second sets of data were primary data, collected in 2016. These sets of data were comprised of freshly administered TSPCK tests that measured the quality of TSPCK in the respective topics used during the intervention studies; classified in this study as in-practice TSPCK tests.

Figure 3.9 below shows a spread of the summary of data collection to determine for retention of the quality of planned TSPCK that provided a means to respond to the first research question.

Data collection to determine retention of planned TSPCK	
Year of data collection 2014	**Year of Data collection 2016**
End of intervention TSPCK tests (7x teachers) ✓	In-practice TSPCK tests (7x teachers) ✓

Figure 3.9: Data collection to determine retention of planned TSPCK

A comparison of shifts in the TSPCK test scores generated from the seven intervention GBTs in the post- versus in-practice TSPCK tests assisted in determining for retention of the quality of planned TSPCK in practice.

3.6.3 Data for determination of added advantage derived from explicit exposure to planned TSPCK

In order to evaluate for the advantage (if any), derived from an early exposure to explicit TSPCK development, the data collected from completed in-practice TSPCK test tools shown in Figure 3.9 above were compared with a second set of data collected from new topics. As mentioned earlier, the new topics in this study refer to different topics from those used during the intervention studies.

It is however known that PCK improves with practice (Abell, 2008). It is also notable that while measuring for retention of the quality of the GBTs' planned TSPCK since their pre-service programme attendance, the likely level of improvement of TSPCK as a result of mere exposure to teaching practice be determined. A comparable control group of three beginning teachers who majored in physical science, with the same teaching experience as the intervention-GBTs, but who had not been exposed to the specific TSPCK intervention programmes, was constituted. This group of teachers is referred to in this study as comparable GBTs. The three comparable GBTs, matching the intervention GBTs were given the same TSPCK test tools as those given to the intervention GBTs in the respective topics used during the intervention studies and in the new topics. In addition, the same TSPCK test tool given to the GBT cohort pairs in one of the topics was also administered to the expert teacher, who was used as a reference on the likely quality of TSPCK of teacher expertise at the time. The data collected at this sampling point were thus comprised of a combination of completed TSPCK test tools that measured the quality of planned TSPCK in both topics of intervention and the new topics, administered to both GBTs groups and one expert teacher.

A comparison of the findings from the data generated from the intervention GBTs planned TSPCK versus that of their comparable GBT counterparts in both topics of intervention and the new topics helped me to respond to research Question Two.
As mentioned earlier, the reason for selecting a smaller sample comprising of three GBT cohort pairs was because of the need for deep understanding of each case, which required in-depth analysis of the GBTs tracked progress (Goodrick, 2014). Figure 3.10 shows a summary of data collection for this question.

Data collected to determine the advantage in the topics of intervention and the new topics (in 2016)		
Topic	**Intervention GBTs**	**Comparable-GBTs**
	Completed TSPCK tool	Completed TSPCK tool
Topics of intervention	✓(3x teachers)	✓ (3x teachers)
New topics	✓(3x teachers)	✓ (3x teachers)
Expert teacher		
New topic	-	✓ 1x expert teacher

Figure 3.10: Spread of data collected in response to research Question 2

3.6.4 Collection of data for evaluating the nature of enacted TSPCK

To investigate the nature of the quality of GBTs' enacted TSPCK, data was collected from two consecutive classroom video recorded lessons lasting 45 minutes each, making a total of 90 minutes. The observed lessons were captured from the real classroom teaching of the same subset of the two GBT groups and the expert teacher shown in Table 3.3 above. However, during the data collection exercise, each individual GBT was considered as a separate case. Part of the reason for considering each participant as a separate case was because each of the GBTs and the expert teacher taught a topic of his own choice. There was no one topic that was common or pre-determined across any pair, therefore, the data collected were from seven separate mini cases within the main case study.

The reason why the topics used during the actual classroom lesson observations did not pertain was because the research question sought to understand the nature of TSPCK displayed in actual practice, which was best answered by investigating enacted TSPCK in topics of the participants' own choice. In addition, these were topics in which the respective participants appeared to possess sufficient content knowledge mastery, hence confident and likely to enjoy teaching.

The different sets of data collected for this phase were comprised of: (i) data on planning for teaching, collected from pre-lesson interviews; (ii) classroom observations of the delivered lessons, captured using a video tape-recorder; (iii) post-lesson video stimulated recall interviews, which focused on the beginning teachers' reflections on action. The data captured from the post-lesson video stimulated recall interview sessions were used to try and understand the reasoning behind the instructional practices and actions observed during the actual classroom teaching. During the classroom observations, field notes on salient features observed during the lesson were also captured. The primary empirical data collected at this sampling point, reflected TSPCK in practice and was captured from secondary school grades (viz. Grades Nine to 12), which the GBTs were trained to teach.

According to Ormston et al. (2013) qualitative research is a blend of empirical investigation and creative discovery. Therefore, the multiple data collection instruments used for data collection in this study helped in the triangulation of data collection sources. As pointed out by Baxter and Lederman (1999), data triangulation from different sources results in a general profile of teachers' PCK. The data collected at this sampling point helped me to respond to research Question Three, which investigated the nature of the GBTs' enacted classroom teaching in topics of their own choice. Figure 3.11 below shows a summary of the spread for collection of data on enacted TSPCK in the topics of participants' choice

Data collected in actual teaching in 2016		
Cohort year	**Intervention GBTs; Lesson videos**	**Comparable GBTs; Lessons videos**
2014	✓(1x teacher Menjo) Electromagnetism in a ▪ Straight wire and Circular wire ▪ Faradays law	✓(1x teacher Dido) ▪ Introduction to organic Chemistry ▪ Primary, secondary & Tertiary alcohols
2014	✓(1x teacher Jaba) ▪ Endothermic and Exothermic reactions ▪ Acids and Bases -Ionization and precipitation reactions	✓(1x teacher Mpho) ▪ The three states of matter ▪ States of matter (Diffusion)
2014	✓(1x teacher Tzepo) ▪ Mechanical energy ▪ Solubility of salts	✓(1x teacher Thembu) ▪ Chemical bonding ▪ The Doppler Effect
Year	**Expert teacher**	
2006	✓ (1x teacher Chetu) • Matter & Materials-Atomic combinations	

Figure 3.11: Data collection for enacted TSPCK in the topics of choice

In the section below, I briefly outline the sequence followed during the data collection exercise. Prior to the start of each observed video lesson, I would first begin by administering the adapted CoRe pre-lesson interview tool. The pre-interview sessions then helped me to gain insights on the participants' thoughts from a planning context, about particular aspects of the planned lessons. I however adopted a non-judgmental stance towards the teachers' views on the anticipated lessons.

During the interview sessions, the participants discussed the probable difficulties that learners face with particular topics and the reasons why the learners experienced such difficulties. However, although the pre-interview questions appeared to cue the

participants to respond accordingly, the responses provided were brief with little elaborations especially those captured from comparable-GBTs.

The post-lesson interviews were conducted as stimulated-video recall sessions, where the video-recorded lessons were played in front of the teacher as follow-up sessions to confirm the interpretations of the observed classroom lessons, reflected in the teachers' actions in practice (Schön, 1995). The participants were thus offered an opportunity to reflect on their decision-making processes during the videoed event, which helped them to re-construct their thinking while they were teaching. This assisted the GBTs to explain some of the choices made for certain classroom actions as well as to confirm the findings and seek clarification in the written comments provided in the completed TSPCK test tools. The act of going back to confirm the patterns with the participants helped to enhance the reliability of the observed patterns.

As alluded to above, the classroom observations were conducted informally, where data were captured using a video-tape recorder. According to Robson (2011), qualitative studies typically use informal participant observations. I did not, therefore, prepare any formal observation protocols for the observed classroom lessons. In addition, researcher field notes were also collected for later transcription and analysis, as data supporting the observed classroom lessons. Edwards and Holland (2013) argue that observations involve paying attention to the whole event as it unfolds and taking field notes on salient issues related to the researchers' hearing, observations and experiences as transcripts which are qualitatively analysed later. The video-recorded lesson observations thus provided me with a chance to observe participants' behaviour in different contexts, where actual teaching takes place. The videoed lesson recordings provided further opportunity to re-play, view and share the recorded classroom lesson interactions repeatedly with the team of enlisted independent raters for purposes of analyses. However, while video recorded observations enabled us to observe and listen to exactly how individual teachers act and interact in different contexts, my presence as the researcher could have influenced the observed behaviour. I have acknowledged this limitation under the reflexivity section. Moreover, the observation exercise was time-consuming. The

quality of enacted TSPCK displayed in real classroom teaching by the GBTs and the expert teacher was evaluated and graded using a newly developed and validated TSPCK classroom rubric for scoring TSPCK in action. The new rubric is fully discussed in Chapter 4. The analysis of the findings captured from the participants enacted classroom teaching are presented in the Chapter 8. Figure 3.12 below presents a summary of the timeline and the sequence followed during the data collection exercise.

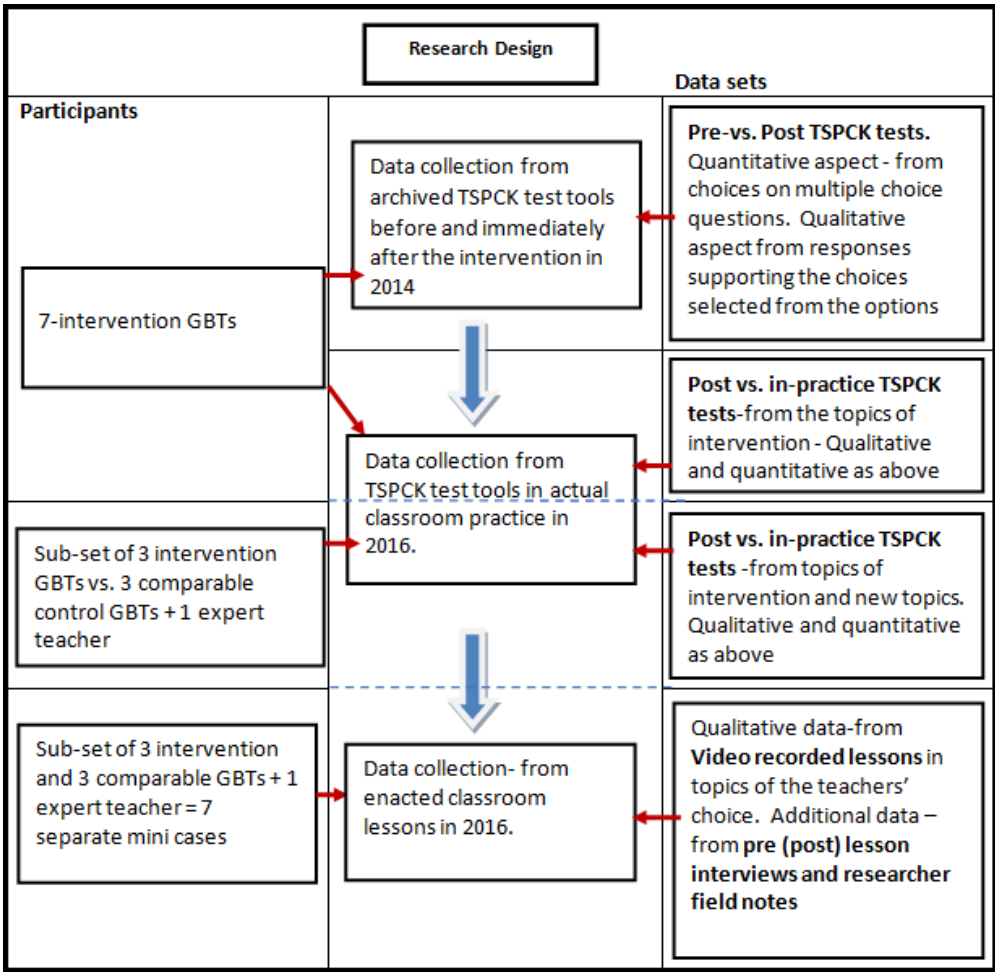


Figure 3.12: Timelines and Sequence of Data Collection

3.7 Data Analysis

As described in the preceding section, different sets of data were collected for analysis. The analysis for each set of data is discussed separately based on the different research question asked in the study.

In selecting data for this study, I embraced a pragmatic curiosity. Researchers need to evaluate or confirm the relevance of theories to the documents or artefacts, often based on coherence. Coherence in this study refers to "whether or not parts of an explanation are contradictory or whether conclusions follow from given premises" (Haris, 2007, p. 46). Therefore although the data collected for this study were largely qualitative in nature, there were deliberate points in the analysis where data from the quantitative strand were used to cohere qualitative data in supporting emerging patterns. This point was illustrated in the analysis of responses captured from the TSPCK test tools. For instance, the data captured from the TSPCK test tools were descriptive in nature. The questions asked in the test tools were comprised of semi-closed items with prompts for provision of explanations for the choice of answers made as discussed under instruments for data collection above. The intention of combining two question items into a single task was to elicit for evidence of the teachers' reasoning process, for the selected answer choices. The process of analysis therefore required matching the descriptive responses captured from the TSPCK test tools to the criteria provided by Mavhunga & Rollnick (2013) in their TSPCK rubric for scoring the quality of planned TSPCK. The TSPCK rubric (discussed in the next section) is comprised of four categories of numeric values ranging from 1-limited TSPCK, to 4 exemplary TSPCK ability. The captured responses were then assigned numerical values corresponding to the criteria that the participants' responses matched most, and the scores treated as ordinal data. The mixed-methods component described above was, however, so minimal to warrant calling this study a mixed methods study.

The qualitative descriptive responses written as part of answering the test questions were used as additional data to confirm the score for each test item answered.

Prior to scoring the responses captured from completed TSPCK test tools, I sought the help of a reference team of three independent raters, who assisted in scoring the responses captured from the test tools, thus ensuring reliability of the test scores. The independent raters included: one experienced Physical Science teacher educator with an extensive track record in research and supervision at both undergraduate and graduate levels in science education and PCK development. The other two raters were doctoral science education students, who were both experienced high school Physical Science teachers, with strong background knowledge in science education and interest in PCK research. The independent raters were first familiarised with both the test tools and the scoring rubric. The rules followed in scoring the responses captured from the respondents, in the completed TSPCK test tools were the same as those used during the intervention studies, and included: (1) scoring each question singly by assigning a score corresponding to the category in the rubric where most criteria are met; (2) any question with no response was assigned the lowest score; (3) a question with responses falling across two categories that were close to one another was scored by checking specific gate-keeping criteria for each category, and agreed upon in consultation with the reference team of the independent raters.

Unmarked copies of completed TSPCK test tools were given to the three independent raters, including myself, as the fourth rater for independent marking following the rules stated above. This was followed by looking at the awarded scores collectively, to resolve any discrepancies.where we debated any differing scores and agreed by consensus as to which mark to award based on the specific gate-keeping criteria for each category. The extent of agreement between my scores and the scores awarded by the independent raters were further addressed through the calculated reliability indices generated by the Kappa-Cohen inter-rater reliability index (Landis and Koch, 1977).

The Cohen's kappa inter-rater agreement for qualitative items, which measures agreement between two raters, was calculated between each of the three independent raters and I before working out an aggregate average score as shown in Appendix (P).

The scores generated from completed pre- (post-) TSPCK test tools helped me to respond to research Question one, which sought to establish retention of the quality of planned TSPCK, acquired from the TSPCK-based pre-service teacher intervention programme in the topics of intervention.

Similarly, the scores captured from the post- (in-practice) test tools helped me to respond to Research Question 2, which investigated the advantage derived from the early exposure to explicit PCK development in specific topics.

In the following section, I briefly describe the rubric used to score the quality of planned TSPCK.

3.7.1 Description of the rubric used to score planned TSPCK

A specially designed instrument that measures the quality of TSPCK in chemical equilibrium was adopted and used for analysing and scoring the responses captured from completed TSPCK test tools. The Mavhunga & Rollnick (2013) TSPCK rubric for scoring the quality of planned TSPCK (Appendix A), is premised on the understanding that transformation of SMK is one of the key elements in the establishment of PCK. The authors of the rubric regard topic-specific PCK as the understanding that provides the needed knowledge for subject matter knowledge (SMK) transformation in a particular topic. According to Shulman (1987), teachers with high quality PCK transform each topic as they reason about its teaching. In the same vein, Mavhunga and Rollnick (2013) argue that when a particular element of SMK is thought about and reasoned through the five content specific components of PCK; understanding for teaching is generated that is specific to that topic. This process is considered as transforming that specific topic, and it is therefore Topic Specific PCK (TSPCK). The authors have identified the five components as: (i) learners' prior knowledge; (ii) curricular saliency; (iii) what makes a topic difficult to understand; (iv) representations including powerful examples and analogies; and (v) conceptual teaching strategies. All these components are similar to those established by Geddis and Wood (1997). The Mavhunga & Rollnick (2013) TSPCK rubric for scoring the quality of planned TSPCK is structured according to the five content components of TSPCK listed above.

As described above, the TSPCK test tools are structured in such a way that the test items use semi-closed questions with multiple choice responses, from which the respondents select, while allowing them the opportunity to explain and expand on the choices made. The TSPCK test items were therefore used to assess the selected option/choice from the multiple-choice options, or the response given for the short answer question items, as well as qualitatively providing explanations for the selected choice, or the answer provided.

As alluded to earlier, the scoring rubric corresponds to the five content components of TSPCK, with each component being rated on a four point scale ranging from a minimum of (1) limited ability to a maximum of (4) 'exemplary', similar to that of (Park. et al., 2011). The test questions in each component are scored singly as an item, with each item having a maximum score of four points.

The Mavhunga & Rollnick 2013 TSPCK rubric for scoring the quality of planned TSPCK was developed and validated with a reference team of qualified and experienced physical science teachers, as well as pre-service teachers, with the aim of capturing and measuring the quality of topic-specific PCK of teachers in chemistry topics. It is worth noting that the rubric has also been used in several other studies (Rollnick., Davidowitz., & Potgieter., 2017; Rollnick. & Mavhunga, 2016).

The rubric calls for the interactive use of the individual content components, with the other TSPCK components. The quality of TSPCK is thus defined as requiring the understanding of the five content components of TSPCK and their interactive use in formulating explanations and responses in teaching a topic (Mavhunga & Rollnick, 2013).

Figure 3.13 below shows a sample extract on how the rubric could be applied for scoring one of the five TSPCK components of learner prior knowledge.

TSPCK Component	Limited (1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • No attempt to address the misconception	• Identifies misconception or prior knowledge • Provides standardized knowledge as means to counteract misconception • No evidence of drawing on other TSPCK components.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using one other component of TSPCK interactively	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on two or more other components of TSPCK interactively

Figure 3.13: A TSPCK extract for scoring the TSPCK component of learner prior knowledge

Looking at the shaded text in Figure 3.13 above, it can be noted that for a teacher's response to be scored as, for example, Category 3 (i.e., the developing category of TSPCK proficiency), a second TSPCK component must have been seen to be interactively used with the component of learner prior knowledge (LP) in formulating a response. Likewise, Category 4 (i.e. exemplary TSPCK proficiency) requires the interactive use of two other TSPCK components in addition to the component of learner prior knowledge (LP). All the TSPCK test tools used during the intervention studies were developed and validated in the same fashion in separate studies, such as that by Vokwana (2013) in the topic of organic chemistry and Ndlovu (2014) in the topic of electrochemistry.

The Mavhunga & Rolnick (2013) TSPCK rubric for scoring the quality of planned TSPCK was adopted and used to analyse for shifts in the quality of the planned TSPCK, acquired at the time of the pre-service TSPCK based intervention programme and its retention in actual practice. The rubric was also used to analyse for any added advantage in the reasoning and planning to teach a topic, derived from the GBTs early exposure to explicit TSPCK development in specific topics. The adopted rubric therefore helped me to score all the completed TSPCK test tools administered in this study, and thus respond to research Questions 1 and 2

3.7.2 Analysis of enacted TSPCK classroom practice

To measure the nature of the quality of enacted TSPCK displayed in real classroom teaching, two consecutive video recorded classroom lessons each lasting 45 minutes were captured from the subset of the two groups of intervention and comparable GBTs, and one expert teacher shown in Figure 3.11 above. All the participants taught in Grade 11 classes, in schools considered comparable, as indicated in Table 3.4. In addition, pre/post-lesson interviews were also held. In this analysis, as mentioned above, each participant was considered a separate mini case, unlike in planned TSPCK, where the comparisons were done across pairs.

According to Maykut and Morehouse (1994), "the task of the researcher in qualitative data analysis is to find patterns within words and present the patterns for others to inspect, at the same time staying as close to the construction of the world as the participants originally experienced it" (Maykut & Morehouse, p. 18).

All the video recorded lessons and interviews for each participant were first transcribed verbatim into a textual format. The converted texts were then analysed using both qualitative in-depth analysis and comparative methods.

The qualitative in-depth analysis method, similar to in-depth analysis of explicit PCK (Park and Chen 2012), involved watching the recorded video lessons vis-à-vis the textual transcripts and looking for evidence of moments that demonstrate presence of TSPCK episodes displayed in the observed video recorded lessons with the help of a team of three independent raters, including myself as the fourth rater. This was followed by marching the identified episodes into pre-determined categories of quality in a newly-developed and validated TSPCK classroom rubric for scoring TSPCK in action (described in greater depth below).

The comparative method involved continuous comparison of suggested similarities and differences of specific incidents in the transcribed scripts to show the different kinds of quality episodes and merging them into a proxy value, before coding them into the quality categories. Methodologically, the qualitative in-depth analysis of the identified TSPCK episodes and comparative methods helped to ensure credibility of the research findings (Baton, 2002). The extent of agreement between my scores

and the scores awarded by the independent raters were further validated using the Cohen kappa inter-rater reliability index for qualitative items (Landis and Koch, 1977) as discussed above.

The data collected from the pre- (post-) lesson-interviews, where there were no a priori categories were analysed inductively and used as content supporting emerging patterns from the identified TSPCK episodes.

According to Park and Chen (2012) the quality of PCK depends on the coherence among the PCK components as well as the strengths of individual components.

In this study, similar to the study conducted by Park and Chen (2012), a TSPCK episode is described to indicate a specific teaching or planning segment that displays the interactive use of two or more components of TSPCK. This is where the components are seen to work together to support an explanation of a single or pair of related concepts. However, unlike Park & Chen (2012), in this study, in addition to the identification of TSPCK episodes and the sequence in which they emerge, the nature of the teacher task from which the episode emerges, is also identified (Mavhunga, 2018). According to Mavhunga (2018), the identification of such tasks informs science educators of the task that promote emergence of TSPCK, which is a desired attribute of pedagogical transformation of content knowledge.

The pictorial visual display that describes connections between two or more components used in portraying how TSPCK components interact in a teaching context is defined in this study as a TSPCK Map, similar to PCK Maps (Park & Chen 2012).

The teacher task from which the episode emerges was represented as a rectangular box, a platform onto which the TSPCK Map is depicted. Particular attention was placed on capturing and portraying the evidence exhibiting the structure in which the visible component interactions occurred. For example, where the component interactions were found to be inseparable and interlinking, they were presented in an interwoven sequence with overlapping circles. In cases where the components were found to interact evidently and distinguishably in a linear standalone sequence, they

were represented with a linear arrow pointing out the sequence in which the components emerged in a TSPCK Map.

The identified episodes were therefore based on observable aspects of teaching, the reasoning and the opportunity to access the thinking underpinning and/or informing the actions displayed in the observed lessons.

I went a step further to try and evaluate the quality of component sophistication brought to the explanations in the identified episodes by the multiple levels and/or dimensions of the identified TSPCK episodes. For example, identifying the multiple sub-component levels in the TSPCK component of representations at the three levels of teaching as macroscopic, symbolic and sub-microscopic simultaneously; or the different dimensions in the TSPCK component of curricular saliency, where emphasis is placed on the most important aspects in the discussion. In addition, showing evidence of awareness of foregrounding concepts needed prior to teaching a topic, while indicating what to avoid in an explanation, considered in the same TSPCK episode. Evidence of such multiple levels of TSPCK component sophistication, where the components were found to be repeated more than once, was viewed as adding more depth to the explanations.

According to Park and Chen (2012) the "synergistic interactions among these components contributes to the quality of PCK and by extension TSPCK in a topic" (p. 937). I considered this ability a manifestation of the quality of TSPCK inherent in the displayed TSPCK episodes, and thus the quality of enacted TSPCK observed in real classroom practice or not. The integration among the components of TSPCK therefore formed the focal character that illuminated the quality of TSPCK in the observed lessons. For instance, a TSPCK episode displaying more content components in a stretch of time reflected high quality TSPCK. On the contrary, a TSPCK episode, where fewer content components were displayed, was categorised as pedagogically weak.

In the following section, I provide a brief description of the rubric used to capture and score the nature of enacted TSPCK in real classroom teaching.

3.7.3 Instrument used to capture enacted TSPCK in classroom teaching

In order to respond to research Question 3, there was a need for a rubric that would evaluate and grade the quality of enacted TSPCK displayed in the classroom teaching of the sampled GBTs and the expert teacher. I scanned the available literature but could not find an appropriate tool that could fit the TSPCK construct in enactment. The construct of TSPCK is premised on the visible interaction of its components. Studies conducted along this line, but for the PCK construct, capture such interactions, but do not proceed to evaluate the quality of their observations (e.g. Park & Chen 2012). Therefore, I developed a rubric that would score and grade the quality of enacted TSPCK observed in real classroom teaching, which I have called a TSPCK classroom rubric for scoring TSPCK in action.

The development of the new rubric resulted from the qualitative in-depth analyses and comparison of repeating patterns of analysed video-recorded classroom lesson observations of three experienced physical science teachers. The technique used for analysis and coding the observed video recorded lessons followed a process of qualitative in-depth analysis of explicit TSPCK similar to that of Park and Chen (2012), with the assistece of a team of three independent raters, including myself as the fourth rater. The validity of the rubric was established using construct validity as described by Kane (2012) in interpreting empirical data collected from the classroom teaching of the two different samples of teachers. A sample of three experienced Physical Science practicing teachers and a separate sample of three pre-service teachers, all taught the same topic of stoichiometry.

The newly developed and validated rubric is comprised of three categories of quality that capturers and portrays the different TSPCK episodes demonstrated in a lesson and the subsequent display of the identified episodes in a pictorial analytical tool that I have called TSPCK teaching profile.

The three categories of quality have been named in this study as: (i) simple TSPCK quality episode category, which corresponds to the limited quality of TSPCK; (ii) Proficient TSPCK quality episode category, which indicates developing quality of TSPCK; and (iii) sophisticated TSPCK quality episode category, which designates

exemplary quality of TSPCK. These were the quality criteria used in the new TSPCK classroom rubric to capture and grade the enacted TSPCK displayed in the observed classroom lessons of the six GBTs and one expert teacher in response to Question 3 (see Figure 3.11).

The newly developed and validated classroom rubric for scoring TSPCK in action helped me to score and grade all the identified TSPCK episodes observed in the real classroom teaching of all the participants. Because the newly developed rubric was so critical in establishing results on enacted TSPCK, I have fully expanded on its development and validation in the next Chapter 4 (see Appendix B).

In summary, the findings from the analysis of both primary and secondary data sets were corroborated and used to respond to the main research question asked in this study, which sought to find out how the early exposure of GBTs to explicit PCK development in specific topics influences retention of the quality of acquired TSPCK and their actual classroom teaching.

I made deliberate efforts to fully describe and document, in thick detail, all the methods, procedures and techniques followed in carrying out this study. This was to make thorough interpretations of all the participants involved through data triangulation, as discussed in the next section.

3.8 Reliability and Trustworthiness

Trustworthiness refers to the confidence or trust one can have of a study and its findings (Robson, 2011). According to Jason Loh (2013) citing (Lincoln & Guba, 1986), trustworthiness involves ensuring that the research process is truthful, careful and rigorous enough to qualify to make claims that it does. The author argues that the quality and rigour of using a set of quality criteria should be widely recognised and accepted in the broader field of research, through member checking and peer/audience validation. Lincoln and Guba (1986) contend that the use of the terms internal validity, external validity, reliability and objectivity by quantitative researchers parallel the use of qualitative researchers' use of the terms credibility, transferability,

dependability and confirmability respectively, as analogue in demonstrating the trustworthiness of a research project. In this study, these terms have been used interchangeably, as both qualitative and to a lesser extent quantitative scores were used to measure retention of the quality of GBTs acquired TSPCK at the time of the pre-service intervention programme and their actual classroom teaching. According to Cohen, Manion, and Morrison (2011), threats to validity and reliability can never be erased completely, but rather the effects of threats can be attenuated by attention to validity and reliability throughout a piece of research.

To ascertain the trustworthiness of the data collection process, use of appropriate research methods were employed. According Yin (2015), credibility or internal validity refers to the extent to which the study actually investigates what it claims to investigate and reports what actually occurred in the field. The American Educational Research Association (1999) meanwhile defines internal validity as the degree to which the evidence supports that the interpretations are correct and that the way the interpretations are used is appropriate. Credibility in this study was ascertained by first enlisting three qualified and experienced physical science teachers, with strong background knowledge in PCK education and research as independent raters. The independent raters helped in scoring the completed TSPCK test tools, as well as watching, analysing and scoring data captured from the video recorded lessons. For instance, the independent raters and I discussed and corroborated the analysed data for each identified TSPCK episode displayed in the video recorded lessons, following a discussion on the rules for scoring, explained under the data analysis section. Secondly, the extent of agreement between my scores and those awarded by the independent raters was validated using the Cohen's Kappa inter-rater reliability calculations for qualitative items (Landis & Koch, 1977).

The validity of the research findings was further ascertained by discussions about the conceptual rationale of TSPCK in the literature review Chapter 2, and its distinction from other versions of PCK, as suggested in the taxonomies of PCK (Nezvalová, 2011; Veal & Makinster, 1999). According to Kane (2006), construct validity requires arguments that provide the conceptual understanding behind the

entity being measured, as well as arguments showing evidence that the generated data or measurements actually measures the intended entity. Kane (2006) refers to conceptual argument as the interpretive argument, and arguments on measurements as validity arguments. Therefore, the discussions about the conceptual rationale of TSPCK contributed towards the interpretive component of validity for this study.

To ensure the dependability of my study findings, care was taken through describing in thick detail, the treatment given to the GBTs over the entire intervention programme. Ponterotto (2006) has shown that the researcher's task of fully describing and interpreting the participants observed actions in adequate detail provides a context for understanding the study results. Furthermore, a control group of three comparable-GBT participants, marching the sample of intervention GBTs' was used as a research technique, so that similar studies can be replicated elsewhere within the same context. In addition, triangulation of data from multiple sources to collaborate written responses in the test tools served as a reliability or dependability measure for the study. According to Stake (2005, p. 453), triangulation clarifies and verifies the repeatability of an observation and interpretation. Therefore, triangulation of data sources and methods were used to help in answering the same research question from different perspectives.

For example, through methods of triangulation i.e., use of lesson observations, pre/post lesson interviews etc., I was able to fully explain the richness and complexity of the TSPCK component interactions displayed in the GBTs video lessons.

Transferability, which according to Yin (2009) involves establishing the domain to which study findings can be generalised, was determined largely during the sampling process, where any member of the target population had an equal chance of participating in the study on a willingness, convenience and availability basis. This ensured the generalisation of the research findings to the whole target population. The issue of transferability was further addressed through comparisons of the findings generated from experiences of the different GBT cohorts over the same period of teaching time.

On the other hand, confirmability is according to Jwan & Ong'ondo (2011), the extent to which the research findings are free from both internal and external influences of the researcher, participants or institutions involved in the study in qualitative research. Hammersley and Atkinson (2007) argue that every researcher inevitably influences his/her study to some extent, through selection of participants, deciding on the research questions and at times where to conduct the research. This influence did not however justify pre-determined desired outcomes, but instead drove a commitment to generate the most confirmable data that circumstances would allow. According to Bourke (2014), there is a need to be clear with oneself and the participants, about the motivations for collecting data. I thus made sure I was forthright in communicating my positionality with all the participants through fostering greater openness between the participants and myself. I also endeavoured to maintain an open mind, by keeping thick descriptions of the procedures and methods followed over the entire study period. Furthermore, my status of having not been involved in the pre-service intervention study programmes, made my data generation more objective than it perhaps could have been. Therefore, although I might have had some slight influence on the research findings, it did not lessen the trustworthiness of my research findings. Finally, I have acknowledged my reflexivity in the research process and any possible influence on my study findings in the following section.

3.9 Reflexivity

Reflexivity suggests that "researchers should acknowledge and disclose their own selves in the research, seeking to understand their part in, or influence on the research" (Cohen et al., 2014 p. 225). Reflexivity thus involves a self-scrutiny on the part of the researcher; a self-conscious awareness of the relationship between the researcher and an "other" (Pillow, 2003). According to Tracy (2010) self-reflexivity, in qualitative research is considered as honesty and authenticity with one's self, research and the audience. My personal experience as a science education researcher remained an integral part of this research process. In Chapter 1, I described the positionality from which I approached this study as a product of

biographical location and social context. This is a position I tried to be aware of in respect to my own values, assumptions, bias and worldview, as a lens through which I constructed meaning from the data acquired during the research process. I valued other professionals' contributions that included my supervisor's constant advice and genuine guidance, the independent raters' comments made during the peer validation process of the video recorded lessons and scoring the TSPCK test tools, as well as the teachers that I observed during the lesson observation sessions in real classroom teaching.

3.10 Ethical considerations

This study requires consideration of how research purposes, contents, methods, reporting and outcomes abide by ethical principles and practices (Cohen et al., 2011). I had to first satisfy my University's Human Research and Ethics Committee (Education) for clearance involving non-medical participants (Appendix, M) by confirming that I had complied with all the requirements to ensure appropriate informed consent, confidentiality and anonymity of the participants. Secondly, I sought clearance from the Gauteng Department of Education (GDE) in Gauteng Province (Appendix N). The GDE approved the study, endorsing that it bore no potential harm to the participants and the learners in the classrooms. After this approval was granted, I met with the participants and utilised the same opportunity to seek for their consent, both verbally, and in writing. The principle of voluntary participation and informed consent was applied in this study. A request for consent was sought from all the other participants, who were fully informed about the intentions and procedures to be followed in the research study. All participants voluntarily consented to participate in the study by signing consent request forms. Samples of the consent letters written to each of the sampled participants, clearly setting out the aim of the study are provided as (Appendix O).

In all the cases for the learners, I explained the issue of informed consent, although, I did receive some assistance from the GBTs, who helped me to collect the signed consent letters from the learners, as well as in helping to talk to the learners to

request their parents/guardians to read and sign up their respective consent forms, on my behalf. A brief discussion with the learners assured me that most parents were able to read and understand what they were signing.

The study did not pose any physical or serious psychological harm to the participants, as a result of their participation. The partcipating teachers and their students, remained in their formal learning environment, undisturbed in my presence as the researcher. However, besides having sought the participants permission to collect data in their classroom lessons, the GBTs experienced the risk of anxiety regarding the audio video-tape recordings of their enacted lessons and the video-stimulated post lesson interviews. This risk was mitigated by clarifying upfront the confidentiality of the study findings, and protection of the privacy of all participants who took part in the research study. In order to protect the privacy and confidentiality of the research participants, pseudonyms were used to conceal the identity of the sampled participants and their respective schools. Furthermore, any identified information was not made available to anyone else, except myself as the researcher, my supervisor and the enlisted independent raters who assisted in scoring the completed TSPCK tools and watching/coding the video-recorded lessons.

All the participants accepted to participate in the study willingly and voluntarily. The study attempted to bring out; that which is normally implicit, tacit, private or individual, into view of participating physical science teachers, their colleagues and the entire science education PCK community. The teachers who participated in this research study might benefit from the research findings through renewed reflections on their own classroom practice as beginning teachers. This is because I hope to publish the final research findings of this study and disseminate the same to the PCK science research community, interested education stakeholders, and all other relevant parties. In this way, I hope to address the issue of responsibility amongst the participants.

3.11 Reflection

The research methods employed in this study were designed to first investigate whether the quality of TSPCK acquired by GBTs from the explicit intervention studies conducted during the pre-service programmes is retained when they reach the place of work. Additionally whether the teachers bring any added advantage in their actual classroom teaching.

As alluded to earlier, this study was limited by the small sample size used, and hence the data collected could not be sufficient in generalising the research findings. However, as pointed out by Goodrick (2014), generalisation in comparative case study designs emphasises transferability of the causal propositions to other contexts, rather than generalising from one case to a wider set of cases. This difference in the scope of generalisation diverges from the traditional focus on generalising from a sample to the population to instead emphasise, as in the case of this study, generalising propositions about the characteristics that are predictive of success and failure of an intervention programme. According to Davis et al. (2006) "researchers should try to un-pack differences among individuals, rather than assuming homogenous participants." A closer examination of the patterns emerging from the study findings consequently points to the possible advantage derived from the early exposure to explicit TSPCK development regarding the quality of intervention GBTs' actual classroom teaching.

CHAPTER FOUR

DEVELOPMENT AND VALIDATION OF A CLASSROOM RUBRIC FOR SCORING TSPCK IN ACTION

In Chapter 3 I outlined the research methodology followed in eliciting answers to the research questions in this study. This chapter focuses on the third research question posed regarding the nature of the quality of enacted TSPCK that was displayed in real classroom teaching by graduate beginning teachers of science (GBTs) in the early years of their careers. In the absence of a suitable tool in the literature that would capture and grade the quality of GBTs' enacted TSPCK displayed in their classroom teaching, there was a need to design one. The conceptualisation of the TSPCK classroom rubric was guided by the TSPCK theoretical framework, which is based on the five content specific components of TSPCK. It was further informed by two principles that when interpreted and combined, point to the need to spell out explicitly the behaviour of the components of the construct of TSPCK that reflects proficiency. The development of the rubric followed the two common stages in qualitative research of development and validation. Finally, the validity and reliability of the classroom TSPCK rubric in action is argued.

4.1 Introduction

According toDarling-Hammond and Lieberman (2013), teacher quality is one of the most important contributing factors to student learning. Many education researchers argue that teachers' professional knowledge is an internal construct, which is tacit and difficult to observe and articulate easily (Hume & Berry, 2010; Loughran et al., 2008). According to Shulman, PCK is the category of professional knowledge base for teaching that embodies the aspects of content most germane to its teachability (Shulman, 1986, p. 9). PCK is thus defined to be influenced by a combination of what a teacher knows, what a teacher does, and the reasons for his/her actions (Rohaan et al., 2009, p. 158). This suggests that the process of capturing and

portraying PCK is a challenging endeavour, and not easy to express in any particular context (Aydeniz & Kirbulut, 2014). Despite this complexity, there is a general consensus among education researchers that PCK is a valuable theoretical construct for implementation in initial teacher preparation programmes (Abell,2008; Mavhunga, 2015). In acknowledging the complexity associated with PCK, Aydeniz and colleagues (2014) advocate for tools that capture PCK in both planning and classroom practices. The motivation for developing a new TSPCK classroom rubric was premised on the fact that I could not find reference in the litertaure to an instrument that would specifically measure the quality of PCK (and by inference, TSPCK) displayed in real classroom teaching, particularly for Physics and Chemistry teachers. By way of contrast, tools that capture and also measure the quality of PCK and TSPCK in a planning context are readily available, for example CoRes (Loughran. et al., 2004) and a specially designed TSPCK tool in Chemical Equilibrium (Mavhunga., 2012).

In Chapter 3, I have outlined the research methodology followed in eliciting answers to the research questions in this study. Of particular interest in this chapter is the research question to assess the nature of the quality of enacted TSPCK displayed in the classroom teaching by the different cohorts of graduate beginning teachers of science (GBTs), research Question 3. A suitable tool to capture and grade enacted TSPCK displayed in classroom action had to be designed. The task of judging behaviour invites some degree of subjectivity in the sense that the rating given often depends upon the rater's interpretation of the construct. One of strategies for reducing this subjectivity is to develop scoring rubrics (Moskal & Leydens, 2000; Tierney & Simon, 2004). The tool designed for the task was therefore in form of a rubric.

The process followed in developing the rubric utilised methods common in qualitative research and involved the two stages of development and validation. Primary data for the development stage was derived from analysis of two video recorded classroom lesson observations of three experienced physical science teachers, all teaching the same big idea, viz. the concept of the mole in the topic of Stoichiometry.

The data used for validation was based on the classroom teaching of two different samples of teachers, which were a sample of experienced practicing teachers and a separate sample of pre-service teachers, respectively. I conclude this chapter by making comments on the validity of the tool. Starting below is a discussion on the development stage.

4.2 Conceptualisation of the topic-specific PCK classroom rubric

The conceptualisation of the TSPCK classroom rubric for this study was guided by the TSPCK theoretical framework, based on the five content components of TSPCK. These components have been highlighted in both the TSPCK model presented by Mavhunga and Rollnick, (2013) and in the PCK consensus model as Topic Specific Professional knowledge (Gess-Newsome, 2015). The emphasis was, however, on ways of documenting and codifying experienced physical science teachers' pedagogical constructions employed in a classroom. According to Shulman (1987), one of the most important tasks of the research community is to work with practitioners, collecting, examining, and codifying the emerging wisdom of practice among experienced teachers. The traditional procedure proposed by Rohaan et al. (2009) for developing the rubric was chronologically broadly followed from:

(i) confirming the focal character revealing the TSPCK construct;
(ii) generation and Judgement of quality categories of TSPCK; and
(iii) validation of the instrument (Rohaan et al., 2009).

4.2.1 Confirming the focal character revealing TSPCK

Capturing enacted PCK and making judgments about teachers' PCK is problematic, because although there is consensus on the definition of PCK (Gess-Newsome, 2015), it is a form of tacit knowledge (Kind., 2009), which is difficult to fully describe and capture in action. The challenge in examining PCK, and by inference TSPCK, remains to be the defining focal evidence that reflects the construct.

According to the Teacher Professional Knowledge and Skill (TPK & S) model (Gess-Newsome, 2015), the “Topic Specific Professional Knowledge base” (TSPK), which parallels TSPCK in this study, makes explicit that:

- the content for teaching occurs at a topic level and not at a discipline level;
- the knowledge blends subject matter, pedagogy and context; and
- it is recognised as public knowledge or knowledge held by the profession, allowing it to assume a nomadic role.

TSPCK is thus construed as canonical knowledge, generated by research and best practice, and can have a normative function in terms of what teachers know about a topic. The development of the rubric was informed by two principles. The first is based on the emphasis placed by Moskal and Leydens (2000) on the importance for criteria in a rubric to spell out the qualities that need to be displayed and regarded as reflecting proficient performance. That is, what constitutes proficiency is spelled out explicitly.

The second principle, proposed by Arieli-Attali and Liu (2015), asserts a well-crafted rubric where the measurement of the proficiency of a performance should be described from spelling out the desirable behaviour of the components of the construct. That is, what constitutes proficiency should be described from the perspective of the components of the construct being measured. Furthermore, the criteria should display aspects of response types in terms of how they indicate partial or full understanding of the focal construct the rubric should describe. In this study, I adopted both authors’ views, interpreted when combined to point at a need to spell out explicitly the behaviour of the components of the construct of TSPCK that reflects proficiency. The first step followed was to spell out the behaviour of the components of the TSPCK construct through which proficiency is defined. This was achieved through the interpretive argument (Kane, 2012) on the conceptualisation of the quality of TSPCK. As discussed before in the literature review, TSPCK has components that are known to be content specific. These are:

(i) Learner Prior Knowledge (LP), which refers to common learner misconceptions and alternative conceptions about a particular content.

(ii) Curriculum Saliency (CS). This component refers to the learning of the various topics relative to the curriculum as a whole. It is the understanding of which topics are the most central (big ideas), and the ones that are more peripheral. Such understanding enables teachers to judge the depth and sequence to which a topic should be covered and hence the amount of time to spend on it.

(iii) What makes a topic difficult to understand (WD). This component constitutes the teacher's ability to identify key gate-keeping concepts, within a lesson that pose potential difficulty for learner understanding and generates dedicated awareness and possible interventions for teaching them.

(iv) Representations (RP). This component refers to a range of subject matter representations including examples, illustrations, analogies, simulations and models that are appropriate for teaching various concepts of the topic. Chemistry teachers in particular make extensive use of a variety of representations and the rationale for using them to represent subject matter.

(v) Conceptual Teaching Strategies (CTS), which refer to effective instructional strategies for particular misconceptions, known areas of difficulty to learn, or known importance of concepts. CTS also refer to the use of a combination of conceptual principles and rules of a topic as tools to confront potential confusion and misconception. This componenet therefore pulls all the thoughts from the other four categories, in descriping how a lesson would unfold sequentially.

TSPCK is, however, considered not to be a linear sum of the listed components, but their interaction among each other (Park & Chen 2012). Similar to the broader PCK construct, the extent of this interaction is considered to reveal a measure of the quality of TSPCK (Aydin, Demirdogen, Akin, et al., 2015). Therefore, the TSPCK component interaction was the 'focal character' of classroom practice. It is the visible evidence of component interaction that reveals the quality of the focal construct in this study. What was however not known at the beginning of this process were the formats in which this character (TSPCK component interaction)

occurs in classroom practice, and whether the formats differ from each other to distinguishable extents that could be regarded as different categories of the quality of TSPCK. A performance that demonstrates component interaction in a teaching context would show explicitly how a teacher uses these components interactively in a particular time. Such a performance is referred to as a 'TSPCK episode'. The idea is taken from Park and Chen (2012), who define a PCK episode as a performance where at least two components of PCK interact to support teaching. Similar to Park and Chen (2012), a TSPCK episode is described in this study as connections between two or more of the content-specific components used in defining TSPCK. Seeking for the TSPCK episodes in the recorded lessons of practicing teachers allowed me to further identify the nature of specific teacher tasks within which the episodes were embedded. The connections and the observed relationships between the TSPCK components in a TSPCK episode were portrayed pictorially as TSPCK maps. A TSPCK map is defined in this study as a visual display that describes connections between two or more components used in defining how TSPCK components interact from a teaching context. In this study, the visual display includes the teaching task, from where the TSPCK episode has been extracted, represented as a rectangular box, a platform onto which the TSPCK episode is depicted. To clarify this, an example where a TSPCK episode is identified from a teaching segment and its analysis is provided below. The sample used below is a direct transcription of text that was extracted from one of the video recorded lessons. The text is a teaching segment with a TSPCK episode, which contains the simplest component interaction made of only two TSPCK components. Figure 4.1 shows the visual display called TSPCK Map depicting the observed component interaction.

Below is an example of a teaching segment on video of a lesson introduction on the topic of mole:

Extract: Teacher: "what do you understand by the term mole? What comes into your mind when you hear the word mole, a unit of measure, or amount of a substance? Like a bag of oranges, a dozen eggs, a litre of gas… what comes into your mind?" **(LP)**. The teacher repeats the same question, as he lifts up different substances from the laboratory table **(RP).**

Teacher: "What comes in your mind when I mention, one litre of water, a gross of tiles, one ton of sand, what comes into your mind?"

Summarised description of the teaching segment from which the episode emerged.

Prior to explaining 'the mole', which was the new concept to be learnt, the teacher begins the lesson by probing for learners' prior understanding on the meaning of the concept of the mole as an amount of substance indicating an aspect of the TSPCK component of learner prior knowledge (LP), shaded in yellow. His probing is simultaneously done with presentation of macroscopic representations (RP) shaded in green, of substances whose amount is expressed through their bulk packaging. It is interesting to note the nature of the concrete analogous examples of representations used as they all represent bulk counting rather than mass. In the teaching segment, we see a TSPCK episode with two TSPCK components, working together in an interwoven manner to support an intention to make a particular concept explicit. The components involved are (LP) and (RP), which could be represented as (LP/RP) as a configuration that shows that, the teacher simultaneously goes in and out of the two components, but the component of (LP) emerged first and that of (RP), was interwoven into the talk about (LP). Figure 4.1 shows the TSPCK episode pictorially as a TSPCK Map. This process was repeated in analysing and recording all the other TSPCK episodes identified from the recorded video lessons.

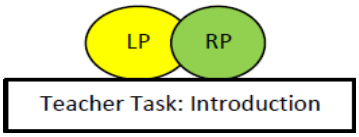


Figure 4.1: A TSPCK Map displaying a simple TSPCK episode

In this study, the TSPCK component interactions were confirmed in a discussion with a reference team of three independent raters. The team of independent raters, who helped in analysing, scoring and hence peer validation of the identified TSPCK episodes, comprised one experienced science teacher educator, with many years of teaching, supervision and research in PCK at both pre-service and in-service teacher development levels. The other two raters were doctoral students in science education, who were both qualified and experienced physical science teachers, with strong background knowledge in science education and interest in PCK research. Prior to scoring the video recorded lessons, the raters were first familiarised

themselves with the rubric and the rules of engagement, as discussed in section 4.2.1 above. The identification of TSPCK episodes in the recorded lessons as the evidence that displays proficiency from the perspective of the interaction of the content components of the construct measured was in line with the call by Arieli-Attali and Liu (2015) to spell out the components of the construct in terms of the evaluation criteria. The next step was to determine the possible categories through which the displayed proficiency (component interaction) could be described and classified.

4.2.2. Generating TSPCK quality categories and their description criteria

(i) The principle behind the generation of TSPCK in action quality categories

The literature points to, among others, two broad different approaches for developing rubrics. One is an approach where the categories and the items are pre-constructed from a well-established based knowledge. For example, a concept-based categorical rubric Arieli-Attali and Liu (2015) serve the purpose of making explicit two distinctions: (a) among the incorrect responses for the type of error or misconception identified; and (b) among the correct responses for the type of strategy or a conception evident in the response. The second approach is to generate the qualities and the associated criteria from real life experiences that demonstrate proficient performance (Moskal & Leydens, 2000). The second approach was adopted as more appropriate for the rubric, as in this case there is no correct and incorrect performance, bearing in mind that in teaching there is rarely a single correct way of teaching. The identification of component interaction (TSPCK episodes) by definition is confirming the presence of proficiency; what is however still missing is a description of its level. In this study, I adopted the approach taken by Moskal and Leydens (2000), where the levels of the scoring criteria for the scoring rubric are described by first establishing the top level. After the top level of performance criteria has been defined, the evaluator may move on to define the criteria for the lowest level of performance. This is the type of performance that suggests the most limited understanding of the concepts that are being assessed. The contrast

between the criteria for the top-level performance and bottom level performance would then suggest appropriate criteria for the middle level of performance. This approach results in three score levels, but if there is a need for greater distinctions, then comparisons can be made between the criteria for each existing category score level. The criteria to constitute a level is decided based on experience and knowledge of the construct, whether it is best to consider a level comprised of few specific lists of points that are evaluated individually or collectively to make a decision. Evaluation based on the individual criteria in a level would mean the rubric is analytic, while evaluation of the listed criteria collectively would mean the rubric is holistic. If an analytic scoring rubric is created, then each criterion is considered separately as the descriptions of the different score levels are developed. This process results in separate descriptive scoring schemes for each evaluation factor. For holistic scoring rubrics, the collection of criteria would be considered throughout the process of construction for each level of the scoring rubric, resulting in a single descriptive scoring scheme.

The new rubric adapted the holistic version of collective listing, which can be said to be aligned to the Mavhunga and Rollnick,(2013) rubric for scoring planned TSPCK, which was used during the intervention studies. The rubric for scoring planned TSPCK requires evaluators to make judgements for quantifying the quality of TSPCK based on the five knowledge components that enables transformation of content knowledge in a topic.

It is commonly expected in the PCK literature that expert teachers have PCK, and the quality of their PCK is likely to be good by virtue of their reflective experience in the field and are likely to demonstrate episodes of TSPCK in their teaching. Therefore, to determine possible differing extents through which TSPCK components interact, in the TSPCK episodes and the likeliness of observing sophistication in the component interactions, it was best to observe the teaching of expert teachers.

I further made reference to the four qualities of a good rubric advocated in the work of Brookhart (1999), which are: (i) having fewer and meaningful score categories; (ii) mutual exclusiveness of the categories; (iii) use of a set of anchors or key

words/labels as a reference to assist raters during the scoring process; and (iv) involving independent raters to validate the descriptions in the scoring rubric.

(ii) Creation of TSPCK quality categories

Three expert teachers were observed teaching two consecutive lessons**,** in the topic of stoichiometry, targeting the big idea of the mole in Grade 11, to the same kind of learners. They were considered expert by virtue of their reflective experience in the field, having taught the same topic in the same Grade for more than six years, see Table 4.1 below. As argued in the literature, PCK is widely understood to be developed with extended time, full of reflection on and re-teaching a particular topic (Bishop & Denley 2007; Magnusson et al., 1999). Hattie (2003) argues that apart from content knowledge, expert teachers exhibit more pedagogical content knowledge that is important in teaching situations. Teacher expertise was thus based on the understanding in the literature that the teachers would effectively activate both content knowledge (CK) and pedagogical knowledge (PK) in line with Shulman's (1987) amalgam thesis of content and pedagogy as the unique province of teaching as a profession. Table 4.1 shows the bio-demographical information of the expert teachers.

Table 4.1: Bio-demographical information of the expert teacher participants

Teacher	Qualification	Number of years of teaching	Main Teaching subject	Type of School
Atas	B.Ed. Dip Edu	7	Physical science	Township
Laurent	B.Sc., B.Ed.	6	Physical science	Township
Charlie	B.Ed. Dip Edu	8	Physical science	Township

Note: Pseudonyms were used to conceal the identities of the expert teachers who participated in the video-recorded classroom lessons

The expert teachers who participated in the collection of data that was used to generate the quality rubric categories were all holders of a Bachelor of Education degree in Physical Science (B.Ed). The teachers were all practicing physical

science teachers, whose experience ranged from five to eight years of teaching the subject at senior Grades 10-12. In addition, the three teachers were all enrolled as part-time master's degree students in the department of Mathematics and Science Education at my University. The analysis of the recorded video lessons was in two stages, the first of which involved watching and replaying the video-recorded lessons and looking for evidence of moments that demonstrate presence of TSPCK episodes. This was followed by categorising the identified TSPCK episodes into different quality categories of TSPCK. The identified episodes were categorised by their similarity and complexity in order to bring to the fore the existing pattern. The emerging categories of TSPCK episodes were described to elucidate their criteria and nature. Table 4.2 below shows the number (quantities) of TSPCK episodes identified in the different teaching segments for each teacher.

Table 4.2: Number of TSPCK episodes identified per expert teacher

Teacher	Quantity of TSPCK Episodes across 2 lessons
Atas	5
Laurent	4
Charlie	4

The analysis of the video-recorded lesson transcripts captured from the classroom practice of the three expert teachers revealed a total of 13 TSPCK episodes. As mentioned before, the purpose here was not to compare the teachers, but to capture the kind of TSPCK episodes they display, in order to establish emerging categories for use to create levels of quality in the rubric. On close examination, the 13 episodes could be classified based on the number of TSPCK components found interacting in a TSPCK episode, into four categories. These are two, three or four component episodes with versions of components found repeated. Table 4.3 below shows the breakdown of the identified four-episode categories.

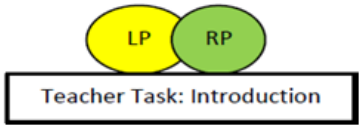
Table 4.3: Breakdown of the expert teachers' TSPCK episodes per category

Expert Teacher	2-component TSPCK Episode	3-component TSPCK Episode	3 components plus one repeating TSPCK episode	4 components plus one repeating TSPCK episode	Total
Atas	1	2	1	1	5
Laurent	1	2	0	1	4
Charlie	1	2	0	1	4

Generally, the two component episodes were identified from the teachers' introductory statements, while the other three component episodes unfolded as the lessons progressed. The TSPCK component interactions would either be in form of a standalone linear sequence, or interwoven component interactions or both. Interwoven interactions are episodes where the teacher explains a concept by moving in and out of the two components or uses one as symbol, as she/he explains 'over' it simultaneously. A linear sequence, on the other hand, refers to components in a TSPCK episode that were used one at a time in a sequence. Following below are sample extracts of TSPCK episodes, lifted from the expert teacher's video recorded classroom lessons in each of the four-episode categories and their corresponding TSPCK Maps.

A. Nature of Category -1 interactions: 2- component TSPCK episodes

Herewith below, I describe the nature of two-component TSPCK episodes observed and grouped as representing the lowest quality category of TSPCK component interactions.

<table>
<tr><th>Video extract from Teacher –Atas: Interwoven 2-component TSPCK Episode</th><th>Corresponding TSPCK Map</th></tr>
<tr><td>Teacher: "we are going to learn about a new physical quantity used for measurement called the mole; who can give me any physical quantity of measurement she/he has heard of, and the unit it measures…?"
The teacher gives leaners time to suggest various quantities of measurements, as he writes their suggestions and respective units in a tabula form on the blackboard.
Teacher: "Now, I want you to tell me…. what do you understand by a mole? What comes into your mind when you hear the word mole, amount, or quantity of a substance? Like a dozen eggs, a litre of water, a gross of tiles, one ton of sand as an amount, what comes into your mind?"(LP).
The teacher repeats the question, lifting up different quantities of substances from the laboratory table (RP).</td><td>

In this segment the components of Learner Prior Knowledge (LP) and Representations (RP) are used in a manner that shows interwoveness i.e. the two components interactively moving into each other. This is shown by the fact that while the teacher is asking learners about what they understand by mole as a unit of measure, he simultaneously refers to known counting packages and quantities of various substances as representations.</td></tr>
<tr><td colspan="2">Summarized description of the teaching segment from which the episode emerged. The teacher introduces a new physical quantity, the mole as amount of substance by probing for learners' prior knowledge (LP) about the meaning of mole, as a counting unit. He then uses examples of known counting measures of specific quantities of real objects, like a dozen of eggs, a litre of water, etc., an indication of use of representations at macroscopic level (RP) to link the new physical quantity to learners' daily life experiences of counting quantities/packages. Two TSPCK components working together to support an explanation of a single concept on the meaning of mole-TSPCK Episode; LP/RP</td></tr>
</table>

Figure 4.2: A sample video extract of a two-component episode from the teacher Atas

In the two-component TSPCK episode above, we see evidence of the simultaneous use of two components, interacting evidently in an interwoven structural formation, in the same teacher task segment. This is evident in the fact that the teacher begins by probing for learners' understanding about the meaning of mole as a unit of measure, an element of the component of leaner prior knowledge. He however simultaneously refers to different known counting quantities and packages, by physically lifting up the substances as representations. Figure 4.3 below shows examples of two-component TSPCK episodes.

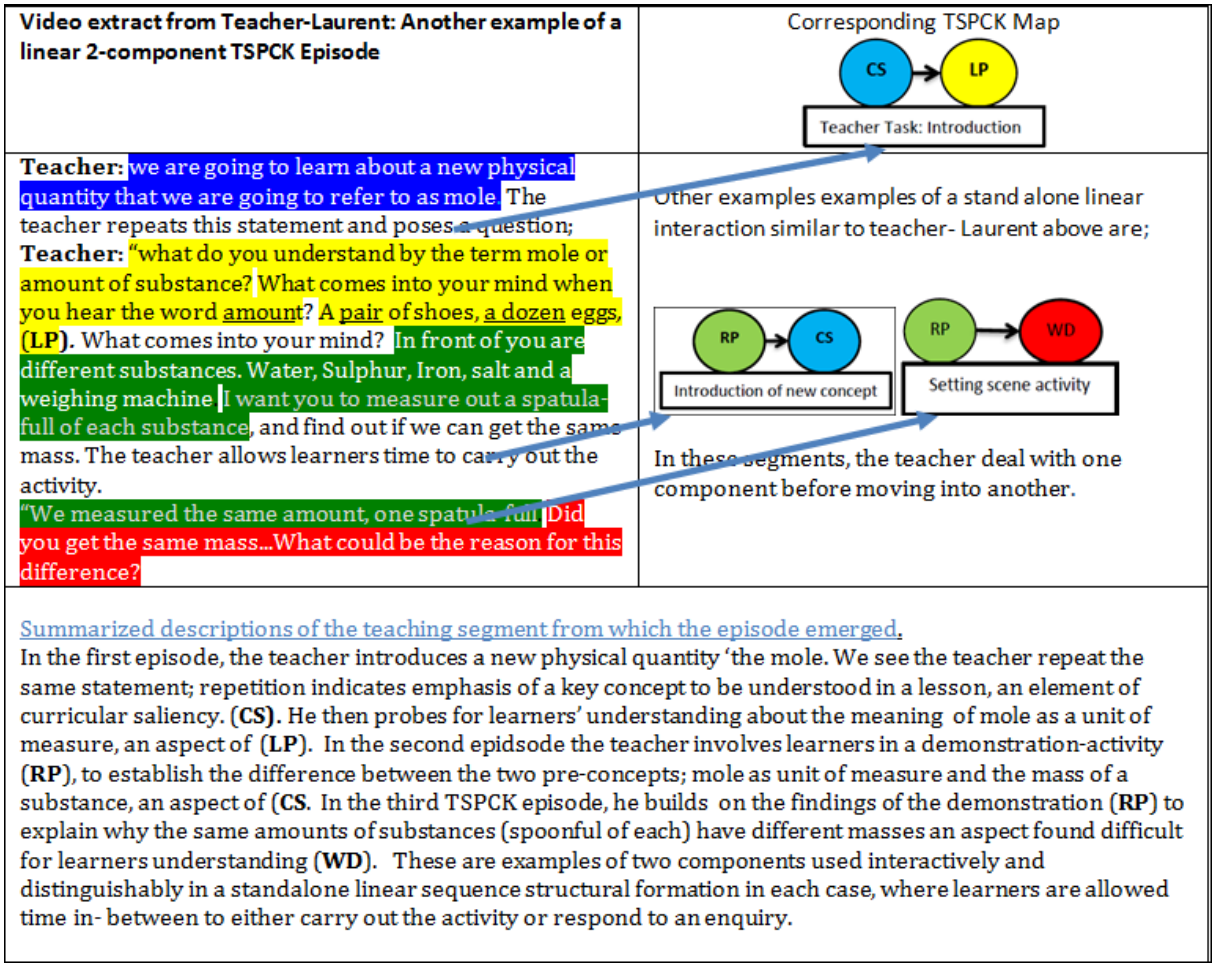


Figure 4.3: A sample video extract of a two-component episode from the teacher Laurent

In the TSPCK episodes described above, we see two different kinds of component interactions. In the first map, the teacher introduces the lesson by stating upfront the main concept to be learnt in the lesson. He emphasises the importance of the concept, by repeating the statement, which indicates awareness of the most important aspects in a lesson, an indication of the component of curricular saliency (CS). The teacher moves into the second component, by posing more questions, on what the learners understand about the new quantity of measurement, viz. the mole. He re-phrases the questions, for clarity as he continuously probes for learners' prior knowledge about the meaning of the mole as a unit of measurement (LP). In the second TSPCK episode, the teacher involves his learners in a demonstration activity (RP), to establish the differences between the two key pre-concepts; the mole as unit of measurement, and the mass of a substance, which need to be understood prior to

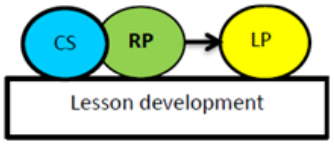
teaching the mole concept. The understanding of what pre-concepts are needed prior to teaching a particular concept is an aspect of curricular saliency (CS) (Geddis and Wood, 1997).

In the third TSPCK episode, the teacher builds on the findings of the learners' demonstration of weighing one spatula-full of different respective substances to find out why they are different in terms of their mass. According to Gabel (1998), experiments fall under macroscopic level of representations (RP). The explanation as to why the masses are different, yet the amounts weighed were the same, signals an aspect that learners often find difficult to understand (WD). In this segment, we see evidence of two difference components, where the macroscopic representation (demonstrations) comes first; before establishing the reason for the differences observed between the amounts measured and the observed masses, which indicates interaction of the components of representation and what is difficult to teach in a linear sequence. In the descriptions above, we see indications of three TSPCK episodes, in a linear standalone sequence structural formation: CS-LP, RP-CS, and RP-WD.

Under this category, Figures 4.2 and 4.3 indicates two-component TSPCK episodes that have component interactions of a different structural format. Each format emerges from a teaching segment that has its own merits. The next category presents examples of three-component TSPCK episodes.

B. Nature of Category -2 interactions: 3- component TSPCK episodes

Figure 4.4 below shows a sample of a video extrcts of a three- component episode.

<table>
<tr><th>Video extract from Teacher Charlie: Interwoven /linear 3-component TSPCK Episode</th><th>Corresponding TSPCK Map</th></tr>
<tr><td>Teacher: "We have realized that there is a relationship between mass and the mole. The bigger the mass the bigger the quantity of the substance-mole" The teacher repeats this statement. "This means that if we know the mass of a substance, we can calculate the number of moles of that substance" (CS)
The teacher then derives the formula for calculating the number of moles, on the chalk board (n=m/M) (symbolic- RP), and asks learners to use the formula to work out the number of moles for the different masses of the quantities of substances they had weighed earlier in their groups. Teacher: "Are you getting the same number of moles? What is the same here?" He repeats the question...." what are we finding different? When I talk about the mole I don't mean mass or volume, I mean mole (n) a scientific unit of measurement" (LP). The explicit emphasis of the meaning of mole not to refer to mass or volume but a unit of measurement is evidence of understanding of common misconception about the topic which indicates presence of the component of Learner Prior Knowledge (LP).</td><td>

In this segment three components; curricular saliency(CS), Representations (RP) and learner prior knowledge (LP)are used evidently and interactively in both an interwoven and a linear standalone sequence formation.
In the segment, the teacher begins by explaining the relationshiop between mass and number of moles(CS) . He then introduces an equation, to show the relationship between mass and number of moles (RP). He allows learners time to apply the equation, before finally summarizes the meaning of mole, by emphasizing what it does not represent. An indication of understanding a common misconception about the topic (LP).</td></tr>
<tr><td colspan="2"><u>Summarized description of the teaching segment from which the episode emerged.</u>
The teacher begins the segment by explaining the relationship between the number of moles and mass of a substance, a key concept needed to be understood in the topic, which falls under the component of curricular saliency (CS). He then introduces a formula to show the relationship between the number of moles and mass. The teacher allows learners time to apply the formula to work out the number of moles of different substances. Formulae fall under representations at the symbolic level (RP). He then moves into a separate component, emphasizing the meaning of mole, not to refer to mass or volume, but a scientific quantity of measurement which indicates evidence of understanding common learner misconception about the topic (LP). Three different components are interactively and evidently used in both an interwoven and linear standalone sequence structural formation.
TSPCK episode; (CS/RP-LP).</td></tr>
</table>

Figure 4.4: A sample video extract of three-component episode from the teacher Charlie

In contrast to the two-components interwoven and linear stand-alone sequence episodes depicted in Figures 4.2 and 4.3 above, the three-components episode, shown in Figure 4.4, displays three components in both an interwoven and a linear stand-alone sequence structural formation. This is evident in the opening statement, where the teacher begins by explaining the key concept in the lesson, which is the relationship between mass and number of moles. This indicates drawing on the element of curricular saliency (CS). He then applies an equation, to relate the mass and number of moles before allowing learners time to work out a few examples

using the equation. Equations fall under the symbolic sub-level of the component of representations (RP). The teacher then moves into a different component, where he confronts a common learner misconception by emphasising the meaning of mole not to represent mass or volume, an indication of presence of the component of Learner Prior Knowledge (LP). The first two components are used together in an interwoven manner, before the teacher moves into the third component. The TSPCK components emerge in both interwoven and linear structural sequence formation (CS/RP-LP).

Another example of a three-component interaction similar to the three-component TSPCK episode above shows a stand-alone linear structural sequence, as indicated below.

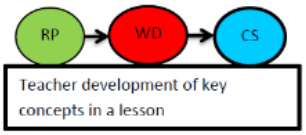
Sample Video extract from Teacher- Atas: showing 3-component linear TSPCK Episode.	**Corresponding TSPCK Map**
Teacher: "In front of you are five different substances. I want you to take the same spatula- full measure of each substance and find out the mass of each". **(Macroscopic-RP)**. The teacher allows time for students to carry out the activity. **Teacher:** "You measured the same amount of each substance, but you got that the mass of sulphur is different from the mass of sodium chloride, which is different from the mass of iron and different from that of water, same quantities, a spatula-full of each substance but the masses are not the same" The teacher then poses several questions. **Teacher:** "What could be the reason for these differences? What is different about the different substances? What makes water, water, how is sulphur different from iron?" **(WD)** The teacher finally explains the findings observed. **Teacher:** "we are getting different masses because atoms of different elements have different atomic masses, because of the differences in the number of protons and neutrons" **(CS).**	 In this segment, teacher Atas begins with a demonstration-activity, thus drawing on the component of representations (RP). He then probes for reasons why similar measures of different substances have dfferent masses, which indicates an aspect leaners find difficut to undestand (WD), before explaining the reason for the observed findings, which ushers in the component of curricular saliency. (CS). Three components are seen to interact evidently and distinguishably in a linear stand alone structural component formation.
Summarized description of the teaching segment from which the episode emerged. In this episode, we see evidence of three different TSPCK components interacting evidently, in the same teacher task segment. The teacher introduces the segment with an activity, measuring the same amount of different substances (RP). He repeatedly probes for the reasons behind the observed experimental findings, which indicates awareness of a key gate keeping concept deemed difficult for learner understanding in the topic (WD). He explains the reason for the observed differences, addressing the main concept under discussion (**CS**). Three components interacting one after the other in a linear stand-alone sequence. **TSPCK episode: (RP-WD-CS).**	

Figure 4.5: A sample video extract of three-component episodes from the teacher Atas

The three-component linear standalone sequence in Figure 4.5 above is different from the two components standalone linear episodes in Figures 4.2 and 4.3, and the three-component' interwoven/standalone linear sequence structural formation

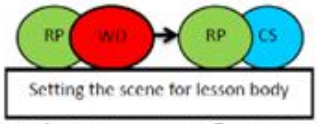
episodes shown in Figure 4.4. In the episode above, we see evidence of the three components interactively used concurrently, but one after another in a distinct standalone structural formation. In the episode, the teacher deals with the component of representations (RP) first, which is evident when he begins the segment with a demonstration. He then allows time for learners to carry out the activity, before moving into a second component of what leaners find difficut to undestand (WD), shown when the teacher probes for reasons why similar measures of different substances have dfferent masses, and finally explains the reason behind the differences observed in the demonstration (CS).

It is observed that, similar to the two-component interactions, the 3 –component TSPCK episodes could either be of an interwoven nature or a distinct linear sequence or comprise both an interwoven and linear stand-alone sequence. However, this category also had a different version of TSPCK episodes, where one of the three components was found repeated, as discussed below.

C. Nature of Category 3 interactions: Three-component TSPCK episodes with one component repeating.

Figure 4.6 below shows a sample video extract of three-component episode with one repeated from Teacher.

<table>
<tr><th>Sample Video extract from Teacher-Laurent; Interwoven /linear 3-component +1 repeating TSPCK Episode</th><th>Corresponding TSPCK Map</th></tr>
<tr><td>Teacher: "It is very difficult to measure the mass of a gas...For gases we use volumes".
The teacher displayed a visual slide depiction, showing different volumes of gases formed during electrolysis of water, as indicated below.

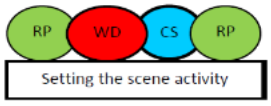
He simultaneously wrote the reaction equation for the experiment on the chalk board: $2H_2O \rightarrow 2H_2 + O_2$ (RP), which he used to link the mole ratio of reactants and products to the resulting molar gaseous volumes of the products, over the slide.
Teacher: "from the balanced equation, we expect hydrogen gas to be twice as much as oxygen, from the (mole: mole=vol: vol) ratio (2:1). This means that the relative molecule ratio of the equation or the relative moles of reactants and products give us the the mole: volume ratio of reactants and products".
He the posed several questions, Teacher: "which of the two gases would be more? Hydrogen or oxygen. What does the equation tell us"? (WD). He then derived an equation on the chalk board, which he used to relate the number of moles, volume and the Avogadro's constant, (RP). The teacher finally explained the meaning of mole, stating that: "The amount of substance in science gives us an idea about the number of moles of a substance. Particles contained in the substance can be used as a counting unit. We can also use the number of moles of various reactants to determine the products in our industries and everyday life" (CS).</td><td>

In this segment three components: Representations (RP), What is difficult to teach, (WD) and Curricular saliency (CS) were seen to be used interactively in both linear and interwoven structural sequence, with one of the components, representations repeated in the explanation. This is shown when the teacher begins the segment by first displaying a visual slide showing electrolysis of water (RP). He then equates the reacting mole ratios of the reactants and products to the resulting molar gaseous volumes of the products, using an equation. This link is considered difficult to understand as it works only with gases and the conceptual reasons for this pattern is not fully explained in textbooks (WD).
The teacher then uses a second equation (RP) to explain the meaning of mole in relation to mass and number of particles (CS)</td></tr>
<tr><td colspan="2"><u>Summarized description of the teaching segment from which the episode emerged.</u>
The teacher introduces the concept of reacting volumes by displaying a visual slide showing electrolysis of water (RP). He then applies an equation (RP –symbolic level) to explain the concept of molar gas volumes. Talking over the visual slide, he explains the relationship between two key concepts; number of moles, mass and the Avogadro's constant (WD). He finally explains the meaning of the mole, relating it to everyday life experiences (CS). We see three different TSPCK components interacting evidently and distinguishably in both linear and interwoven sequence but one component representations bringing two levels of component sophistication (micro and sub-microscopic and symbolic) to the explanation: TSPCK episode: (RP/WD-RP/CS)</td></tr>
</table>

Figure 4.6: A three-component liner/interwoven episode with one repeated from teacher Laurent

In the example shown in Figure 4.6 above, the two-component interwoven interactions connected by a linear sequence structural configuration emerge when two components; Representations (RP), and What is difficult to teach, (WD) are first used interactively in an interwoven manner. The teacher then moves into a second

set of two other components; representations (RP) and curricular saliency (CS) in the same segment. This is shown when the teacher begins the segment by displaying a visual slide projection, depicting electrolysis of water (RP). He then links the reacting mole ratios of the reactants and products to the resulting molar gaseous volumes of the products based on the reaction equation. This link is considered difficult to understand as it works only with gases and the conceptual reasons for this pattern is not fully explained in textbooks (WD). The teacher further uses a second equation (RP) to explain the meaning of mole in relation to mass and number of particles, one of the key concepts to be understood in teaching the topic. Understanding which topics are central and which are peripheral enables teachers to judge the depth and sequence of a topic, which is an indicator of the component of curricular saliency (CS). Another example of a three-component TSPCK episode with one component repeating, from the same teacher- Laurent is given in Figure 4.7 below.

<table>
<tr><th>Sample video extract teacher- Laurent: Interwoven-3 components plus -1 repeating TSPCK Episode.</th><th>Corresponding TSPCK MAP</th></tr>
<tr><td>Teacher: "I want you to measure 0.1 moles of each of the substances, Sulphur, Iron, and NaCl and then compare their masses (RP-macroscopic). As the learners measured the masses of the substances, the teacher moved around, asking whether they were getting the same mass.
"We used the same quantity, but we are we getting different masses" (WD). In the same segment, the teacher explains the findings. Teacher: "The reason for this is that, different atoms have different masses because, of the different number of protons and neutrons in their nucleus "(CS).
On the board, the teacher derived an equation showing the relationship between the number of moles and mass, which he used it to show how to calculate number of moles (RP-symbolic). He then gave out an exercise for learners to apply the equation and work out the number of moles of the various substances measured.</td><td>

The teacher begins this segment, with a demonstration-activity (RP). He simultaneously probes for reasons, why the same measure is giving different masses (WD), before explaining the reason for the observed differences (CS). He then uses an equation to show the relationship between number of moles and mass, using one example, (RP) before giving out an exercise to the learners</td></tr>
<tr><td colspan="2">Summarized description of the teaching segment from which the episode emerged
To explain the concept of the mole, the teacher begins with a demonstration, (Macroscopic representations (RP), which he relates to the mole as a unit of measurement. He then explains the observed experimental results (WD). He further applies an equation (RP) to link two key concepts, mass and mole (CS), before allowing learners to work out related examples. We see three different components interacting evidently and distinguishably in a specific teacher task segment but one component; representations used at both macroscopic and symbolic levels in an interwoven manner, to explain the same concept of the mole as a unit of measurement.
TSPCK episode:(RP/WD/CS/RP)</td></tr>
</table>

Figure 4.7: Extract of three-component interwoven episode with one repeated from the teacher Laurent

It is observed that the three-component plus -1 repeating TSPCK episodes could be either of an interwoven nature, or a distinct standalone linear sequence, or of both interwoven and standalone linear structural formation. The components appear to work together in an interactive way to explain the same concept. It is noted that the repeating component in both the two cases above was the component of representation. Following below are examples four-component TSPCK episodes.

D. Nature of Category 4 interactions: Four-component TSPCK episodes

Figure 4.8 shows a sample video extract of a four-component interwoven episode from the teacher Atas.

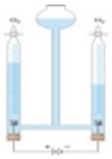
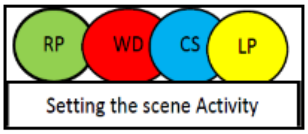
<table>
<tr><th>Video extract from teacher-Atas: interwoven -4-component TSPCK Episode</th><th>Corresponding TSPCK Map</th></tr>
<tr><td>The teacher picks up a balloon filled with air, Teacher: "If we can find the mass of this balloon, we can be able to find the amount of gas inside, but it is difficult to measure the mass of gas". He repeats this statement before moving on...
Teacher: "So when looking at the amount of gas, we normally talk of volumes".
He then projected a visual slide showing electrolysis of water using the Hoffman's apparatus, with different volume levels of H_2 & O_2 gases formed during the experiment (RP).

Teacher: "What do you notice about the volumes? How do you know which flask contains (H_2) & which one is (O_2)? Look at the amounts, H_2 should be twice as much as O_2" He then explained the observed differences over the visual slide, linking the reacting mole ratios, with the resulting gaseous volumes. (WD). He went on to state the molar gas volume constant; Teacher; "An important property about gases is that the same amount (mole) of any gas at STP occupies the same volume (22.4 dm^3 " (CS). He then cautioned learners that; "this does not however work for solids" (LP).</td><td>
In this segment four components; Representations (RP), what is difficult to teach, (WD), curricular saliency(CS), and learner prior knowledge (LP)are all used interactively in an interwoven structural formation. In this example, the teacher begins by displaying a visual slide depiction showing electrolysis of water. He then explains the differences in the resulting gaseous volumes observed over the visual slide depiction (RP). He uses a balanced reaction equation to show that the mole ratio of reactants could be considered equivalent to the ratios of the resulting gaseous volumes. As mentioned before the link from molar ratio to volume ratios is difficult to understand as the conceptual reasons are linked to theoretical ideal scenarios and thus very abstract in nature(WD). He then states the molar gas volume constant, an imortant concept in the topic (CS). He then cautions that this applies to only gases and not solids and liquids (LP), an indication of awareness of a common learner misconception.</td></tr>
<tr><td colspan="2">Summarized description of the teaching segment from which the episode emerged. The teacher Introduces the concept, of reacting molar volumes using a visual slide depiction (RP). He then explains the resulting molar gaseous volumes of the products formed over the visual slide,, emphasizing the importance of a balanced equation in understanding the observed findings (WD). He goes on to state the molar gas volume constant an important concept to be understood when learning about molar gas volumes (CS). He cautions that this value applies to reacting gaseous volumes only and not solids, which indicates evidence of knowledge of a common learner misconception in the topic, an aspect of the component of (LP) We see evidence of four different TSPCK components, all interactively and evidently used in an interwoven structural format. TSPCK episode: RP/WD/CS/LP.</td></tr>
</table>

Figure 4.8: Extract of four-component interwoven episode from the teacher Atas

In the episode shown in Figure 4.8, four components, viz. representations (RP); what is difficult to teach (WD); curricular saliency (CS); and learner prior knowledge (LP) are all used interactively in an interwoven structural formation. In this segment,

the teacher begins by displaying a visual slide depiction showing electrolysis of water (RP). He then explains the differences of the observed resulting gaseous volumes, by linking the reacting mole ratios of the reactants and the gaseous products over the visual slide (WD). As mentioned earlier, the link from molar ratio to volume ratios is considered difficulty to understand as the conceptual reasons are linked to theoretical ideal scenarios and thus very abstract in nature. The teacher goes on to explain the link between the number of moles and the molar gas volume constant, a key concept in learning about the mole as a unit of measurement (CS). He finally cautions that this applies to gaseseous products only, and not solids or liquids, as an acknowledegment of a common misconception among learners (LP). All the four components appear to work together in an interwoven structural formation to explain the same concept. Another example of a four component TSPCK episode interaction similar to teacher-Atas above, but with one component repeating was taken from teacher Charlie, and is shown below.

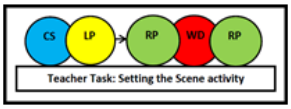
Extract from teacher- Charlie: Interwoven/linear – 4 component TSPCK Episode + 1 repeating.	**Corresponding TSPCK Map**
Teacher: "Does a gas have a mass? When it comes to gases, we consider their volumes. We know that one mole of any substance consists of a fixed number of particles or entities, represented as a constant 6.02×10^{23}; similarly one mole of any gas occupies the same volume of $22.4dm^3$ at STP **(CS)**. Note that this applies to gases only and not solids or liquids, **(LP)"**. The teacher then displays a visual slide projection showing an animated equation, with different colours for the gases formed during electrolysis of water, **(RP)**. **Teacher:** "During electrolysis, water decomposes into hydrogen and oxygen. The equation tells us the reacting mole ratios. What do you notice about the volume of the gases shown? Are they the same?" The teacher repeats the question before explaining what the equation implies. **Teacher:**" Look at the equation, the ratio of H_2:O_2 is 2:1. Two moles of H_2 are produced for every mole of oxygen" The mole: mole ratio=volume: volume ratio **(WD)**. The molar gas volume constant, can therefore help us to calculate the volume of gas occupied by different moles of gases". He then derives the relationship between number of moles and molar gas volume (n=v/V) **(RP, symbolic)**, and asks learners to work out one example to test their understanding.	 This is an example where two sets of interwoven TSPCK components interact in a linear structural formation sequence. In this example, the teacher begins by linking the Avogadro's constant to the molar gas volume **(CS)** . He at the same time cautions that the molar gas constant does not apply for solids and liquids **(LP)**. He then displays a visual slide showing electrolysis of water**(RP)**, and moves on to explain the reacting mole ratios and the resulting gaseous volumes, over the slide depiction **(WD)**. He finally derives an equation showing the relationship between the number of moles and the volumes of gases formed **(RP)**. Four TSPCK componets used interactively with one component representations repeated at macroscopic and symbolic levels.
Summarized description of the teaching segment from which the episode emerged. The teacher Introduces the concept of molar gas volume by relating it to the Avogadro's constant, which indicates presence of the component of curricular saliency (CS). He then cautions that this applies to gases only and not solids or liquids, which signals awareness of a common learner misconception (LP). Talking over the visual slide depictions, (RP), the teacher relates the resulting gaseous volumes to the mole ratios of reactants and products (WD). He finally derives an equation (RP) to show the mathematical relationship between the number of moles and the volumes of products formed, before giving out an exercise to the class. We see four different TSPCK components interact evidently in a distinct manner, but one component, representations used at both symbolic and sub-microscopic levels. **TSPCK episode: CS/LP-RP/WD/RP**	

Figure 4.9: Four component-linear/interwoven Episodes, with one component repeating

It is observed that the four-component and the four-components plus -1 repeating TSPCK episodes shown in Tables 4.8 and 4.9 could either be of an interwoven nature, or a combination of both interwoven and linear sequence components interacting in the same episode. It is also noted as with the three-component episodes, that the repeating component is the component of representation, however repeating in a different version, i.e. the first occurrence mostly at macroscopic level, and the repeated emergence as symbolic, bringing the important link to the visual macroscopic level representation.

Based on these episodes, five categories of quality of TSPCK episodes were suggested. It is however, important to make clear how certain decisions were made in deciding the fine difference between the categories.

Decisions made to differentiate between categories

The difference across the quality categories largely dependent on the quantity of interacting components and the depth brought about by the nature of their interactions. This was the major criterion used to distinguish the level of quality of episodes. As alluded to in section 4.4.1 above, the visible evidence of Topic-specific PCK component interactions reveals the quality of the focal construct in this study. This argument is in line with other empirical findings, which argue that the quality of PCK in a topic is demonstrated by the extent of the synergistic interactions of the specific components of PCK and by extrapolation TSPCK (Aydin, Demirdogen, Akin, et al., 2015; Park & Chen 2012). Therefore:

- The two-component (interwoven + linear) TSPCK episodes were regarded to be in the same category. However, I considered the interwoven and linear episodes that have the same number of TSPCK components found interacting in an episode to belong to the same category, because the identified episodes seem to be dependent on the teacher task and location of the task in the lesson, which all have good merits. For example, in the introductions, such as the two-component interwoven video extract captured from the teacher Atas in Figure 4.2, it seems the teacher talking and likely to integrate the two-components in an interwoven sequence. The linear sequence interactions

seem to come from the body of the lesson, where there is time allowed for learner activity or a demonstration, as can be observed in the linear two-component video extracts captured from the teacher Laurent in Figure 4.3. However, both episodes have strong benefits. The distinct linear standalone sequence component interaction appear to offer a big advantage in the explanation, as there is time built for learners to participate, creating shared meaning in the learning process between the teacher and the learners, as compared to the interwoven nature where the teacher is talking, providing explanations and presenting information to learners, which is however equally important. The same reasons hold for regarding the three-component interwoven and linear episodes to be in the same quality category.

- The three-component interaction TSPCK episodes could be either of an interwoven nature or a distinct linear sequence, or may comprise both an interwoven and linear sequence. However, this category would either have three different TSPCK components interacting evidently in a specific teacher task segment, for example, the video extract captured from teacher Charlie in Figure 4.4, or had a different version of TSPCK episodes, where one of the three components was found repeated like the video extract captured from the teacher Laurent in Figure 4.6. The three-component TSPCK episodes with one repeating (interwoven or linear, or both linear and interwoven) was considered a different category.
- The four-component interaction TSPCK episodes could either be of an interwoven nature or had a distinct linear sequence or comprised both an interwoven and linear sequence. This category like the three-components category had different versions of TSPCK episodes, where evidence of four different components were observed to be interacting evidently in a specific teacher task segment like the example in the video extract captured from the teacher Atas in Figure 4.8 or one of the four components was found repeated more than once; or one of the components bringing different levels of sophistication. For example representations used at macro, symbolic and sub-microscopic levels, like the case of the video extract captured from

teacher Charlie in Figure 4.9, which was also considered in a different category from that of the three-component, while repeating episode above.

I view the repeating element in an episode of TSPCK component interaction as making a big difference in the explanation, making the explanation work in a complementary way at multiple component sub-levels and/or dimensions of component representations. For instance, Gabel (1998) advocates for the teaching of Chemistry concepts using three levels of representations simultaneously. The author emphasises, scaffolding of learning through showing how a concept manifests in real physical visual display, and how it may be represented symbolically from the chemical equation perspective, or even graphs, as well as how the microscopic particles actually behave to demonstrate the concept. The simultaneous use of representations at the different levels of explanation in most of the episodes analysed above brings about an added benefit in the depth of the explanations, and hopefully an improved chance for learners to understand. The repeating component sub-level sophistication of representations (RP) seems to equally allow the teacher to go deeper into the understanding of the given explanation. This makes the distinct difference between the initial suggested three and four-episode categories and the episodes with a repeating component. The repeating component aspect was observed to promote the development of teacher knowledge for teaching specific content of a topic, in this case TSPCK.

In an effort to make reference to the different categories that display different levels of component interaction to this TSPCK quality, five titles of categories were suggested and labelled. These were: Simple, Fair, Moderate, Proficient, and Sophisticated TSPCK episodes.

Table 4.4 below shows a summary of the descriptions of the initial five-episode categories.

Table 4.4: Five categories TSPCK Classroom rubric for scoring TSPCK in action

Simple TSPCK	**Fair TSPCK**	**Moderate TSPCK**	**Proficient TSPCK**	**Sophisticated TSPCK episode interplay**
• Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teacher task segment • The component interactions maybe interwoven or have a linear sequence structural format.	• Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teacher task segment. • The component interactions maybe interwoven or have a linear sequence structural formation or both	• Evidence of three different TSPCK components interacting, evidently, and distinguishably in a specific teacher task segment, but with one component repeating bringing a different level of explanation that complements the initial emergence • The component interactions maybe interwoven or have a linear sequence structural formation or both.	• Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment. • The component interaction maybe interwoven or have a linear sequence structural formation or both.	Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment, with one of the components repeated more than once, or One of the components repeating in a manner that brings different levels of sophistication (e.g. representations used at macro, symbolic and sub-microscopic levels. The TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both.

(i) Refinement of the categories and producing examples

The next stage of the development process was to assign exemplars of TSPCK Episodes to each of the suggested categories. It is argued that sets of examples or anchors should be used to assist raters in the scoring process (Arieli-Attali & Liu, 2015; Moskal., 2003). This process took the reference team back to re-watching the same video-lessons from which the categories emerged. After continuous review and refinement to determine the mutual exclusiveness of the categories, it was realised that some of the TSPCK episode categories could be assigned into the same category with minimum modifications.

For example, both the second and third episode category levels reflected simple evidence of three TSPCK component interactions. The distinguishing feature between the two categories was the level of sophistication, where one component would either have multiple levels/dimensions or multiple component interactions brought to an explanation. The same features were also observed between the fourth and fifth categories. After lengthy deliberations with the reference team of independent raters, it was agreed by consensus that for ease of scoring, the number of the episode categories be reduced by merging some of the categories. The main reason was that the categories are fundamentally emerging from the same quantity of components interacting, thus locating the observed TSPCK episode into a particular category. The added benefit derived from a repeating component was noted and agreed to be useful when a fine difference is needed to make a distinction between compared entities. Following this suggestion, the second and third as well as the fourth and fifth episode category levels were merged respectively, resulting in a three-category rather than a five-category rubric.

This new development led to saturation of the categories with more examples and reduction in the total number of the episode categories from the initial five to three quality categories, which made the categories more practical and easy to use.

For example, during the analysis and refinement process, an issue arose over one point of departure observed from my scores, where I had scored a teacher's activity (demonstration) as a macroscopic representation. In this specific teacher task, the

teacher had used an unrelated analogy of weighing a dozen coins and linking the analogous macroscopic example to the mole as a unit of measurement. This representation was the disparity that was queried by one of the raters, who argued that the identified component does not reflect a conceptual learning representation. After lengthy discussions with the reference team, it was agreed by consensus that such activities, where unrelated analogies or examples are used to explain a concept, could be included in the categorisation as aspects that are addressed implicitly, based on the choice of representations or explanations provided. This brought to light the limitations of models or analogies used to make abstract concepts visible and concrete even when they have been suggested in the literature (Kolb, 1978). A counter-argument to this were cases where the identified macroscopic representations worked more efficiently, like in the cases of the teachers Laurent and Atas, who used visual slide projections to depict hydrolysis of water experiments as a means to illustrate the visible differing volume ratios of the product gases, and linked this symbolically to the molar ratios in the balanced equations. This approach of sharing insights into individual raters scores, that would be at variance was adopted and followed during the refinement process in other related cases that emerged. For example, a score would be retained or changed depending on the merit and the degree of the convincing argument.

The episode categories that were finally derived from the recorded lessons resulted from constant comparison of repeating patterns of the analysed video recorded transcripts. According to Darling-Hammond and Lieberman (2013), citing Glaser & Strauss (1967) the rationale for selecting comparison groups is their theoretical relevance for fostering the development of emergent categories. The final refinement process therefore involved repeating and continuously looking for similarities and differences within the transcribed data sets and scoring them with the help of the independent raters (Petty, Thomson, & Stew, 2012). The repeated comparisons and scoring of the raw data lead to the refinement in the wording of the criteria under each suggested quality category. This process gave rise to three final categories of the teachers' classroom practices. According to Miles and Huberman (1994), a good display of data in the form of tables, charts, networks and other graphical formats is essential for drawing conclusions from a mass of data. The

three categories of descriptions that emerged from the repeating patterns of the analysed raw data captured from the classroom practices of the expert Physical Science teachers were finally named as: simple TSPCK episode category; proficient TSPCK episode category; and sophisticated TSPCK episode category.

As alluded to above, rubrics should be complemented with “anchors”, or examples, to illustrate the various levels of attainment. The anchors may be in form of written descriptions, or even better, actual work samples (Perlman, 2003).

In this study, actual work samples from the recorded lesson videos of the expert teachers were used as sample anchors. Figure 4.10 below presents the three quality categories TSPCK rubric with sample anchors for each quality category.

Type 1: Simple TSPCK Episode	Type 2: Proficient TSPCK Episode	Type 3: Sophisticated TSPCK Episode
• Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teacher task segment • Component interaction maybe interwoven or have a linear sequence structural formation.	• Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teacher task segment; or • Evidence of three different TSPCK components interacting, evidently, and distinguishably in a specific teacher task segment, but one component repeating bringing a different level of explanation that complements the initial emergence, • Component interaction maybe interwoven or have a linear sequence structural formation or both	• Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment or • Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment, with one of the components repeated more than once or one of the components bringing different levels of sophistication (e.g. representations used at macro, symbolic and sub-microscopic levels. • TSPCK component interaction maybe interwoven or have a linear sequence structural formation or both.
Teacher: "Today we are going to learn about a new physical quantity, referred to as the mole". **The teacher:** "What do you understand by the term amount of substance? What comes into your mind when you hear the word quantity?" Like a dozen oranges, a tray of potatoes, a litre of gas, what comes into your mind?" (LP). The teacher repeats the same question as he continuously probes for what learners understand by the new physical quantity-mole. **TSPCK Episode: CS/LP**	**Teacher:** There is a relationship between the number of moles and mass of substance. The bigger the mass the bigger the quantity or amount of substance. The teacher repeats this statement. Repetition signifies emphasis of what is considered most important, as aspect of (CS). He then applies a formula to show the relationship between mass and number of moles (RP) Teacher: "If we know the mass of a substance, we can calculate the number of moles". He then explains the meaning of mole by indicating what it does not represent. **Teacher:** "when I talk about number of moles, I don't mean mass or volume; I mean the amount of substance (n) measured in moles (LP) **TSPCK Episode: CS/RP-LP**	**Teacher:** "when looking at the amount of gas, we normally talk of volumes". The teacher displays a visual slide projection showing electrolysis of water, using the Hoffman's apparatus, depicting different volumes of H_2 & O_2 gases formed in the process (RP). **Teacher:** What do you notice about the volumes? How do you know which flask contains which gas, which one is H_2 & which one is O_2 look at the amounts H_2 should be twice as much as O_2. He then explains the observed differences over the visual slide, linking the reacting mole ratios, with the resulting gaseous volumes **(WD)** He then states the molar gas volume constant. **Teacher;** "an important property about gases is that the same amount (mole) of any gas at STP occupies the same volume (22.4 dm^3 **(CS)**. He finally cautions that; "this does not however work for solids" (LP) **TSPCK Episode: RP/WD/CS/LP**

Figure 4.10: A three-category TSPCK classroom rubric for scoring TSPCK in action with sample anchors

It was further observed by all raters that all components in an episode seemed to work together to support the explanation or unpacking of a single concept at hand.

I argue that one advantage of the initial (5) categories rubric is its increased sensitivity of graduating the observed performance. If the purpose of the rubric requires increased sensitivity, such as when training pre-service teachers with an intention to show differences of depth in explanations, then the (5) category rubric has an advantage as it has this sensitivity for evaluation. On the other hand, the (3) categories rubric is simpler and usefully provides an overview of the quality categories of observable TSPCK component interactions. It is particularly useful to use where shifts in the classroom practices are to be determined. It may also be used as the first tool to use when comparing classroom practices to establish the major quality categories, then refine the findings to establish minor differences for scores within the same quality categories, particularly in the second and the third categories of the rubric.

However, both rubrics are limited, in the sense they do not provide a grading towards an overall single score of the quality of TSPCK, but serve to capture and bring to the fore the myriad qualities of TSPCK displayed in different teacher task segments, that reveal the focal character of the TSPCK construct. Teachers who display more TSPCK episodes that are sophisticated in their classroom teaching would be suggested as having an advantage over others. In the following section, the process followed in validating the newly developed TSPCK classroom rubric for scoring enacted TSPCK is discussed.

4.3 Validation and reliability of the rubric

The purpose of this section is to establish the trustworthiness/validity for the developed rubric for evaluating and grading the quality of TSPCK displayed in a classroom practice.

It is argued in the literature that construct validity requires arguments that provide the conceptual understanding behind the entity being measured, as well as arguments showing evidence that generated data or measurements actually measures the intended entity (Haertel, 2006; Kane, 2012). Kane (2OO6) refers to the conceptual argument as the *'interpretive argument'* and the arguments on measurements as '*validity argument*'. Thus, part of the discussions about the conceptual rationale of TSPCK in the literature review (Chapter 2) and its distinction from other versions of PCK contributes towards the interpretive component of validity.

However, I acknowledge that my study had an inherent limitation of a very small sample size used for the conceptualisation and the validation of the rubric, explained shortly. What is particularly drawn from the interpretive argument is the common understanding that the quality of PCK of expert teachers is likely to be more developed, compared to that of pre-service teachers, by virtue of their reflective experience in the field, and more likely to demonstrate sophisticated quality TSPCK episodes in their teaching. It is argued in the literature that "pre-service or beginning teachers may have limited or minimum PCK at their disposal" (Lee et al., 2007 p.52). This theoretical understanding was to be tested using the newly developed rubric. According to Lincoln and Guba (1985), trustworthiness involves ensuring that the research process is truthful, careful and rigorous enough to qualify to make claims that it does. As mentioned in Chapter 3, the terms credibility, transferability, dependability and confirmability, are used to demonstrate trustworthiness in qualitative research, in place of validity, which is associated with quantitative studies. To determine the consistency of the independent raters' scores, reliability has been addressed through the calculated reliability indices generated through the Kappa-Cohen inter-rater reliability index.

4.3.1 A research design towards establishing trustworthiness

A comparative case study design strategy was used to evaluate the quality of enacted classroom practice of two different groups of Physical Science teachers. The first group was comprised of three experienced Physical Science practicing teachers and the second group was comprised of three pre-service teachers in their final year of teaching towards a four-year B.Ed teacher qualification degree. According to Merriam (2009) a case study is an in-depth description and analysis of a bounded system. The author argues that if the unit of analysis is a bounded system, then it can be labelled as a qualitative case study. On the other hand, Goodrick (2014) points out that comparative case studies cover two or more cases in a way that produces more generalisable knowledge. This study is therefore bounded in the sense that it involves a comparison of the same features of a single phenomenon of classroom practice, with the intention of gaining an in-depth understanding of given cases. The three experienced practicing teachers and the three pre-service teachers were chosen because the mix is expected to generate TSPCK episodes of different qualities that are likely to span across the category spectrum of the rubric and best to test this theoretical conjecture.

4.3.2 Data collection

As alluded to above, the data collected was in the form of video recorded lessons from a total sample of (6) participants, comprising the three-expert practicing Physical Science teachers and three pre-service teachers who were in their 4th year of study majoring in Physical Science. The pre-service teachers were in the middle of an intervention teaching on the TSPCK construct in their methodology class. Their classroom practice was in a context of classroom micro-teaching, all teaching Stoichiometry. The three expert Physical Science teachers, who participated in the validation of the rubric, had teaching experience that ranged from five to eight years, teaching both Physics and Chemistry (collectively referred to as Physical Science for Grades 10-12 (see Table 4.1). Two of the three expect teachers taught on Stoichiometry with one teaching on the structure of the atom, under the main topic of

matter and materials. All the expert teachers taught their lessons in Grade 11 classes. Similarly, they all taught Physical Science as their main teaching subject, in different Township schools. As alluded to in Chapter 3, Township schools in the South African context, usually refer to the often underdeveloped and under-resourced urban schools previously reserved for non-white learners (Africans, coloureds and Indians) under the apartheid dispensation.

The refined three-category TSPCK classroom rubric for scoring TSPCK in action was used to capture and display the quality of enacted TSPCK classroom practice by the two groups of teachers, while teaching double lessons ranging between 60-70 minutes each.

4.3.3 Data analysis

The analysis and scoring of the recorded video lessons followed the same in-depth qualitative method as in the development of the rubric categories. Firstly, specific teacher task segments that contained TSPCK episodes were identified. Secondly, the identified TSPCK episodes were analysed for the nature of component interactions they hold and compared to the criteria in the newly developed rubric. For example, an identified TSPCK episode would be analysed for the quantity of interacting components and whether it has a configuration that is either interwoven or a linear standalone sequence, or both. I sought the assistance of the three independent raters, including myself as the fourth person, to help in peer validation of the scores. The process at first followed involved the confirmation of all the identified TSPCK episodes. This was followed by determining the possible categories of quality that describe the identified TSPCK episodes in the new rubric. This helped in ensuring the reliability and trustworthiness of the scoring process. The three independent raters were the same team as described in section 4.2.1 above. An inter-rater reliability agreement was calculated at a Cohen Kappa value of 0.80, which was considered substantial, based on the kappa strengths interpretation of reliability values.

4.3.4 Findings of analysis of the recorded video lessons

Table 4.5 displays a comparison of teacher profiles and a breakdown of the TSPCK episodes identified from the expert teachers, versus the pre-service teachers' observed lessons. Although the duration of the videoed lessons was the same i.e., double lessons, the context was different. The expert teachers were captured teaching two double consecutive lessons in their respective schools, while the pre-service teachers were captured during their micro teaching sessions.

Table 4.5: Total number of TSPCK episodes identified for validation

Teacher participants		Simple Episodes	Proficient episodes	Sophisticated episodes	Total
Pre-service teachers	Agnes	2	1	0	3
	Mohale	2	0	0	2
	Leshole	2	0	0	2
Expert teachers	Teacher Atas (6)	1	2	2	5
	Teacher Laurent (7)	1	2	1	4
	Teacher Charlie (8)	1	2	1	4

Note: The numbers shown in brackets, in Table 4.5 above indicate the expert teachers' years of teaching experience. Pseudonyms have been used to conceal the identity of the participants.

The findings of the analysis in Table 4.5 above reveals that the total number of TSPCK episodes identified from the expert teachers were 13, while the pre-service teachers displayed a total of 7 TSPCK episodes. On close analysis, the episodes could be classified into the three-episode quality categories, with the expert teachers displaying more sophisticated TSPCK episodes compared to the pre-service teachers. The total numbers of simple TSPCK episodes displayed by the expert teachers were three. The simple TSPCK episodes were all captured in the introduction teaching segments of the recorded video lessons. The TSPCK episodes displayed in the proficient category level

of the expert teachers were six, while four episodes were demonstrated in the sophisticated category level. On the other hand, out of the total seven TSPCK episodes identified in the classroom practice of the pre-service teachers, six were displayed in the simple quality category of TSPCK and only one in the proficient quality category level of TSPCK. The results from the findings above indicate that the experienced teachers displayed a higher number of higher quality TSPCK episodes, which translates to a higher quality repertoire of TSPCK component interactions compared to the pre-service teachers. The pattern shown in Table 4.5 above illustrates evidence of the theoretical expectation, indicating that expert teachers demonstrated more sophisticated TSPCK episode interactions, when compared to the pre-service teachers. The evidence revealed from the observed pattern conforms to the theoretical expectations, which indicate validity when empirical data aligns to a well-defined and informed understanding or postulate.

The newly-developed TSPCK classroom rubric for scoring TSPCK in action was thus used to evaluate and categorise the identified TSPCK episodes into the prescribed quality episode categories. Following below are exemplars of TSPCK episodes representing each of the three different episode categories of TSPCK. The episodes were extracted from the teachers' video-recorded classroom lessons that were evident of enacted TSPCK in practice for depth and tracked progress analysis.

(i) Example 1: Simple two-component linear/interwoven sequence TSPCK episode from the pre-service teacher Agnes

Teaching segment: setting the scene
Topic: Limiting reagents.
Teacher: **"**Let us look at what happens at the atomic level, before the reaction took place and after the reaction".

The pre-service teacher wrote the equation between zinc and dilute Hydrochloric acid ($Zn + 2HCl \rightarrow ZnCl_2 + H_2$) on the black board and moved on to perform a simple experiment; mixing 10ml of HCl and a few granules of zinc metal, to form $ZnCl_2 + H_2$ gas **(RP)…** She took a few minutes performing the demonstration.

Teacher: "You would expect the substance with the lesser quantity to be our limiting reagent, but we have excess zinc remaining in the reacting flask, the question is why. The issue here has to do with reacting ratios, the amount does not matter."

The teacher then displayed a flip chart showing the reaction equation, on which the reactants (Zinc atoms, and HCl) and the products ($ZnCl_2$ and H_2) were depicted in different colours. (**RP-sub-microscopic/symbolic level).**

Teacher: "we had less of the zinc atoms as the reagent and zinc is however still on the products side" (WD)

The teacher then used the equation, to explain the reacting ratios of reactants and products. Explaining over the flip chart, she emphasizes that "The Hydrogen gas given off is a product and not the excess reagent". That is the reason why zinc is our excess reagent and HCl becomes our limiting reagent (WD The last sentence indicates the teacher's ability to identify a key gate keeping concept that poses potential difficulty for learner understanding.

Summarised description of the teaching segment from which the episode emerged

The teacher begins this segment with a simple class demonstration, creating a reaction between Hydrochloric acid and zinc granules. She however enriches her lesson with visual depictions displayed on a flip chart, showing the reacting particles at both symbolic (equations) and sub-microscopic levels (illustrations) (RP). She then explains the observations of the demonstration, indicating that although the zinc granules appeared less in quantity compared to the HCl acid, it was still the excess reagent, which indicates understanding of a key gate keeping concept that learners often find difficult to comprehend (WD). The teacher introduced an equation (RP), over which she explained the reacting mole ratios, emphasising that the Hydrogen liberated was not part of the excess reagents. We see evidence of two components (WD) and (RP) interact together in both interwoven and linear structural sequence, with the component of representations repeated in the explanation, at both macroscopic and sub-microscopic levels. Figure 4.11 shows a visual display of the of the described TSPCK episode in form of a TSPCK Map **TSPCK Episode: (RP-WD/RP)**.

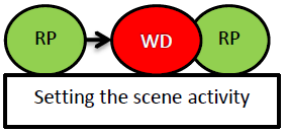


Figure 4.11: Simple TSPCK Map from pre-service Agnes's group

The next example displays evidence of a TSPCK episode in the category of proficient quality of TSPCK.

(ii) Example 2: Proficient three-component TSPCK episode linear/interwoven TSPCK episode from the expert teacher-Laurent's lesson.

Teacher Task segment: Introduction
Topic: Matter and Materials
Teacher: "Before we can start this lesson, who can tell me what an atom is. What is atomic number?" (LP). The teacher repeats the question and refers learners to the periodic table chart on the class wall as he continuously probes for their understanding about the meaning of an atom. **Teacher**: "Look at the atoms, on the periodic table chart."

The teacher then depicted the structure of the atom of lithium on the chalk board, specifying the sub-atomic particles symbolically with (**-**) representing electrons and (**+**) representing protons (**RP-sub-microscopic**). He then draws a table on the chalkboard, showing the first six elements, in the rows and their corresponding groups and valence electrons. He went on to explain how to use the octet rule to show sharing of valence electrons across the elements over the table (CTS) The teacher was thus seen to apply the variation theory to help students discern differences among the six elements. Variation theory is applied by identifying aspect(s) of the lesson content that are critical for students' understanding, which indicates drawing on aspects of the component of conceptual teaching strategy.

Summarised description of the teaching segment from which the episode emerged

The teacher introduces the lesson by drawing on learners' prior knowledge, (LP), before building on the learners' positive responses to introduce the topic, of matter and materials. He then uses representations at both symbolic and sub-microscopic levels (RP) to introduce the octet rule and simultaneously applies the variation theory as a conceptual teaching strategy to help students discern patterns and differences among the successive elements (CTS). We see evidence of three different components of TSPCK interactively used in both linear and interwoven sequence structural formation. Figure 4.12 below shows the visual display of a TSPCK Map extracted from teacher Charlie's video lesson, teaching the topic of structure of the atom, under matter and materials. **TSPCK Episode: LP-RP/CTS**

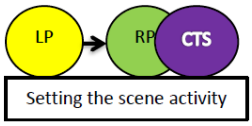


Figure 4.12: Proficient TSPCK Map extracted from the teacher Charlie's lesson

The next example displays an example evaluated as falling in the sophisticated quality category of TSPCK.

(iii) Example 3: Sophisticated four-component + 1 repeating-interwoven/linear TSPCK episode extracted from teacher Charlie's lesson

Teacher Task segment: Setting scene activity
Topic: The mole
Teacher: "There are different ways of measuring things out there, but chemists deal with different kinds of substances. We are going to carry out an activity to find out whether the same amount of a substance gives us the same mass."
Teacher: "In front of you are five different substances. I want you to take the same amount/quantity; measure out a spatula-full of each substance provided and find out the mass of each, starting with Sulphur take a spatula-full and record the mass in a table. Do the same with zinc, iron, and sodium chloride. For water, take the mass of the beaker first and add a spatula-full of water. Same amount of each substance." **(RP-macroscopic representation)**

The teacher allows learners time to carry out the demonstration, before posing questions.

Teacher; "What did you find out? Is the mass the same?" You measured the same quantity of each substance, but you got that the mass of sulphur is different from the mass of sodium chloride, which is different from the mass of iron and different from that of water. Same quantities, a spatula-full of each substance but the masses are not the same."

Teacher:"what could be the reason for these differences? What is different about different substances? What makes water, water, how is sulphur different from iron?" (WD what do we know about elements and compounds? What contributes to the mass of atoms? Think about the atomic structure, particles in atoms, which ones are responsible for the mass? What contributes to the mass of atoms? Think back to what you were taught in Grade 10, which particles form the nucleus in the periodic table" (LP).

The teacher then distributed pieces of envelops to learners in groups.

Teacher: "Inside the envelopes are transparent pieces of paper on which I have drawn the simplest particles of different types of substances. The red dots represent protons, the blue dots represent neutrons. This is a model of the particles that make up the different substances. Count the protons and neutrons and write the number next to the mass you measured for the different substances". (RP) sub-microscopic representations).

The teacher then summarised the observations of the activity;

Teacher: "We are getting different masses because atoms of different elements have different atomic masses. This is because of the different number of protons and

neutrons you counted, hence the difference in the masses obtained. It is the protons and neutrons that make up the atomic mass of atoms ”

The teacher emphasises this statement by repeating it again and again. Emphasis of key concepts in the topic indicates presence of the component of curricular saliency (CS). He then gave out a class exercise.

Teacher: I want you to work out the relative atomic masses (RAM) of the different elements that you measured, refer to the periodic table for the different atomic numbers.

Summarised description of the teaching segment from which the episode emerged.

The teacher introduces this segment with an activity, measuring the same quantity of different substances (RP-macroscopic representation). He probes for the reasons as to what could be contributing to the differences in the masses observed in the demonstration, (WD) by referring learners back on what they learnt in previous Grade level (LP). He then uses representations at sub- microscopic level (protons and neutrons) to explain the observations made in the activity (RP-sub-microscopic). He finally summarises the segment by linking the observations made in the activity with understanding of two core concepts, distinguishing between mass and the mole as a unit of measurement (CS). We see evidence of four different components interactively used in both linear and interwoven sequence structural formation, with one of the components, viz. representations, repeated in the explanation. **TSPCK EPISODE: (RP-WD/LP/RP-CS)**

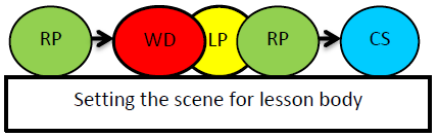


Figure 4.13: Sophisticated 4 plus 1 repeating component TSPCK Map

The three categories TSPCK classroom rubric was able to distinguish and categorise all the identified TSPCK episodes across the three-episode categories. There was no new TSPCK episode that could not be described in terms of the rubric categories. In addition, all the identified components in an episode appeared to work together to explain or unpack a single or pair of concepts.

4.4 Reliability of the rubric

In assessing teachers' TSPCK classroom practice, an important type of reliability is an agreement among those who evaluate the quality of the teacher's performance relative to a set of stated criteria. According to Stemler (2004), the three main approaches to determining the accuracy and consistency of interrater reliability are: consensus estimates, consistency estimates, and measurement estimates. Consensus estimates have to do with measuring the degree to which raters give the same score to the same performance, while consistency estimates involve measuring the correlation of scores among raters. This means measuring, for instance, the degree to which scores can be attributed to common scoring rather than to error components. Measurement estimates, on the other hand, allow for the creation of a summary score for each participant, taking into account the extent to which each rater influences the score.

In this study, both consensus and consistency estimate measurements, were used to analyse and score the identified TSPCK episodes displayed in the video-recoded classroom lessons of both experienced and pre-service teachers. The preconditions for the interrater agreement between me and the team of the enlisted independent raters who helped in analysing and scoring the video-recorded lessons in this study were:

(i) to have a scoring rubric that was clear and unambiguous in what it demands of the teacher by way of classroom demonstration, while making sure that we were all in agreement with our individual scores as a team; and

(ii) to highlight the focal evidence that reflects the varied categories of the quality of TSPCK

According to Pandey and Patnaik (2014), member checking strengthens the study's credibility, and may arise during the normal course of observation and conversation. The authors use the term analyst triangulation to refer to multiple observers and analysts when reviewing findings (Pandey & Patnaik, 2014, p. 5748). The continuous process of reviewing and refinement of the rubric with a team of the independent raters

during the process of development and validation of the rubric provided checks on what would have been my selective perception and bias, by illuminating blind spots in the interpretive analysis, hence ensuring credibility of the identified TSPCK episodes prior to categorisation. Likewise, the experience and special interest in PCK research, especially in exploring and identification of TSPCK episodes in core science topics by the enlisted independent raters, contributed to enhancing the validity of the scoring rubric. In addition, the calculated interrater reliability, based on percent agreement and kappa strengths of interpretation of reliability values were used to estimate the degree of agreement between my scores, as well as those generated by the independent raters; hence further addressing the reliability of the rubric.

4.5 Validity of the rubric

According to Barbara and Leydens (2000), construct related evidence is the evidence which supports that an assessment instrument is completely and only measuring the intended construct. In this study, it was important that the rubric measures a single construct of teachers' enacted TSPCK classroom practice, as pointed out by Veal and Makinster (1999, p. 11) multilevel taxonomy of PCK. Gess-Newsome (1999, p. 11) has expressed the difficulty of detecting teachers' knowledge base in practice by stating that, "when observing an expert teacher, the movement from one knowledge base to the next will be seamless, giving the appearance of a single knowledge base for teaching. " The author posits that "assigning knowledge to specific categories is easier to accomplish in theory than in practice" (Essay Review, 2001, p. 982). This awareness illuminates the elusive nature of PCK as a theoretical construct (e.g. Kind., 2009b). I consequently made deliberate efforts to pull together three elements of establishing validity to ensure that a single construct, viz. PCK, at a topic level (TSPCK), was being measured within reason. These were: (i) use of a well-defined theoretically argued evidence for describing the quality of PCK, which is the interactions among the components of PCK. For this study, with an interest on PCK at a topic level, the

components used in defining the construct and sought out in an interaction, were all considered topic-specific in nature. The second element was to test a well-established theoretical conjecture about PCK, extrapolated to TSPCK. This is namely the understanding that practicing teachers will display more sophisticated TSPCK than their student-teacher or beginning teacher counterparts. This is in line with the argument of Park & Oliver (2008) that the most powerful changes in a teacher's knowledge result from experiences in practice. The validity argument of the rubric was thus established by showing that the rubric provided empirical results that match this theoretical conjecture. The third element is the realisation that there was no TSPCK episode that could not be matched to a category in the rubric. Pulling the three elements together, one observes a good alignment between the empirical findings and the theoretical interpretive argument provided in the discussions about the conceptual rationale of evaluating Topic Specific PCK and its distinction from other versions of PCK; which in turn contributes towards the interpretive component of validity (Kane, 2012). In addition, a critical review of the operational definitions of the key concepts used in the rubric contributed towards the internal validity of the rubric. The discussion above presents an 'interpretive argument' for construct validity, which according to Cohen et al. (2011, p. 188) concerns the extent to which a particular measure or instrument for data collection conforms to the theoretical context in which it is located.

4.6 Summary

The newly developed classroom rubric followed a rigorous process for deriving the episodes, with the help of a team of independent raters. The three categories rubric was found to be is in line with the rubric forwarded by Moskal & Leynolds (2000), which generates qualities and associated criteria from real life experiences that demonstrate proficient performance as argued in section 4.2.2 above. The rubric has an advantage in such case that the interest of the evaluation process is to generate experiences from shifts in the quality of enacted classroom practice that reveals the focal character of TSPCK, as was the case in this study. Likewise, if the purpose of the evaluation criteria

requires comprehensive evaluation, as for the pre-service teacher training programmes, the more sensitive five categories rubric can be more suited in verifying the generated scores, due to its high sensitivity value of graduating the observed performance. Both rubrics are aligned to the concept-based (Arieli-Attali & Liu, 2015) categorical rubric, which spells out the desirable behaviour of the components of the construct, which constitute proficiency from the perspective of the components of the construct being measured.

While the new rubric assisted in the goal to reasonably follow a good and rigorous process for deriving the participants' identified TSPCK episodes with the help of the independent raters, it was however limited in the sense that it does not provide a grading of the overall single score quality of TSPCK in a lesson. The rubric nonetheless captures and reveals the combinations and extent of component sophistication demonstrated in line with the character of a complex and tacit construct like PCK. The other limitation was the small sample size and data used in my study, which may require a larger study sample in future. Despite the limitations pointed above, the findings are encouraging for the value of the new TSPCK classroom rubric, as I was able to use the three quality categories rubric to distinguish and score all the identified TSPCK episodes. The findings between expert teachers and pre-service teachers did not warrant the use of the more sensitive five categories quality rubric as there were no sophisticated episodes identified in the classroom practice of the pre-service teachers as it was for the expert teachers. If there were such cases, the fine differences would have been sought through the use of the more sensitive five categories rubric. The newly developed TSPCK classroom rubrics for scoring TSPCK in action therefore met the purpose of the study, which required comparing shifts in the quality of enacted TSPCK in the real classroom teaching displayed by the three intervention GBTs and their comparable three GBT counterparts, in addition to that of the one expert teacher who participated in this study.

The observation by all the independent raters and myself in the analysis sections 4.2.2 and 4.3.3 above, indicating that all components in an episode seemed to work together

to explain a single or pair of related concepts was considered as a very important element and added as criteria to update the rubric after the validation process, although sounding general.

In Figure 4.14 below, I present the refined three categories TSPCK classroom rubric, together with sample anchors that was used in my study.

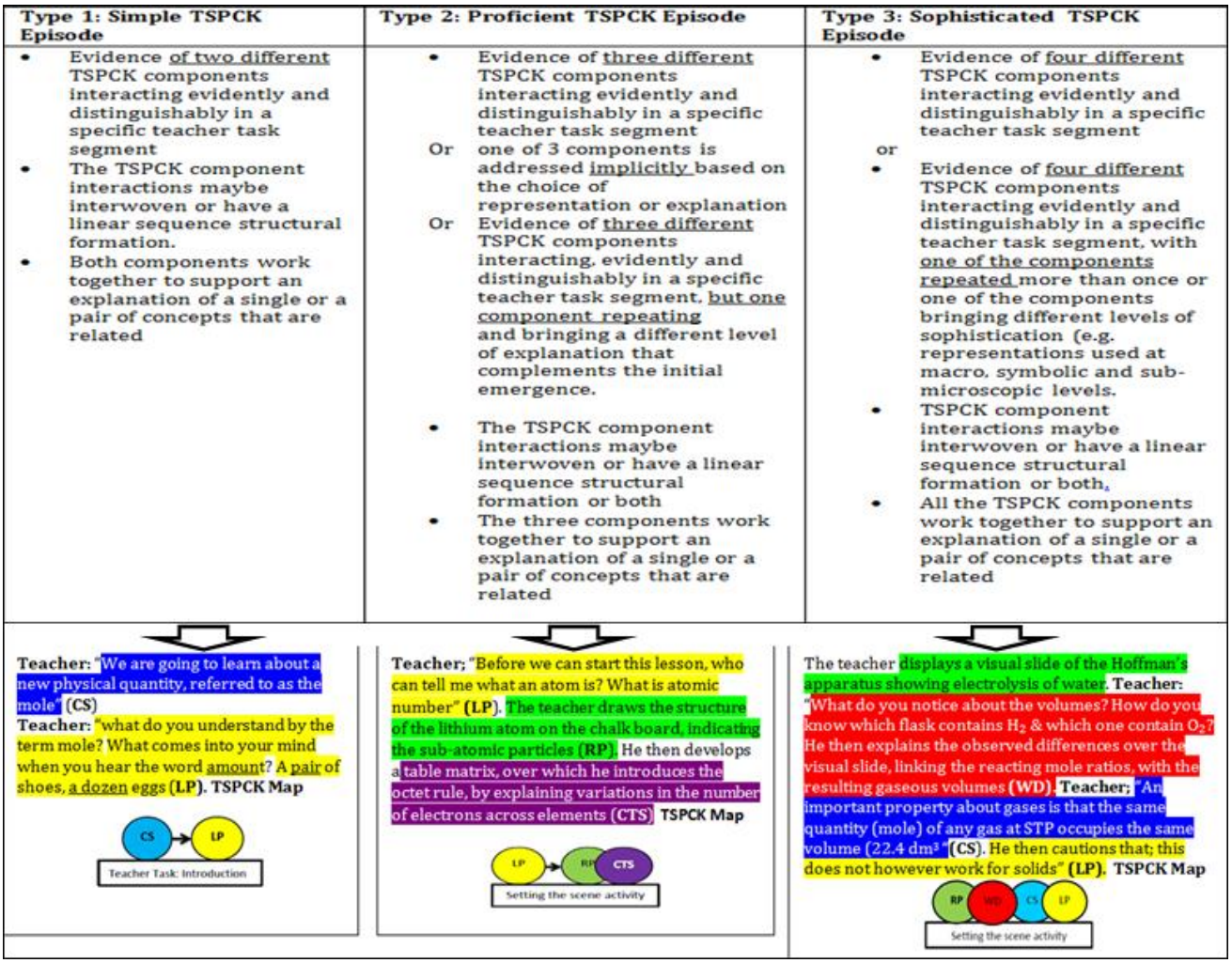


Figure 4.14: TSPCK classroom rubric for scoring TSPCK in action with sample anchors

CHAPTER 5

THE MEASUREMENT OF THE QUALITY OF PLANNED TSPCK DEVELOPED FROM AN INTERVENTION

In this chapter, I analyse data for the quality of planned TSPCK attained by graduate beginning teachers of physical science, (GBTs) while they were in training as science pre-service teachers. The GBTs were exposed to an explicit intervention that aimed at developing the quality TSPCK in a Chemistry topic. In this study, and for the purpose of the research question answered in this chapter, my sample is purposefully selected. The selection was based on several criteria, the most important of which being that the pre-service teachers would be in practice for two years as fulltime beginning science teachers at the time of collection of data. The data analysed was collected in 2016 retrospectively from the archives of the methodology classes of 2014 and freshly analysed. The analysis served to confirm any improvement in the quality of planned TSPCK as a result of the intervention pre-service teachers received during the final year of training. The findings from this chapter are important to my entire study, as they served as a baseline for the interpretation of my further findings in Chapters 6 and 7, which explored the retention of the acquired quality of TSPCK and for any added advantage of GBTs, respectively. I present the analysis and close the chapter with a summary of key findings to be borne in mind for the analysis of retention in the next chapter.

5.1 Re-capturing the background of the study briefly

It is important to recall that the key purpose of this study was to explore the retention of the quality of TSPCK in a special case of graduate beginning teachers of physical science, referred-to in this study as intervention-GBTs. Furthermore, the study existed to determine whether the GBTs have any added advantage in their teaching

practice as a result of an early exposure to TSPCK. So, in order to achieve this purpose, I first needed to confirm whether the intervention-GBTs indeed experienced a gain in the quality of planned TSPCK in their respective topics as a direct result of the intervention received. The phrase 'confirm' is purposefully used in association with this analysing due to the fact that earlier empirical studies on similar interventions in various topics such as chemical equilibrium (Mavhunga & Rollnick, 2013) and the particulate nature of matter (Pitjeng, 2015), reported a significant improvement in the quality of TSPCK. A positive confirmation finding would not constitute new information, but a necessary credible starting point for my analysis for retention of the quality of planned TSPCK when in practice, which is outlined in the next Chapter. It was also important to confirm such improvement for the purposes of enhancing the reliability of the data collection instruments used. It is argued in the literature that interrater reliability must be demonstrated afresh for each study, even if the study is using a scoring rubric or instrument that has shown high interrater reliability in the past (Stemler, 2004).

As outlined in Chapter 3, intervention-GBTs were exposed to an intervention on TSPCK during their last year of study which was in 2014. The intervention was located in the chemistry component of the physical science methodology course. Four groups of pre-service teachers attended an intervention on the development of TSPCK, which was structured similarly, but with different topics used in the discussion as topics of intervention respectively. The GBTs were given the choice of an intervention with a topic of interest between Chemical Equilibrium or Electrochemistry or Organic Chemistry or Stoichiometry. The content of all these topics had been covered in a separate physical science content course that typically runs parallel to the methodology course. All the topics had been covered in the content course by the time of the intervention.

Participants were purposefully sampled from a combined class of (N=24). The first criteria for selecting the participants, involved identifying only those intervention-GBTs from the 2014 cohort, who were in active employment as fulltime beginning teachers for two years within the Johannesburg region in the Gauteng Province.

For instance, some of the intervention-GBTs (10), who had already enrolled in post graduate studies, were considered unsuitable, as they were seen to be receiving extra coaching as post-graduate students, which could give them undue advantage.

Also, those employed outside the Johannesburg region (7) were not suitable due to distance. This filtered the sample to a total of seven GBTs. A period of two years in practice was decided upon based on an understanding that the first year of practice is commonly challenging as the beginning teachers experience many changes in the new environment as alluded to in the literature Chapter 2. These include adjusting to the culture of schools, learning about the needs of their students, heavy workloads, and maintaining discipline among others (Luft, et al., 2015;Helms-Lorenz, et al., 2016). Also, allowing an additional year before conducting the study had a high risk of working with a more reduced sample of GBTs from this specific cohort due to the high teacher attrition in the region (Spaull, 2013). The final criterion used for selecting participants was the willingness of the teachers to participate in the study as per ethical considerations.

For the analysis in this chapter, which is for the confirmation of gain in the quality of TSPCK as a direct result of the intervention, various GBTs data resources found in the archives were used for the analysis. These included completed specially designed tools, submitted responses to short class activities, and stimulated recall evidence-based interviews. The data found most comprehensive were completed pre- and post-TSPCK test tools in the topics of choice used in the intervention. The two sets of completed TSPCK test tools, viz. pre- vs post-tests, were easily distinguishable from each other by the different dates of submission. The completed test tools were re-labelled as “pre- (post-) intervention-TSPCK” tests. The pre- vs post-TSPCK tests of the sample were analysed and compared to confirm the anticipated improvement in the quality of planned TSPCK acquired from the pre-service intervention programme. To safe guard against searchlighting the archived data, I employed several strategies, such as bringing in fresh eyes and carefully articulating the rules of scoring explained in detail in section 5.2 below.

5.2 Analysis for gain in planned TSPCK

The analysis procedure followed for scoring the completed pre-(post)-intervention-TSPCK test tools, involved matching the qualitative descriptive responses captured from the test tools, on the TSPCK rubric by Mavhunga and Rollnick, (2013) for scoring the quality of planned TSPCK. The scoring rubric was developed and validated in a separate study (Mavhunga and Rollnick, 2011) and used in several other studies (Rollnick. et al., 2017; Rollnick. & Mavhunga, 2016) (see Appendix A for the full rubric). Prior to scoring the responses, I sought assistance of three independent raters, who helped in the validation of the generated TSPCK test scores. According to Baton (2002) the quality and rigour of using a set of quality criteria should be widely recognised and accepted in the braoder field of research, through member checking and peer/audience validation. The three independent raters who helped in the peer validation process were experienced physical science teachers, with strong background knowledge in science teacher education and interest in PCK research. The enlisted raters were first familiarised with the test tools and the scoring rubric. The rules followed in scoring the responses were similar to those used in previous studies and included: (1) scoring each question singly by assigning a score corresponding to the category in the rubric where most criteria are met; (2) assigning the lowest score to any question with no response; and (3) scoring any question with responses falling across two categories that are close to each other, by checking specific gate-keeping criteria for each category and evidence that maybe in other resources such as the submitted class activities (as agreed upon between myself and the enlisted independent raters).

The process followed in scoring the responses captured from the pre- (post-) intervention TSPCK test tools involved independent marking and scoring of unmarked copies of the completed test tools with the assistance of the independent raters, and then collectively to resolve any discrepancies following the rules stated above. Any discrepancies observed in the scores were debated and agreed by consensus (Stemler, 2004) regarding which mark to award based on the specific gate-keeping criteria for each rubric category, as mentioned above. The qualitative

descriptive responses written as part of answering the test questions were used as additional data to confirm the score for each test item answered.

As mentioned in Chapter 3, the extent of agreement between the scores awarded by the independent raters and myself were further validated using the Cohen Kappa inter-rater reliability calculations (Landis & Koch, 1977). An inter-rater agreement Cohen Kappa value of 0.82 was obtained. According to Landis and Koch, in order to describe the relative strength of agreement associated with Cohen Kappa statistics, the labels assigned to the corresponding Kappa statistics range between poor (< 0.00) to almost perfect agreement (1.00) (Landis and Koch, 1977 p.165). The calculated Kappa value, **(**Appendix P) therefore indicated better than chance agreement.

Table 5.1 below shows a comparison of the GBTs' pre- (post-) intervention TSPCK test scores generated at the beginning and at the end of the intervention studies.

Table 5.1: Pre- (post-) intervention GBTs TSPCK test scores

Participants	Topic of intervention	Five components of TSPCK					
		LP	CS	WD	REP	CTS	Person Average
Sharon	Stoichiometry	1 (3)	2 (3)	2 (4)	1 (3)	1 (3)	**1(3)**
Michael	Organic Chemistry	1 (3)	1 (2)	1(3)	1 (3)	1 (2)	**1(3)**
Menjo	Chemical equilibrium	2(3)	1(3)	2(3)	1(3)	1(3)	**1(3)**
Tzepo	Electro Chemistry	1(3)	2(3)	1(3)	1(3)	2(3)	**1(3)**
Kgomotso	Stoichiometry	1(2)	1(3)	2 (3)	1 (3)	2 (2)	**1(3)**
Jaba	Organic Chemistry	2(3)	2(3)	3(3)	2(3)	2(3)	**2(3)**
Ntombi	Organic Chemistry	1(3)	2(3)	1(2)	1 (2)	1 (2)	**1(2)**
Average component score		1(3)	**2(3)**	**2(3)**	1(3)	**1(2)**	**1(3)**
Average pre (post) group score							**1(3)**

Note: Post-TSPCK test scores are shown in brackets. Pseudonyms have been used to conceal the identities of the participants.

Table 5.1 above, shows a summary of the pre-(post-) intervention TSPCK test scores drawn from a sample of seven GBTs, who were purposefully sampled from the four groups (N=24) of the GBTs, as pre-service teachers then, mentioned above. The first row in the table shows the five content components of TSPCK. For purposes of ease of use, the components of TSPCK have been abbreviated as follows: LP = learner prior knowledge, CS = curricular saliency, WD = what is difficult to teach, RP= representations and CTS = conceptual teaching strategies. The last (bottom) row represents the average score per TSPCK component investigated. The last (far right) column indicates the pre- (post-) intervention-TSPCK person average scores for the individual GBTs investigated. As mentioned in Chapter 3, a person average score does not mean that TSPCK is measured from the mathematical sum of the TSPCK components, but rather the overall TSPCK component interaction of individual components with each other. It must thus be noted that the score assigned to each TSPCK component has taken into account the extent of interaction of each component with the others. As alluded to in Chapter 3 (section 3.7.1.), such component interaction is the key criteria in the rubric used for determination of the quality of TSPCK across each of the four categories. The calculated person average score is therefore used as a measure or a proxy of the possible overall effect of the component interactions seen when each individual component was evaluated. It is important, however, to note that the calculated average person and component scores naturally occurred in form of mathematical fractions which were rounded up or down to a single digit, in order to locate the aggregated score in the appropriate categories in the scoring rubric. This is consistent with the understanding that PCK (Abell 2008) as well as TSPCK Aydin, Demirdogen, Akin, et al. (2015) is not the sum of the individual components, but rather their interactive use in working together to support an explanation of a single or a pair of related concepts.

Looking at the overall patterns displayed in Table 5.1 above, two major patterns are observed. Firstly, the overall pattern emerging from the individual person average scores indicates an overall average positive shift by two quality category levels except for two teachers who improved by one category from the pre- to the post-intervention tests across the seven pre-service teachers. In addition, all the GBTs

except teacher (Ntombi) were located in the category denoted by a score of 3, which is the 'developing' level of TSPCK at the end of the intervention. The criteria denoted by a score of 3 in the TSPCK rubric used in this study refers to the competence to reason through a topic by identifying possible learner misconception and providing corrective responses that show evidence of considering one other component of TSPCK interactively. In addition, the teacher should be able to identify at least two big ideas of the topic, and logically link them to the subordinate concepts. The teacher should equally demonstrate the ability to identify specific gate keeping concepts that, when not fully understood, add to the difficulty of a concept; and be able to apply scientific representations that link to aspect(s) of the concept under discussion.

As mentioned above, one of the GBTs, Ntombi, although she experienced an improvement, had her person average score remain in the lower categories of quality with a score of 2; which according to the scoring rubric, means the GBT, was still limited to identifying a misconception without providing a substantive corrective response, but only based to standard textbook definition as a pre-service teacher then. The responses provided should however show evidence of at least two big ideas and use of representations, although the teacher may not provide linking explanatory notes to aspects of the concept being explained. In addition, the identified concepts/pre-concepts may be a mix of the big ideas and subordinate concepts and the suggested sequencing may have one or two illogical placings of big ideas/subordinate concepts. Furthermore, the reasons provided may refer to concepts generally regarded as basic for the subject or no reason provided at all. The full adopted scoring rubric is provided as (Appendix 1).

The second pattern derived when looking at the average scores generated per TSPCK component shows a positive jump in the scores across all components by at least one quality category level, towards categories that denotes high quality TSPCK, particularly a score of three, which designates the 'developing' quality of TSPCK. In other words, the quality of understanding of the topic from the perspective of both the knowledge of the TSPCK components and the competence

to use the components in an interactive manner when formulating teacher responses, improved by at least one quality category for all the GBTs, as pre-service teachers then. There were positive exceptions, where on average, the then pre-service teachers experienced an average jump of two quality categories in two TSPCK components. These were the components of learner prior knowledge and representations.

It was further noted that the overall patterns observed in both the person average scores and the average TSPCK component pre- (post-) scores seemed independent of the topic of intervention. The same improvement observed above was seen across the entire class of (N=24), but focus was specifically placed on analysing the shifts from the seven GBTs that met the selection criteria.

In the section below, I analyse these patterns more closely.

5.2.1 Improvement across the TSPCK components

In order to observe the finer features of the overall pattern of the TSPCK components, the TSPCK scores were presented in a graphical representation as shown in Figure 5.1 below. The *x*-axis represents the five content components of TSPCK, while the y-axis represents the average pre- (post-) intervention-TSPCK test scores per component across all the GBTs

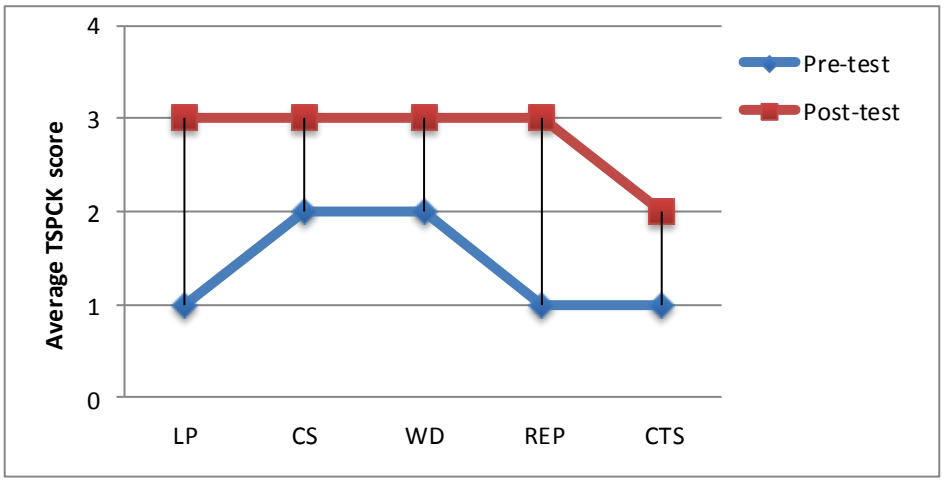


Figure 5.1: Average pre- (post-) intervention TSPCK test scores per content component

The overall pattern emerging from Figure 5.1 shows an average shift of at least one quality category jump, across all the TSPCK components from the pre- to the post-intervention TSPCK test scores. The most noticeable shift as pointed out earlier was observed in the components of learner prior knowledge and representations, where both components experienced a positive average jump of two quality category levels up from the pre- to the post-TSPCK average tests, across the intervention GBTs studied. In the discussion below, I present sample qualitative extracts, showing insights into the nature of responses reflecting the positive shifts experienced per component shown in Figure 5.1. I start by showing typical responses that demonstrated a 2-quality category level jump.

(i) Example 1: Pre- (post-) TSPCK test scores in the component of learner prior knowledge

The first example was an extract of written responses lifted from the component of learner prior knowledge, where the GBTs, as pre-service teachers then, experienced an average jump of two quality category levels up from the pre-tests to the post-tests. The individual intervention GBTs' person scores in the TSPCK component of learner prior knowledge are first collectively presented in Figure 5.2 below.

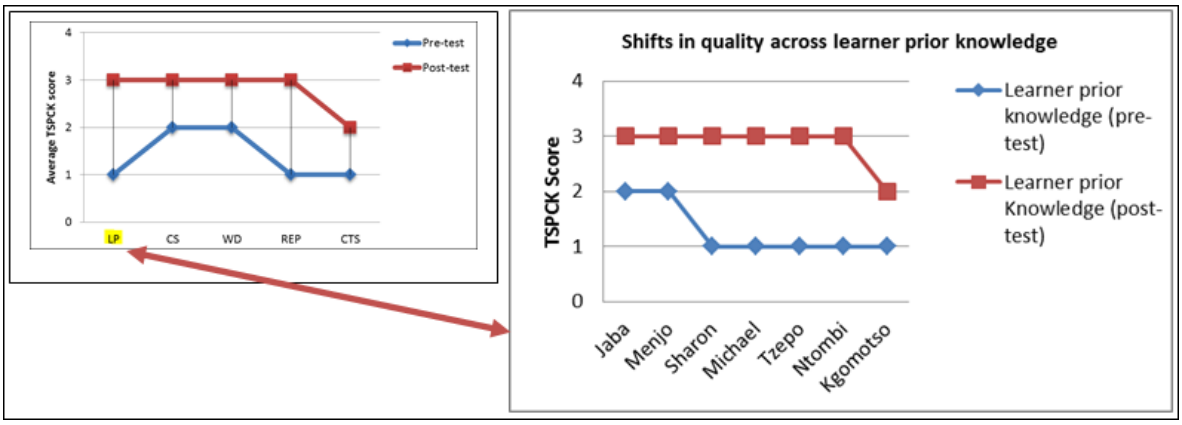


Figure 5.2: Pre- (post-) TSPCK person scores in the component of leaner prior knowledge

The TSPCK person scores shown in Figure 5.2 above reveal that four out of the seven sampled intervention GBTs experienced a shift of two quality category levels jump from the pre- to the post-TSPCK tests. Similarly, three intervention GBTs experienced a shift of one quality category level jump from the pre- to post-TSPCK tests in the component of learner prior knowledge.

For instance, in the test tool administered in the topic of stoichiometry under the category of learner prior knowledge, the pre-service teachers were asked how they would respond in writing when giving feedback to learners' who consistently demonstrate difficulties with preparing molar solutions. Examples of responses captured from some of learners' incorrect reasoning in a homework assignment contained in the TSPCK tool, were extracted and are shown below. This is followed by an example of a typical response captured from one the intervention GBTs, who contributed to the average shift of two quality categories jump, as a pre-service teacher then, in Figure 5.3.

Extract from the TSPCK tool on stoichiometry

Homework Exercise

During a practical lesson you have to make up molar solutions. You are provided with 10 g of sodium chloride, sodium bromide and sodium iodide. You dissolve each of these salts in a 100-ml volumetric flask. Do these solutions have the same or different molar concentrations? Explain your answer. How would you respond when giving feedback to learners who provide the following answers?

Learners' answer:

The concentration of the three solutions will be the same because you dissolve the same amount of solute in the water.

THE CONCENTRATIONS ARE EQUAL BECAUSE YOU ARE DISSOLVING THE SAME MASS OF THE SALTS IN 100ML OF WATER.

Figure 5.3 below shows a comparison of written responses captured from teacher Sharon. This example shows teacher Sharon's contribution to the overall average positive jump of 2 quality category levels jump experienced by the then pre-service teachers, in the component of learner prior knowledge, indicated in Figure 5.1.

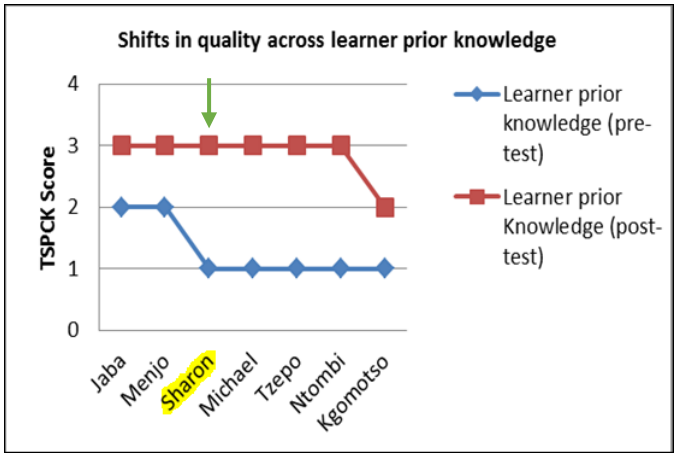
TSPCK score	Extract from pre-test tool	Extract from post-test tool
	I will provide an explanation of the concept of concentration by proving a realistic example instead of simply telling the learners what calculations need to be used. I will then refer them to the periodic table. Furthermore, I will include a calculation as well to vary learners understanding to serve as an application to the theory.	I will point out to the learners that, "the mass of the salts does not mean that the numbers of particles are the same. The ions of the different salts have different relative atomic masses and therefore the molar mass of each salt is different and so the concentration of solutions will be different". I will then refer them to the periodic table to see that sodium chloride has a smaller molar mass than sodium iodide, and would therefore have greater number of ions. Therefore, the amount of salt, measured in moles, will also be different. I will remind the learners that just because the mass of each salt is the same does not mean the amount of salt, measured in moles will be the same. Since concentration is the amount of substance per unit volume, the concentration of the sodium chloride solution will be greater than that of the sodium bromide, which would be greater than that of sodium iodide. I will then remind them that "If you add ten grams of the salt to the same volume of solvent you are not adding the same number of ions for different salts.

Figure 5.3: Teacher Sharon's responses in the pre- (post-) TSPCK tests in the component of learner prior knowledge

An inspection of teacher Sharon's pre-test responses reveals that the GBT appeared to lean more towards algorithmic options related to mathematical calculations. For instance, the teacher points out that she would first refer to the periodic table before applying a calculation to explain the theory behind molar concentrations. The teacher does not, however, provide evidence of how she would link the periodic table as a representation for teaching with the calculations to build conceptual understanding of the concept under discussion. The teacher was thus assigned a score of 1, which corresponds to the limited quality category of TSPCK, in the scoring rubric for suggesting use of representations without linking explanatory notes to enforce learners' conceptual understanding and not drawing on any other component of TSPCK.

In the post-test, the teacher explained that "*the mass of the salts does not mean that the numbers of particles are the same*." She then identified the specific gate keeping concepts that when not fully understood adds to the difficulty of a concept, citing reasons related to aspects of the component of curricular saliency, by stating that "*the ions of different salts have different relative atomic masses and therefore the molar mass of each salt is different, which means the concentration of solutions will be different, and therefore, the amount of salt, measured in moles, will also be different.*" The teacher further suggested reference to the periodic table to confirm the molar masses of sodium chloride and sodium iodide, to help explain the differences in the number of ions observed therefore linking the suggested representation to the specific concepts represented.

In the last part of her response, the teacher emphasised: *"If you add ten grams of the salt to the same volume of solvent you are not adding the same number of ions for the different salts."* The explicit emphasis of same grams of salt, not to refer to the same number of ions for different salts shows evidence of the teacher's awareness of a common misconception about the topic, an element of the component of learner prior knowledge. The teacher was assigned a score of 3, which matchers into the category of developing quality of TSPCK in the adopted scoring rubric, in the post-test. This score was based on her ability to interactively draw on the TSPCK

components of representations in helping learners move towards correct reasoning when learning about the concept of molar concentrations, the main concept under discussion, when the focus of the discussion was on the component of learner prior knowledge

(ii) Example 2: pre (post) intervention-TSPCK tests in the component of representations

The second example, where the GBTs experienced an average jump of two quality category levels was lifted from the component of representations. The individual intervention GBTs' person scores in the component of representations are presented collectively in Figure 5.4 below. The *x*-axis in the bigger figure indicates the intervention GBTs, while the *y*-axis shows the average pre- (post-) TSPCK person scores.

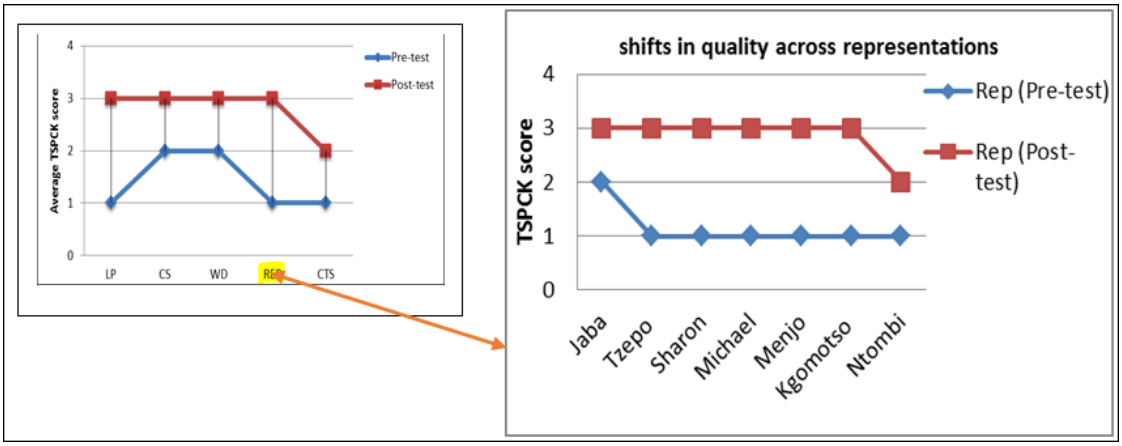
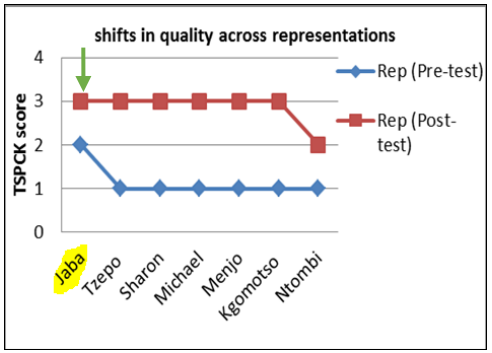


Figure 5.4: Pre- (post-) TSPCK person scores in the component of representations

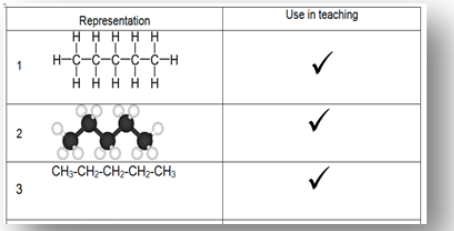
The findings in Figure 5.4 indicate that five out of the seven intervention GBTs experienced a shift of two quality category levels jump from the pre- to the post-TSPCK tests in the component of representations. Likewise, two intervention GBTs experienced a shift of one quality category level jump from the pre- to the post-TSPCK tests in the same component.

Teacher Jaba's written response was used here as a typical example of pre-service teachers who contributed to the observed two quality levels jump in improvement in the TSPCK component of representations shown in Figure 5.5 below.

TSPCK score



Extract from pre-TSPCK tool



	Representation	Use in teaching
1		✓
2		✓
3	CH_3-CH_2-CH_2-CH_2-CH_3	✓

Extract from post –TSPCK tool

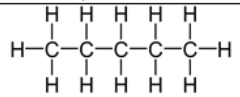
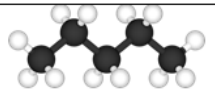
	Representation	Use in teaching
1		This representation is useful as it makes identification of functional groups easier and can also show double and triple bonds. This will be used when teaching functional groups, IUPAC naming and isomers. In teaching of organic reactions, this representation also provides a good visual mode, useful to compare products and reactants to identify what took place.
2		Because this representation is an image of a 3D molecule, it helps learners to better understand the configuration of atoms within organic molecules. Electronegativity and how it shapes the molecule is now easier to understand. I would also want to use these representations as examples of models that I would ask learners to build using molecule modelling beads. These physical models can be used to teach organic reactions by learners building the reactants and then using the reactants to build the products. This will help learners understand the reaction mechanisms better.

Figure 5.5: Teacher Jaba's responses in the pre- (post-) TSPCK tests in component of representation

The tool administered to teacher Jaba's class at the time of the pre-service intervention was in the topic of Organic Chemistry. The question item asked required the GBTs to first identify two representations they find most useful in teaching the topic, from a list of five options provided in the test tool (see Appendix F). They were then required to explain how they would use the selected representation(s) to explain the differences in the boiling points of butane (-0.5^0C) and pentane (36^0C).

In the pre-test, teacher Jaba selected the representations shown on the left-hand side of Figure 5.5. The teacher did not, however, provide explanatory notes, linking the representation to aspects of the concepts being explained. In the stimulated video recall, interview prompts to confirm the reasons why the teacher failed to provide details on when to apply the selected representations for teaching, the teacher indicated that he understood that the representations would be useful in teaching, however, he was not sure on how to conceptually explain his thoughts from a teaching perspective then. Teacher Jaba was assigned a score of 2 in the pre-test, following the rules in the TSPCK scoring rubric for selecting the most appropriate representations, even though he did not provide linking explanatory notes to the aspects of the concept being explained.

In the post-test, shown on the right-hand side of Figure 5.5, the teacher selected the same representations as in the pre-test. However, this time he provided accompanying explanatory notes on why he considered the selected representations useful for teaching the topic. For instance, in his choice for the line structural diagram, the teacher pointed out that *"in teaching organic reactions, the 1st representation provides good visual mode, useful for comparing products and reactants to identify what took place.*" This aspect reflects the teacher's ability to point out the exact feature to be observed in a drawing, making clearer an aspect that is not easy to understand regarding the way in which chemical reactions change from reactants to products. In the teacher's response, we see understanding of representations with a link on what is difficult to understand in this case. The teacher then identified the second representation as a 3D molecule. This kind of a representation is widely reported to be desirable in helping learners to better

understand the configuration of atoms within organic molecules and link them to their shapes.

In the response, the teacher further referred to electronegativity in the context of explaining the configuration of atoms that yield to the shape of the molecule. This is evidence of awareness of the foregrounding concepts, needed prior to teaching the topic, which indicates an element of the component of curricular saliency. So, taking the teacher's written response as a whole, we see evidence of three components of TSPCK interactively used. These are representations in a way that complements both the understanding the components of what is difficult to understand, as well as curricular saliency. The teacher was assigned a score of 3, which corresponds to the quality category of 'developing' TSPCK in the post-test. This followed the rules of scoring in the adopted rubric, where the teacher considered use of representations at two levels of component sophistication, as well as drawing on two other TSPCK components to enforce understanding of the concept under discussion. The use of representations at different levels of sophistication is noted as bringing depth in the learners' conceptual understanding.

In summary, both the above extracts presented examples of two quality category level jumps, where the GBTs showed evidence of understanding of transformation of content knowledge from a teaching perspective. The discussions below illustrate cases of TSPCK components that experienced a single category jump in their development.

(i) Example 1: Pre- (post-) TSPCK test scores in the component of curricular saliency

The first example explored the quality of the GBTs' TSPCK as pre-service teachers then with 1quality category jump in the component of curricular saliency.

The pre- (post-) TSPCK person scores per intervention GBT in the component of curricular saliency are first collectively presented in Figure 5.6 below. The X-axis shows the intervention GBTs, while the Y-axis indicates pre- (post-) TSPCK person scores

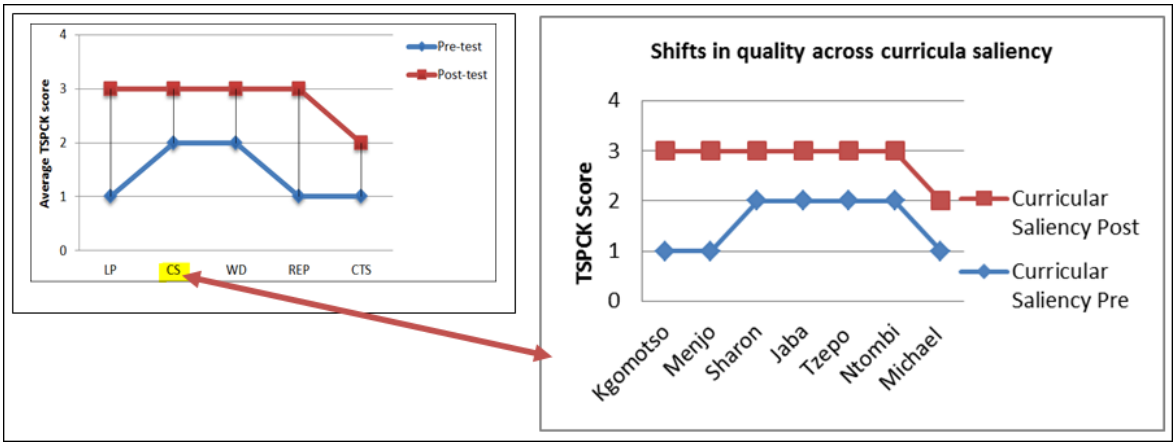


Figure 5.6: Pre- (post-) TSPCK person scores in the component of curricular saliency

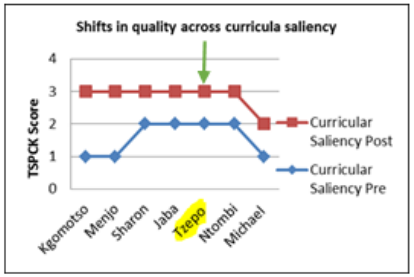
The TSPCK person average scores displayed in Figure 5.6 above indicate that two intervention GBTs experienced a shift of two quality category levels jump from the pre- to the post-TSPCK tests. The other five intervention GBTs experienced a shift of one quality category level jump from the pre- to post-tests in the component of curricular saliency.

The responses captured from teacher Tzepo's pre- (post-) TSPCK tests were used as a typical example, to show his contribution to the overall average positive jump of the one quality category level experienced by the GBTs, as pre-service teachers then, in the component of curricular saliency.

The test tool administered to teacher Tzepo's class at the time of the pre-service intervention was in the topic electrochemistry. Under the category of curricular saliency, the first part of the question required the GBTs to identify the big ideas in teaching the topic at Grade 12.

The teachers were further required to suggest topics/concepts that must be covered in Chemistry before teaching the topic and identify reasons why teaching the topic of electrochemistry is important for the learners.

The written responses captured from teacher Tzepo in the pre- vs. post- TSPCK test tools are presented in Figure 5.7 below.

<table>
<tr><th>TSPCK score</th><th>Extract from pre-test tool</th><th>Extract from post-test tool</th></tr>
<tr>
<td>
</td>
<td>
<table>
<tr><th>Suggested concepts and sequence</th><th>Reasons</th></tr>
<tr><td>Equations must be balanced</td><td rowspan="3">This order helps the teaching process to run smoothly</td></tr>
<tr><td>Oxidation and reduction occur simultaneously</td></tr>
<tr><td>Energy from chemical reactions can produce electricity</td></tr>
</table>
List of topics to be taught before teaching electrochemistry
1. Balancing chemical equations
2. Oxidation and Reduction
3. Explaining to learners the meaning of anode and cathode

Importance of learning electrochemistry
• Guide learners in their future careers
</td>
<td>
<table>
<tr><th>Suggested concepts and sequence</th><th>Reasons</th></tr>
<tr><td>1. Oxidation and reduction occur simultaneously</td><td rowspan="3">This order allows the conceptual flow of Re-dox reactions in the CAPS curriculum</td></tr>
<tr><td>2. Galvanic cells produce electricity</td></tr>
<tr><td>3. Electricity can be used to produce a chemical reaction</td></tr>
</table>
List of topics to be taught before teaching electrochemistry
1. Ionic reactions
2. Oxidation and Reduction
3. Electron configuration

Importance of learning electrochemistry
• Help learners understand the working of batteries
• How batteries charge and get low,
• linking with other concepts such as electric current
</td>
</tr>
</table>

Figure 5.7: Teacher Tzepo's responses in the pre- (post-) TSPCK tests in the component of curricular saliency

Looking at the concepts suggested in the pre-test in the Figure 5.7 above, we see teacher Tzepo identify the main ideas for teaching the topic of electrochemistry as a mix of concepts that are certainly the main ideas, with those regarded as subordinate concepts. For example, in the pre-test, the teacher correctly identified two concepts, which can be regarded as big ideas in teaching electrochemistry. These are oxidation and reduction, which occur simultaneously, and energy from chemical reactions, which can produce electricity. He however included balancing equations, which can be considered a subordinate concept in teaching the topic of electrochemistry, as equations only serve to predict or measure aspects related to the main ideas, but carry no explanatory power in and of themselves.

In the post-test, we see the teacher retain the two main ideas i.e., oxidation and reduction, occurring simultaneously and energy from chemical reactions can produce electricity, and add the idea of galvanic cells producing electricity, which can all be considered concepts central to the teaching of electrochemistry. This indicates an improvement in the knowledge about the most important concepts of a topic, an element that falls under the TSPCK component of curricular saliency. Equally, the teacher correctly identified topics that must be taught before teaching electrochemistry in both the pre-and post-tests. The reason provided for the importance of teaching electrochemistry in the pre-test as guiding learners in their future careers equally appeared limited to the generic benefit of education. In the post-test, the teacher however stated that the topic was important in helping learners understand the working of batteries (cells), how batteries are charged and how they become drained of energy, as well as linking the topic with other topics/concepts in Chemistry, such as electric current. The reasons provided in the post-test were seen to refer to conceptual development of understanding of other topics in the same subject, however without correctly specifying the topics.

The teacher was assigned a score 2, which corresponds to the basic quality category in the TSPCK rubric in the pre- test, for identifying the two big ideas of the topic, and correctly identifying topics that must be taught before teaching electrochemistry. However, the reasons provided for importance of the topic, were limited to the generic benefit of education.

In the post-test, the teacher was assigned a score 3, which corresponds to the developing quality category in the TSPCK scoring rubric, for correctly identifying the three big ideas and the topics that must be taught before teaching electrochemistry. Furthermore, the reasons provided for importance of the topic referred to conceptual development of understanding of other topics in the subject, without specifying the topics.

(iii) Example 2: Comparison of (Pre) post TSPCK test scores in the component of what is difficult to teach

The second example that explored the quality of the GBT's TSPCK with one quality category level jump was retrieved from the component of what is difficult to teach. The pre- (post-) TSPCK person scores per intervention GBT are collectively presented in Figure 5.8 below. The *y*-axis shows the TSPCK person scores, while the *x*-axis indicates the intervention GBTs.

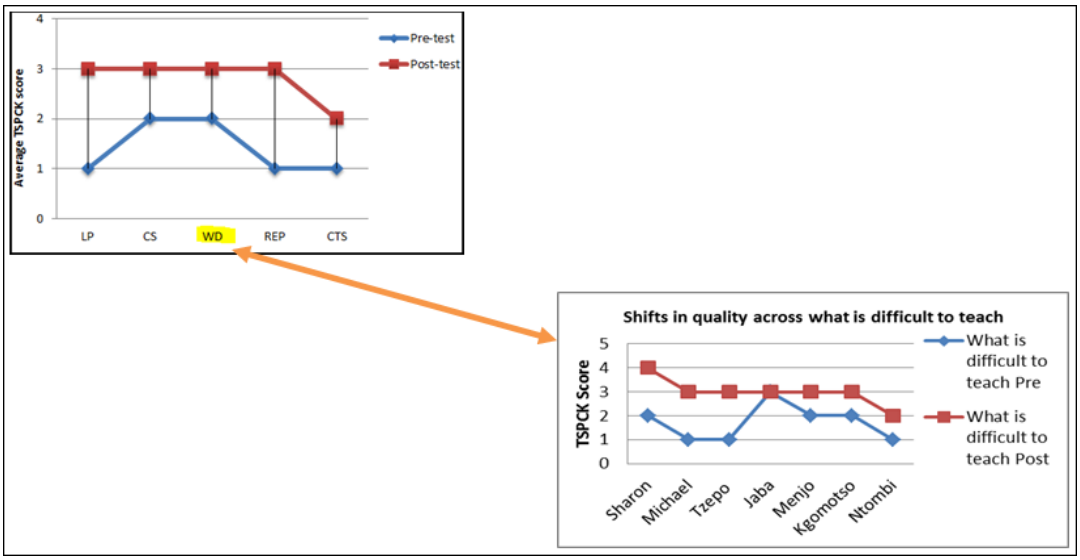


Figure 5.8: Intervention GBTs pre- (post-) TSPCK person scores in the component of what is difficult to teach

When examining the TSPCK average person scores displayed in Figure 5.8 above, it is revealed that three intervention GBTs experienced a two-quality category jump, from the pre- to the post-tests. Likewise, three GBTs experienced a single quality category jump from the pre- to the post-tests. The remaining single GBT retained the same quality score between the pre- and the post-TSPCK test.

The question item asked under the category of what is difficult to teach required the then pre-service teachers to select concepts, which they consider difficult to teach, and provide reasons as to why the selected concepts are considered difficult.
The written responses captured from teacher Menjo's pre- (post-) tests were used as a typical example of his contribution to the overall average positive jump of the single quality category level experienced by the GBTs as pre-service teachers then, in the component of what is difficult to teach. Figure 5.9 below shows teacher Menjo's pre- vs. post-test responses, lifted from in the topic of chemical equilibrium that he considered difficult to teach, and the reasons why he considered the selected concepts difficult to teach for learners' understanding.

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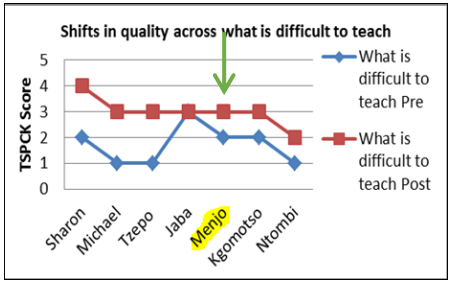
<table>
<tr><th>TSPCK score</th><th>Extract from pre-test</th><th>Extract from post-test</th></tr>
<tr>
<td>
</td>
<td>
<table>
<tr><th>Concept</th><th></th><th>Why considered difficult?</th></tr>
<tr><td>Closed and open system</td><td>✓</td><td>It becomes more difficult in open systems because not only the mixture is in question but more on what the surrounding contribute. Difficult to picture closed and open systems.</td></tr>
<tr><td>Using mathematical ratios in a chemical concept</td><td>✓</td><td>Being used to numbers (mathematics) and shifting to substances and number of molecules becomes difficult</td></tr>
</table>
</td>
<td>
<table>
<tr><th>Concept</th><th></th><th>Why considered difficult?</th></tr>
<tr><td>Closed and open system</td><td>✓</td><td>Leaners would find it difficult to understand closed and open systems if the test tube is for example open</td></tr>
<tr><td>Dynamic equilibrium – in chemical systems</td><td>✓</td><td>Learners confuse dynamic equilibrium with static equilibrium</td></tr>
</table>
</td>
</tr>
</table>

Figure 5.9: Menjo's pre- vs. post-test responses in the topic of chemical equilibrium

An analysis of the findings in Figure 5.9 reveals that the two concepts which teacher Menjo considered difficult to teach at the beginning of the intervention programme were a mix of specific subject matter knowledge that makes teaching difficult, as well as algorithmic options related to mathematical calculations and recall knowledge.

For example, concept of closed and open systems leans more towards higher-level cognitive thinking, and is considered difficult to teach. On the contrary, the concept of using mathematical ratios in chemical concepts tends towards algorithmic options related to mathematical calculations. According to Gess-Newsome (1999), where those main content aspects considered difficult to teach and algorithmic options related to mathematical calculations are mixed and presented in the pre-test, a lack of deep engagement with the topic is revealed. This observation was further reflected in the reasons provided as to why the teacher considered using mathematical ratios in chemical concepts to be difficult, where he alludes to the shift from using numbers in mathematics to chemical substances and numbers of molecules. The teacher was assigned a score of 2 in the pre-test, for considering a mix of specific subject matter knowledge that make concepts difficult to teach, as well as algorithmic options related to mathematical calculations. In the post-test, teacher Menjo retained the concept of closed and open systems.

He then included dynamic equilibrium in chemical systems as aspects found difficult to teach. Both concepts appear to lean more towards higher level cognitive thinking and can be considered difficult to teach for learners' understanding.

The observed shift from algorithmic reasoning towards higher-level cognitive thinking is evident in the reasons provided in Figure 5.9 above, where the teacher explains that learners find it difficult to understand closed and open systems and often confuse between dynamic and static equilibrium. The teacher was assigned a score of 3 for selecting key gate keeping concepts due to specific students' common misconceptions.

The findings also revealed that the improvement in the quality of TSPCK by the intervention GBTs as pre-service teachers then, from the pre- to the post-tests across the five components of TSPCK was achieved irrespective of the topic of choice.

In summary, the analysis for evidence on improvement in the quality of TSPCK analysed per TSPCK component is noticeable when scores in the performance of the then pre-service teachers across each of the TSPCK components are analysed. The following analysis examines the gains (shifts) in the quality of TSPCK across participants' person average scores.

5.2.2 Improvement across the person average scores

Similar to the pattern in the TSPCK scores, the pattern emerging from the person average scores displayed in Table 5.1 indicates an overall gain of at least one quality category level across all the intervention GBTs. This means that when considering the shifts made across each of the five components of TSPCK for each participant, an overall positive shift by one category is noticed.

To observe for the finer features of the person average scores, the individual GBTs' person average scores described in Table 5.1 above were graphically represented as shown in Figure 5.10 below. The X-axis on the graph represents the intervention GBTs, while the Y-axis represents the pre- (post-) person average scores.

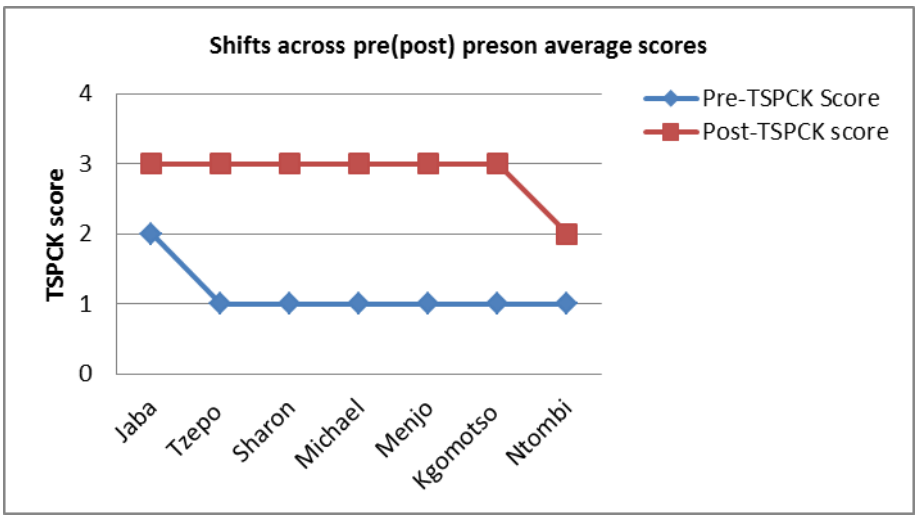
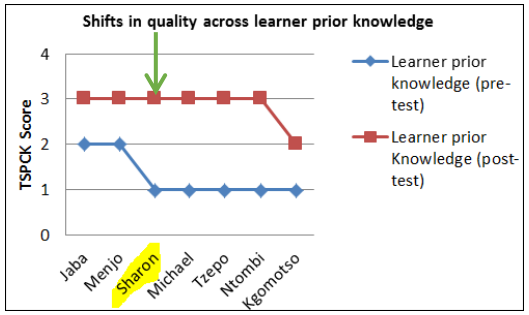


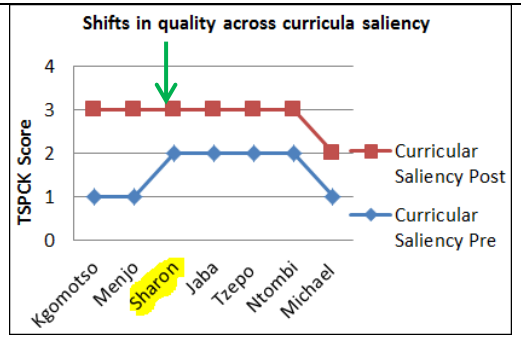
Figure 5.10: Intervention GBTs' pre- (post-) person average scores

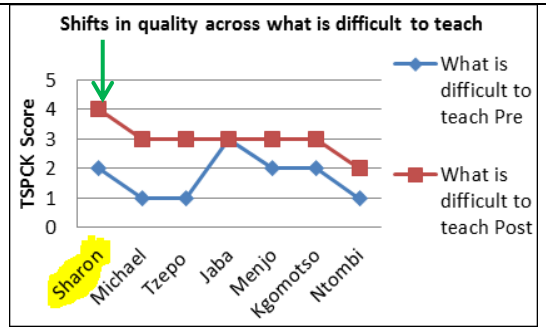
Each point on the graph in Figure 5.10 represents a quality of TSPCK determined from considerations of responses from all the five content components of TSPCK.

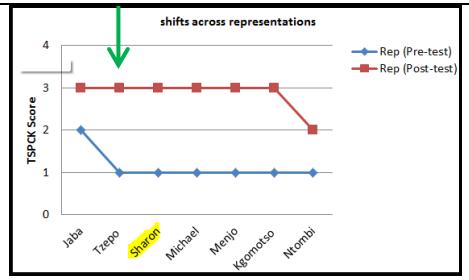
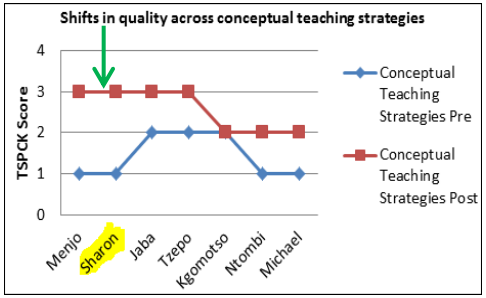
An inspection of the average person scores displayed in Figure 5.10 indicate that five intervention GBTs experienced an average shift of two quality category levels jump from the pre- to the post-TSPCK person average score. The other two intervention GBTs experienced a person average shift of one quality category level jump from the pre- to the post-TSPCK person average score.

When looking for evidence of shift in the quality of TSPCK in order to make a statement about gain or loss of quality for each participant, it is important to look for such shifts across all the five components of TSPCK, in alignment with the theoretical framework used in this study. Figure 5.11 below presents a summary of the analysis of teacher Sharon's pre- vs. post- TSPCK qualitative analysis, responsive to test items in each of the TSPCK components. The example of teacher Sharon was used to demonstrate analysis of depth achieved that leads to the determination of a person's average score in a pre- or post-test. Sharon's actual completed pre- and post-test are shown in Appendix H.

TSPCK Component	TSPCK Score	Extract from the Pre-test	Extract from the Post-test
Learner prior knowledge		To explain the theory behind molar concentrations, I will refer learners to the periodic table. Furthermore, I will include a calculation to vary learners understanding to serve as an application to the theory. **In the extract above:** The GBT identifies learner misconception and provides algorithmic options related to mathematical calculation to explain the theory behind molar concentrations. She then repeats standard definition drawing on the component of curricular saliency alone.	I will point out that, the mass of the salts does not mean that the numbers of particles are the same. The ions of the different salts have different relative atomic masses. This means the concentration of solutions will be different and therefore the amount of salt, measured in moles, will also be different. Just because the mass of each salt is the same does not mean the amount of salt, measured in moles will be the same. For example, If you add ten grams of the salt to the same volume of solvent you are not adding the same number of ions for the different salts". **In the extract above:** The GBT identifies learner misconception, expands and re-phrases the explanation. She then confirms accurate understanding drawing interactively on the components of learner prior knowledge and curricular saliency.
Currricular saliency			

		The main ideas for teaching Stoichiometry include; The mole, Concentration and dilution of solutions and Stoichiometric calculations. The pre-concepts that must be understood before teaching the topic are; Balancing equations, Avogadro's number, Molar concentrations and Stoichiometric calculations. **In the extract above:** The suggested big ideas are a mix of the core concepts and subordinate concepts. For instance, the mole can be considered as one of the main ideas. However, aspects like stoichiometry calculations are subordinate to the main concept for teaching the topic. The developed map provides conceptual links between the big ideas and subordinate concepts. However, the reasons provided for importance of topic had no links with other topics of the subject.	The big ideas of the topic to include; Conservation of mass as a chemical law that allows quantitative relationships to be established in chemical reactions; Molar ratios, which can be used to determine the amount of reactants used or the yield of product formed; Limiting reagent is the reactant that is used up in a chemical reaction and determines the amount of product formed. The pre-concepts needed to be understood before teaching the topic to include; atoms, balancing equations, law of conservation, ratios and molecules. The reasons provided for importance of topic include; measuring the ozone concentration and converting coal into gaseous fuel. **The extract above:** The GBT identifies at least three big ideas. The identified subordinate ideas show links to the big ideas, however with no explanatory notes The identified pre-concepts include those needed for the current topic. The reasons given for importance of the topic include reference to conceptual development of understanding of other topics in the subject.
What is difficult to teach			

		The concepts that are difficult to teach in the topic of stoichiometry are; Amount of substance/mole, Avogadro's number and Stoichiometric calculations. The selected concepts are difficult, because learners struggle with balancing equations and understanding ratios in stoichiometric calculations. **In the abstract above:** The teacher considers specific subject matter knowledge that makes concepts difficult to teach as a mix with algorithmic options related to mathematical calculations. The reasons provided on why the concepts are difficult to teach are algorithmic options related to balancing equations and understanding mathematical ratios.	The concepts found difficult for leaners to understand in the topic of stoichiometry include; Amount of substance/mole, Avogadro's number and Stoichiometric calculations. The selected concepts are found difficult because they are very abstract, as learners cannot physically see moles. They also confuse everyday language with scientific language, especially relating amount to mass. For example it becomes difficult to explain amount of substance vs mass, based on learners' prior knowledge and hence linking understanding with other topics such as rates of reactions, ideal gases, the Haber process, mining, concentration, acid-base reactions is not easy. **In the abstract above**: The GBT identifies specific concepts that make concepts difficult to teach as a mix with algorithmic options related to mathematical calculations. The reasons provided are however related to learners' prior knowledge and aspects of curricular saliency. The reasons provided are linked to specific gate keeping concepts that when not fully understood add to the difficulty in explaining the meaning of abstract concepts like molar concentration. The then pre-service teacher was assigned a score of 4, for identifying specific concepts with reasons related to prior knowledge and drawing on aspects of curricular saliency.
Representat			

ions		I will apply a combination of three levels of representations, Symbolic (chemical equation), Macroscopic and Microscopic to enhance students' conceptual understanding. **In the extract above:** The GBT indicates use of macroscopic representation and use of scientific symbolic representation, however without explanatory notes linking to the aspects of the concept being explained.	I will select the 3D representation, to help me represent configuration of atoms. The representation is important in understanding how electronegativity affects shapes of molecules. **The extract above:** The GBT uses scientific symbolic representation with explanatory notes, linking the selected representation to aspect(s) of the concept being explained. The teacher was scored in the developing category of TSPCK proficiency.
Conceptual teaching strategies		I would make them calculate the actual number of moles of each substance first using the masses given. Then I will tell them to calculate the theoretical number of moles using the mole ratios. I will then tell them to compare the theoretical number of moles and the actual amount of moles. The substance that has the theoretical number of moles greater than the actual amount is the limiting reagent, as all the reactant is used up. **In the abstract:** The GBT provides a typical text book definition for linking theoretical yield measured in moles and actual number of moles of the reactants. There is no	To overcome the learning difficulties of understanding the concept of limiting reagent, I will start by highlighting that a limiting reagent is the reagent that is used up in a reaction, thus limiting the product formed. From the equation the reaction requires 1 mole of $TiCl_{4\,(g)}$ for every 2 moles of $Mg_{(l)}$. I will perform a demonstration, to determine; which substance is completely used up and which one is in excess, before carrying out calculations on solving limiting reagent problems. **In the abstract above:** The GBT acknowledges the difficulty learners' face in understanding the concept of limiting reagents. She confronts the misconception, by focusing on the mole ratios of the reactants, an

		evidence of acknowledgement of learner prior knowledge and/or misconceptions. The teacher further fails to provide a corresponding confrontation strategy.	element of learner prior knowledge. She further suggests use of a demonstration, thus ushering in a macroscopic representation to help explain a concept deemed abstract, before carrying out the calculations. The teacher was assigned a score of 3, for suggesting use of two components; learner prior knowledge and representations at both macroscopic and symbolic levels to enforce understanding of the concept of limiting reagents.

Figure 5.11: Teacher Sharon's person scores by component

Summary of findings on confirmation of planned TSPCK

In summary, the findings from the analysis above revealed two major patterns. Firstly, the pattern derived from the average scores per TSPCK component showed a positive improvement of at least one quality category level up across all the then pre-service teachers. Secondly, the pattern emerging from the individual person average scores similarly indicate an overall gain of at least one quality category level up across all the then pre-service teachers from the pre- to the post-TSPCK test scores.

The findings of the analyses of the pre- versus post-TSPCK tests confirmed a positive gain in the quality of planned TSPCK at the end of the final year of training, as a direct result of the TSPCK based intervention. The observed findings are consistent with other findings from earlier studies, (Mavhunga & Rollnick, 2013; Mavhunga 2016; Rollnick. et al., 2017), on improvement in the quality of planned PCK in the topic of the intervention. For this study, as mentioned earlier, the confirmed findings served as a trustworthy baseline from which the comparison with measurements for retention of the acquired quality of TSPCK in actual practice could be measured. This is the purpose of the next chapter.

CHAPTER 6

RETENTION OF THE QUALITY OF PLANNED TSPCK

The development of TSPCK in GBTs as a result of the intervention attended in their final year of study, as pre-service teachers was confirmed in the previous chapter. In this chapter, the measurement for the retention of the GBTs acquired quality of planned TSPCK into their early years of teaching practice is analysed. Two sets of data were collected for analysis. The first set of data were freshly completed TSPCK tools in the same topics of intervention administered two years into the actual teaching practice of the GBTs. The data from the freshly completed TSPCK test tools were then compared to the post-TSPCK tests scores generated at the end of the intervention programme 2 years ago. .

6.1 Introduction

The purpose of this chapter was to determine the extent of retention of the quality of TSPCK registered as a result of a TSPCK-based intervention at the end of the final year of the pre-service programme. The nature of TSPCK explored, was considered to have been planned TSPCK, since it was mainly based on reasoning and planning to teach than actual enactment. Data was freshly collected from the same seven intervention-GBTs sampled in the previous Chapter 5. The data collected at this stage was in the same topics used at the time of the intervention studies, now two years into the GBTs' fulltime teaching. The freshly-completed TSPCK test tools were labelled "in-practice TSPCK tests" in this study. The scores generated from the freshly completed "in-practice TSPCK tests" were then compared with the post-TSPCK test scores generated at the end of the intervention programme shown in Table 5.1 in the previous chapter. This data was also complemented with face to face interviews.

Table 6.1 below presents a comparison of shifts in the quality of the intervention GBTs' post TSPCK test scores, versus the freshly administered "in-practice TSPCK tests" two years into their actual teaching as beginning teachers.

Table 6.1: GBTs' post- versus in-practice TSPCK test scores in the topics of intervention

Participants	Topic of intervention	The Five components of TSPCK					
		LP	**CS**	**WD**	**REP**	**CTS**	**Person Average**
Kgomotso	Stoichiometry	2(2)	3(3)	3(3)	3(3)	2(2)	**3(3)**
Sharon	Stoichiometry	3(3)	3(3)	4(4)	3(4)	3(3)	**3(3)**
Michael	Organic Chemistry	3(3)	2(3)	3(4)	3(2)	1(2)	**3(3)**
Menjo	Chemical equilibrium	3(3)	3(3)	3(3)	3(3)	3(3)	**3(3)**
Jaba	Organic Chemistry	3(3)	3(3)	3(3)	3(3)	3(3)	**3(3)**
Tzepo	Electrochemistry	3(3)	3(3)	3(3)	3(2)	3(2)	**3(3)**
Ntombi	Organic Chemistry	3(2)	3(1)	2(1)	2(1)	2(2)	**2(1)**
Average TSPCK scores		**3(3)**	**3(3)**	**3(3)**	**3(3)**	**2(2)**	
Group person average score							**3(3)**

Note: Values in brackets show the scores captured from the "in-practice TSPCK tests". Pseudonyms have been used to conceal the identities of the beginning teachers who participated in this study.

The first row in Table 6.1 shows the five knowledge components of TSPCK, abbreviated as in Table 5.1 in the previous chapter. The first column indicates the seven intervention GBTs, while the subsequent columns shows their TSPCK test scores per component at the end of the intervention as pre-service teachers, as well as in their early practice as beginning teachers. The last column shows the GBTs' post- (in-practice) TSPCK person average scores across the five content components of TSPCK.

The overall group person average score is displayed at the bottom of the last column on the right. As alluded to earlier, the individual person average scores are not measured from the average mathematical sum of the TSPCK component scores, but

are a proxy of the overall understanding and interactive use of individual TSPCK components with each other (Abell, 2008; Aydin, Demirdogen, Akin, et al., 2015).

Looking at the overall patterns displayed in Table 6.1 above, two major patterns are observed. The first pattern derived from the shifts experienced across the individual person average scores indicates that all the GBTs retained a person average score of three, between the post and in-practice tests in the quality of planned TSPCK, two years into their actual practice. An exemption to the pattern on retention was one intervention GBTs, teacher (Ntombi), who experienced a visible person average drop of one quality category.

The second pattern derived from the shifts across the TSPCK components, similarly shows that all the intervention GBTs retained the same average score of three, which they attained in the post-tests, two years after in the in-practice tests, across all the components. There was only one exception in the teacher Ntombi, who experienced a drop of one quality category drop across all the components except in the component of conceptual teaching strategies; where although she experienced the same average post (in-practice) TSPCK score, the score remained in the lower quality category of 2, which denotes a merely basic quality of TSPCK. The findings in Table 6.1 indicate that the quality of understanding of the individual components of TSPCK and the influence of their interactions amongst each other was retained by the GBTs between the end of the intervention and actual practice.

These are scores reflecting the quality of TSPCK acquired by individuals from the intervention, and subsequently retained in actual practice. As alluded to in the previous chapter, a score of 3 in the TSPCK rubric used in this study refers to the competence to reason through a topic by identifying possible learner misconceptions, and being able to provide corrective responses that show evidence of considering at least one other TSPCK component interactively used in the same teacher task segment. To score in this category further requires the teacher to identify at least three big ideas of the topic and logically link them to the most important subordinate concepts. In addition, the teacher should be able to identify specific gate keeping concepts that when not fully understood, add to the difficulty of a concept. The teacher should equally be able to apply multiple scientific

representations, which includes those that reflect the concept under discussion at macro, micro and/or symbolic levels. Lastly, she/he should be able to suggest conceptual teaching strategies with evidence of taking most of the other four components named above into consideration.

It was further noted that both the TSPCK component and persons patterns seem to be independent of the topic of intervention. The pattern derived from the shifts experienced per TSPCK component and the person average scores between the post vs, in-practice tests were analysed more closely below. I start by providing insights into the qualitative evidence suggesting retention in the quality of TSPCK per component.

6.2 Qualitative insights into the nature of retention across TSPCK components

In order to observe the finer details of the overall pattern revealing the nature of qualitative evidence suggesting retention in the quality of TSPCK, the average TSPCK scores per component across all the GBTs was presented graphically as shown in Figure 6.1 below. The *x*-axis represents the five content components of TSPCK, while the *y*-axis represents the average post (in-practice) intervention-TSPCK test scores per component.

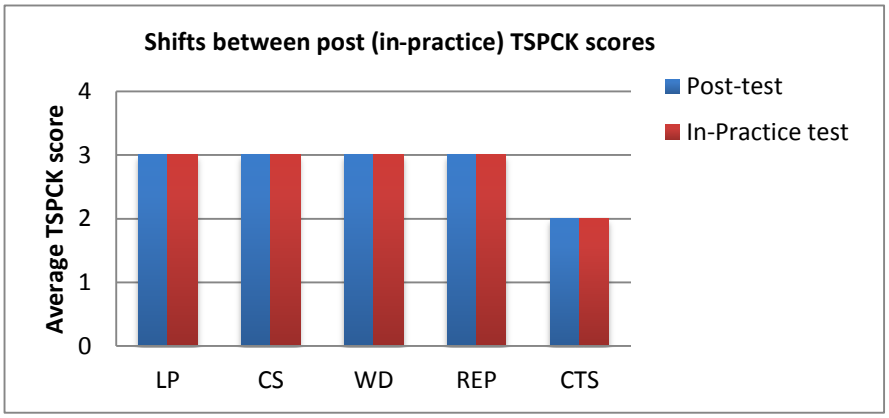


Figure 6.1: Average post- (in-practice) GBT's test scores per component

Note: The blue colour shade represents post TSPCK test scores, while the red colour represents the in-practice test scores per TSPCK component.

The overall pattern emerging from Figure 6.1 indicate that, on average, all the GBTs retained the same quality of TSPCK across all components between the post- and the in-practice TSPCK tests. It is however observed that although all the components showed evidence of retention in the quality of TSPCK, locating most of them in the developing quality category (score 3) of TSPCK, the component of conceptual teaching strategies retained a low-quality score of two, making it the component in which teachers performed most poorly.

In the discussion below, I present examples of extracts revealing the nature of qualitative evidence suggesting retention in the quality of TSPCK per component, indicated in Figure 6.1 above.

(i) Example 1: Retention in Learner Prior Knowledge

Following below is a typical example of an extract of written responses, showing qualitative insights, where the GBTs retained the same quality TSPCK between the post- and in-practice TSPCK tests in the component of learner prior knowledge.

The individual intervention GBTs' TSPCK scores in the component of learner prior knowledge are collectively presented in Figure 6.2 below for comparison. The *x*-axis in the bigger figure shows the intervention GBTs, while the *y*-axis indicates the individual TSPCK scores per GBT in the component of learner prior knowledge.

The *x*-axis on the smaller graphs shows the five TSPCK components, while the *y*-axis represents the individual GBTs' TSPCK scores per TSPCK component

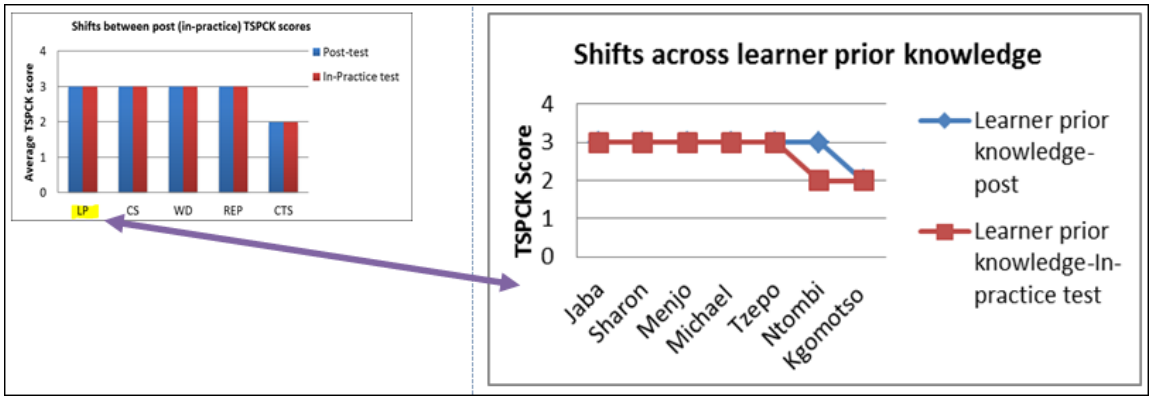


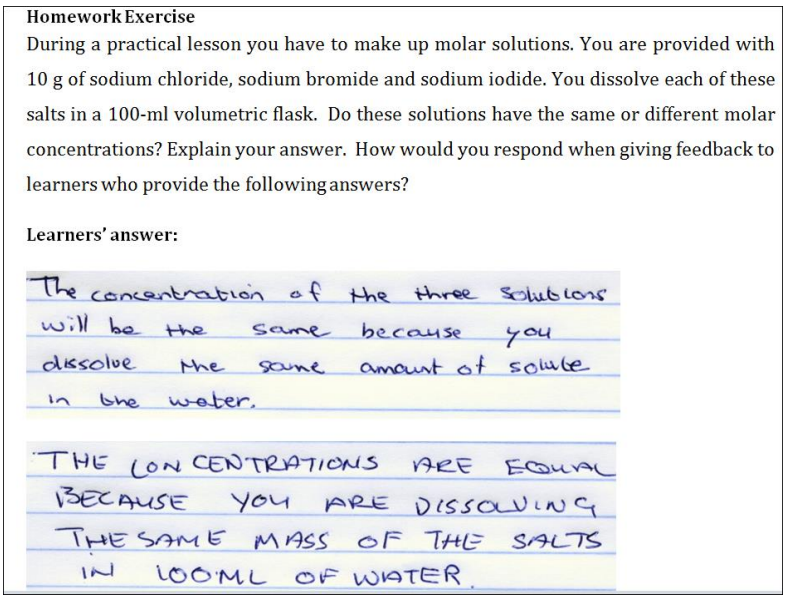
Figure 6.2: Post- (in-practice) TSPCK average scores in learner prior knowledge.

Figure 6.2 shows two diagrams, the smaller one on the left shows the collective average post (in-practice) TSPCK scores per component, calculated to a convincing average as same. The bigger figure on the right shows the individual GBTs post vs. in-practice scores in the component of learner prior knowledge.

The blue points in the bigger figure on the right represent the post TSPCK test scores, while the red points represent the in-practice TSPCK test scores, across the intervention GBTs. The red points are, however, more conspicuous than the blue points, where both the post and in-practice average TSPCK tests were scored in the same quality category of TSPCK.

Looking at the individual GBTs' TSPCK scores in Figure 6.2 above reveals that six intervention GBTs retained the same quality TSPCK score between the post- and the in-practice tests in the component of learner prior knowledge. One GBT teacher (Kgomotso), although he experienced the same post (in-practice) TSPCK score, the score remained in the lower quality category of basic TSPCK. It was however noted that teacher (Ntombi) experienced a visible drop of one quality category level down, dropping from a score of 3, with the developing TSPCK in the post-test to a score of 2, which denotes basic quality of TSPCK in the in-practice test.

Teacher Sharon's written responses were used here as a typical example of the intervention GBTs, who contributed to the retention of quality TSPCK in the component of learner prior knowledge. Under the category of learner prior knowledge, the GBTs were asked how they would respond in writing when giving feedback to learners' who consistently demonstrate difficulties when working on how to prepare molar solutions. An example of learners' incorrect reasoning, to which the GBTs were asked to respond, lifted from the TSPCK test tool is shown below.



Homework Exercise

During a practical lesson you have to make up molar solutions. You are provided with 10 g of sodium chloride, sodium bromide and sodium iodide. You dissolve each of these salts in a 100-ml volumetric flask. Do these solutions have the same or different molar concentrations? Explain your answer. How would you respond when giving feedback to learners who provide the following answers?

Learners' answer:

The concentration of the three solutions will be the same because you dissolve the same amount of solute in the water.

THE CONCENTRATIONS ARE EQUAL BECAUSE YOU ARE DISSOLVING THE SAME MASS OF THE SALTS IN 100ML OF WATER.

Figure 6.3 below shows a comparison of written responses captured from teacher Sharon, where she retained the same score of 3, between the the post-versus in-practice tests. The responses captured from teacher Sharon shows her contribution to the overall qualitative evidence of retention in the quality of TSPCK experienced by the intervention GBTs in the component of learner prior knowledge.

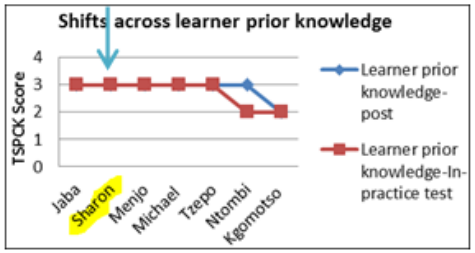
TSPCK Score	Extract from post-test tool	Extract from in-practice test tool
	I will point out that, "the mass of the salts does not mean that the numbers of particles are the same. The ions of the different salts have different relative atomic masses and therefore the molar mass of each salt is different and so the concentration of solutions will be different". I will then refer them to the periodic table to see that sodium chloride has a smaller molar mass than sodium iodide and would therefore have a greater number of ions. Therefore, the amount of salt, measured in moles, will also be different. I will remind the learners that just because the mass of each salt is the same does not mean the amount of salt, measured in moles will be the same. Since concentration is the amount of substance per unit volume, the concentration of the sodium chloride solution will be greater than that of the sodium bromide, which would be greater than that of the sodium iodide. If you add ten grams of the salt to the same volume of solvent, you are not adding the same number of ions for the different salts.	Firstly, I will explain to the learners that equal mass of the salts does not mean the numbers of particles are the same. Since these salts have different molecular weight (molar mass), resulting to different concentration of solutions. From this equation C = m/V x 1/MW (where C is the molar concentration, m is the mass in grams, V is the volume, and MW is the molecular weight or molar mass). I will help them to work out the number of moles and explain to them that sodium chloride has a smaller molar mass compared to sodium iodide and therefore it would have a higher molar concentration. Adding 10 grams of the salt to the same volume of solvent does not mean adding the same number of ions / particles for the different salts.

Figure 6.3: Sharon's post - (in-practice) responses in the component of learner prior knowledge

From the responses provided above, the teacher acknowledges the common learner misconceptions about mass relative to molar concentration, pointing out that *"the mass of the salts does not mean that the number of particles is the same",* in both the post- and the in-practice tests. Similarly, the teacher identifies the specific concepts to be emphasised (different molar masses), which relates to aspects of the component of curricular saliency. This is evident when she states that *"the ions of different salts have different relative atomic masses, which mean the concentration of solutions will be different, and therefore, the amount of salt, measured in moles, will also be different"* in the post-test. In the statement, the teacher makes an effort to link the concepts of concentration, molar mass, and moles more explicitly. The relationship between these concepts is often found difficult to understand by learners. In the post-test, the teacher further suggests referring learners to the periodic table to confirm the molar masses of (NaI and NaCl); while in the in-practice test, she introduces a formula, to help work out the number of moles, which both indicate drawing on an element of the component of representations.

In the last part of the response, the teacher emphasises that adding 10 grams of the salt to the same volume of solvent does not mean adding the same number of ions for the different salts. The explicit emphasis of the meaning of grams not referring to the same number of ions for different salts in both the post- and in-practice tests demonstrates an understanding of a common learner misconception about the topic, which indicates drawing on the component of learner prior knowledge. The patterns observed between the post- (in-practice) tests in the two extracts above indicates qualitative evidence of retention of improved interactive use of the content component of leaner prior knowledge with other components across the intervention GBTs, which indicates retention in the quality of TSPCK from the post to the in-practice tests.

(ii) Example 2: Showing retention in curricular saliency

The second example, where the GBTs retained the same quality of TSPCK from the post- to the in-practice tests, was in the component of curricular saliency.

The individual GBTs' person scores in the TSPCK component of curricular saliency are collectively presented in Figure 6.4 below.

Like Figure 6.2 above, the smaller figure to the left in Figure 6.4 below shows the collective average post - (in-practice) TSPCK scores per component, calculated to a convincing average as same. The bigger figure on the right shows the individual GBTs' post- (in-practice) TSPCK scores in the component of curricular saliency. The *x*-axis in the bigger figure shows the intervention GBTs, while the *y*-axis indicates the individual TSPCK scores per GBT in the component of curricular saliency

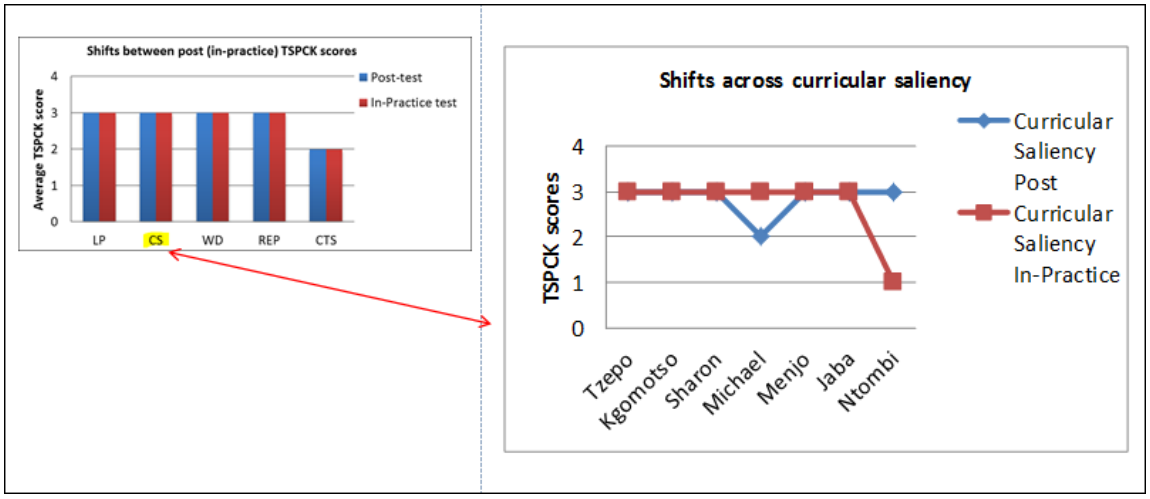
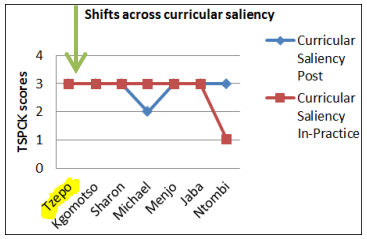


Figure 6.4: Post- (in-practice) TSPCK person scores in component of curricular saliency

The pattern emerging from the TSPCK scores displayed in Figure 6.4 above reveals that five intervention GBTs retained the same quality of TSPCK between the post- and the in-practice TSPCK tests in the component of curricular saliency. One GBT, the teacher Michael, experienced a positive gain of one quality category level in the quality of TSPCK. One GBT, teacher Ntombi, as seen with the component of learner prior knowledge, similarly experienced a visible drop, this time by two quality category levels down from the post- to the in-practice TSPCK test.

Under the category of curricular saliency, the question item asked was structured in two parts. The first part required the GBTs to identify the big ideas (most important understanding to be achieved) in teaching the topic of electrochemistry at Grade 12.

The second part asked the teachers to suggest pre-concepts that must be covered prior to teaching electrochemistry and identify reasons why the teaching of electrochemistry is important for learners. The teacher Tzepo's written responses were used here as a typical example of the intervention GBTs, who retained the same quality of TSPCK between the post- and in-practice TSPCK tests in the component of curricular saliency. Figure 6.5 below shows a comparison of sample extracts of responses lifted from teacher Tzepo post- (in-practice) test tools.

<table>
<tr><th>TSPCK Score</th><th>Extract from post-test tool</th><th>Extract from in-practice-test tool</th></tr>
<tr>
<td>
</td>
<td>
<table>
<tr><th>Suggested concepts and sequence</th><th>Reasons</th></tr>
<tr><td>1.Oxidation and reduction occur simultaneously</td><td rowspan="3">This order allows the conceptual flow of re-dox reactions in the CAPS curriculum</td></tr>
<tr><td>2.Galvanic cells produce electricity</td></tr>
<tr><td>3. Electricity can be used to produce electricity</td></tr>
</table>
List of topics to be taught before teaching electrochemistry

Energy conversion
Oxidation and Reduction
Electron configuration

Importance for learning electrochemistry
Help learners understand;

The working of batteries
How batteries charge and get low,
The link with other concepts such as electric current

</td>
<td>
<table>
<tr><th>Suggested concepts and sequence</th><th>Reasons</th></tr>
<tr><td>Oxidation and reduction occur simultaneously</td><td>Ions form the basics of teaching electrochemistry</td></tr>
<tr><td>Galvanic cells produce electricity</td><td>To understand how energy generation in Galvanic cells</td></tr>
<tr><td>Ions carry charge</td><td>To understand redox reactions and know about movement of ions to different electrodes</td></tr>
</table>
List of topics to be taught before teaching electrochemistry
1. Types of energy
2. Transfer of electrons (Oxidation and reduction)
3. Electronic structure of element
Importance of learning electrochemistry
Help learners;

Understand electroplating, coating of metals /jewellery, painting cars
Have knowledge on how batteries work
Understand fuel cells, recharging cells, cells in calculators, watchers etc.

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

Figure 6.5: Tzepo's post- (in-practice) responses in the component of curricular saliency

An inspection of the responses captured from teacher Tzepo's post-test in Figure 6.5 above indicate that the teacher was able to identify three big ideas for teaching electrochemistry i.e., *oxidation and reduction occur simultaneously, energy from chemical reactions can produce electricity,* and *galvanic cells produce electricity*. This indicates an understanding of the most important meaning to be established in a topic, an element that falls under the TSPCK component of curricular saliency. In the in-practice test, the similarly identified *oxidation and reduction occur simultaneously,* and *galvanic cells produce electricity* and *ions carry charge*, which can all be considered big ideas when teaching electrochemistry. The teacher went ahead to correctly identify topics that must be taught before teaching electrochemistry in both the post-and in-practice tests. He further indicated the importance of teaching electrochemistry to include: understanding the working of batteries (cells); how batteries are charged and discharge and the link between the topic and other concepts in chemistry; such as electric current in the post-test. The teacher repeated the same reasons in the in-practice test, but added application of concepts learnt in the topic in processes like electroplating, coating of metals and jewellery, and painting cars. The reasons provided in both the post-and in-practice tests were seen to refer to conceptual development of understanding of subsequent topics in the subject.

The teacher was assigned an overall score of three, which corresponds to the developing quality category of TSPCK, in both the post and in-practice tests, for correctly identifying at least two big ideas, and the topics that must be covered before teaching electrochemistry. In addition, the reasons provided for importance of the topic, refer to conceptual development of understanding for specific subsequent topics in the subject, and learners' everyday life experiences.

(iii) Example 3: Showing retention in what is difficult to understand

The third example, where the GBTs retained the same quality of TSPCK between the post and in-practice tests was in the component of what is difficult to teach. The question asked under this category required the teachers to select concepts that they consider difficult to teach in the topic of chemical equilibrium. The teachers were further required to provide reasons as to why they consider the chosen topics/concepts difficult to teach for learners' understanding.

The details of the analysis of the intervention GBTs' engagement in the post- versus the in-practice TSPCK tests are briefly described below. The individual GBTs person scores in the component of what is difficult to teach are first presented collectively in Figure 6.6 for comparison. The smaller figure on the left shows the collective average post- (in-practice) TSPCK scores per component, calculated from the individual GBT scores in the component of what is difficult to teach, to a convincing average as same. The bigger figure on the right shows the individual GBTs post- (in-practice) scores for the content component of what is difficult to teach

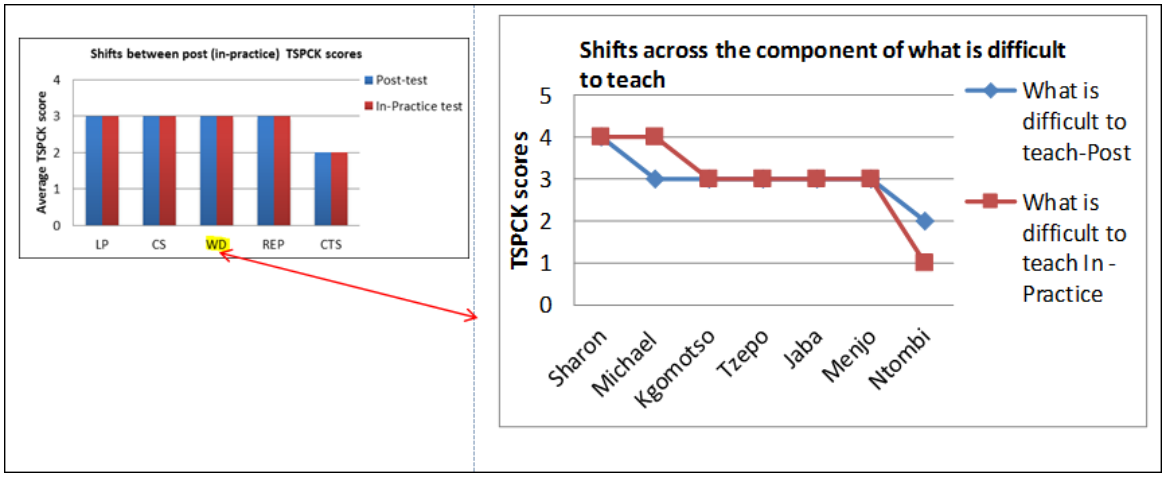


Figure 6.6: Post (in-practice) TSPCK scores in the component of what is difficult to teach

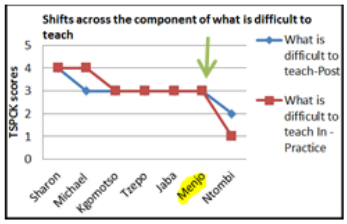
The findings from the scores displayed in Figure 6.6, reveals that five intervention GBTs retained the same quality of TSPCK between the post- and the in-practice tests. It is also observed that one intervention GBT (teacher Ntombi), who was noted

to have dropped in the previous two components of learner prior knowledge and curricular saliency discussed above, also experienced a visible drop of one quality category level drop, between the post and in-practice tests. However, one GBT (the teacher Michael) experienced a positive gain of one quality category, improving from the developing to the exemplary category of TSPCK proficiency. It is worth noting that the same teacher (Michael) also experienced a single positive gain in the quality of TSPCK in the component of curricular saliency in Figure 6.4 above.

Teacher Menjo's written responses were used here as a typical example of the teacher's contribution to the overall qualitative evidence of retention in the quality of TSPCK experienced by the intervention GBTs from the post- to the in-practice TSPCK tests in the component of that which is difficult to teach.

The details of written responses captured from teacher Menjo's post- (in-practice) tests, are presented in Table 6.2 below for comparison.

Table 6.2: Teacher Menjo's post- (in-practice) responses in the component of what is difficult to teach

TSPCK score	Extract from post TSPCK test	Extract from in-practice TSPCK test
	• Dynamic nature of chemical equilibrium • Closed and open systems to physical vs chemical equilibrium	• Physical equilibrium vs chemical equilibrium, because learners fail to understand the concept of backward and reverse reaction occurring at the same rate, • Equilibrium constant

From the findings shown in Table 6.2 above, teacher Menjo identified the dynamic nature of chemical equilibrium and closed and opens systems to physical equilibrium versus chemical equilibrium, as concepts which learners find difficult to understand in the post-test. In the 'in-practice test', the teacher identified physical equilibrium versus chemical equilibrium and equilibrium constant, which can both be considered key gatekeeping concepts that, when not fully understood, add to the difficulty of concepts regarded as difficult. In the in-practice test, the teacher further noted that learners fail to understand the concept of the backward and reverse reaction occurring at the same rate. Teacher Menjo's selection of key gate keeping concepts

regarded as difficult to teach in both the post-in-practice tests is noted, as retention of conceptual understanding of aspects that make a topic difficult for learner understanding. These are concepts that tend to lean more towards higher level cognitive thinking that were developed during the pre-service intervention training programme.

The intervention GBT was assigned an overall score of three, which corresponds to the developing quality category of TSPCK in both the post- and in-practice tests for identifying specific concepts with reasons that make a topic difficult to teach, in both the post- and in-practice TSPCK tests.

(iv) Example 4: Showing retention in Representations

The fourth example, where the GBTs retained the same quality of TSPCK between the post- and in-practice tests, was lifted from the component of representations. The individual intervention GBT's person scores in the component of representations are collectively presented in Figure 6.7 below. The smaller figure to the left, as mentioned earlier, shows the collective average post (in-practice) TSPCK scores per component, calculated to a convincing average from the individual GBT scores in the component of representations. The *x*-axis in the bigger figure similarly shows pseudonyms of the seven intervention GBTs, while the *y*-axis indicates the TSPCK scores per GBT in the component of representations.

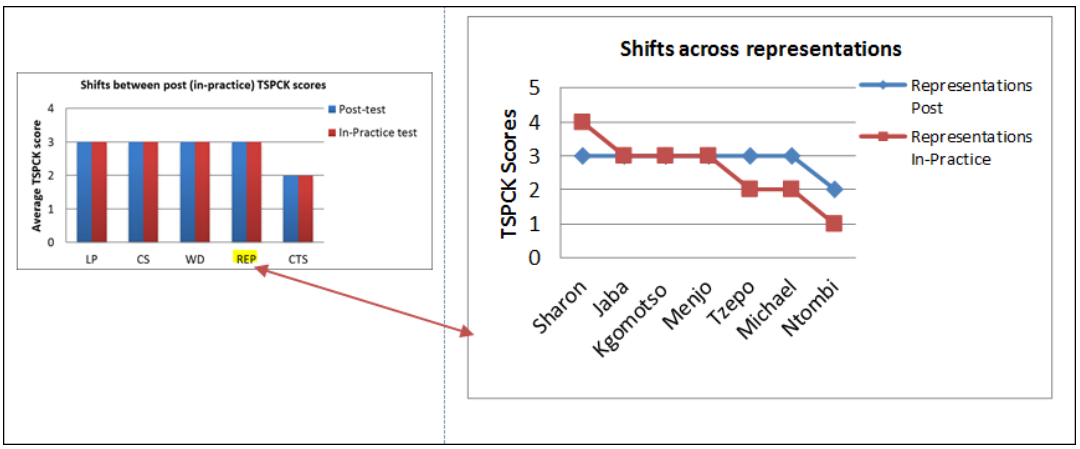


Figure 6.7: Post (in-practice) TSPCK scores in the component of representations

The findings from the TSPCK scores displayed in Figure 6.7 indicate that three intervention GBTs retained the same quality of TSPCK between the post-and the in-practice tests. It is further noted that an equal number of three intervention GBTs experienced a visible drop of one quality category between the post and in-practice tests. Noticeably, among those who dropped in this component is teacher Ntombi, who was also noted to have dropped in the three other components of learner prior knowledge, curricular saliency, and what is difficult to teach, as discussed above. On the contrary, one GBT, the teacher Sharon, experienced a positive gain of a single quality category jump between the post- and in-practice tests.

Teacher Jaba's written responses were used as a typical example of the intervention GBTs' contribution to the overall qualitative evidence of retention in the quality of TSPCK experienced by the GBTs in the component of representations.

The TSPCK test tool in organic chemistry, which was administered to teacher Jaba's class in the post- (in-practice) tests, required the GBTs to identify two representations that the GBTs found most useful in teaching the topic from a list of five options (see Appendix F for the full test tool). They were then required to complete a table describing in detail when they would use each of the chosen representations for teaching. The participants were further asked to select the representation(s) they find most useful and describe how they would use the selected representation(s) to explain the differences in the boiling points of butane (-0.5^0C) and pentane (36^0C).

The details of written responses captured from teacher Jaba's post- (in-practice) tests, where the GBT retained the same quality of TSPCK in the component of representations, presented in Figure 6.8 below for comparison.

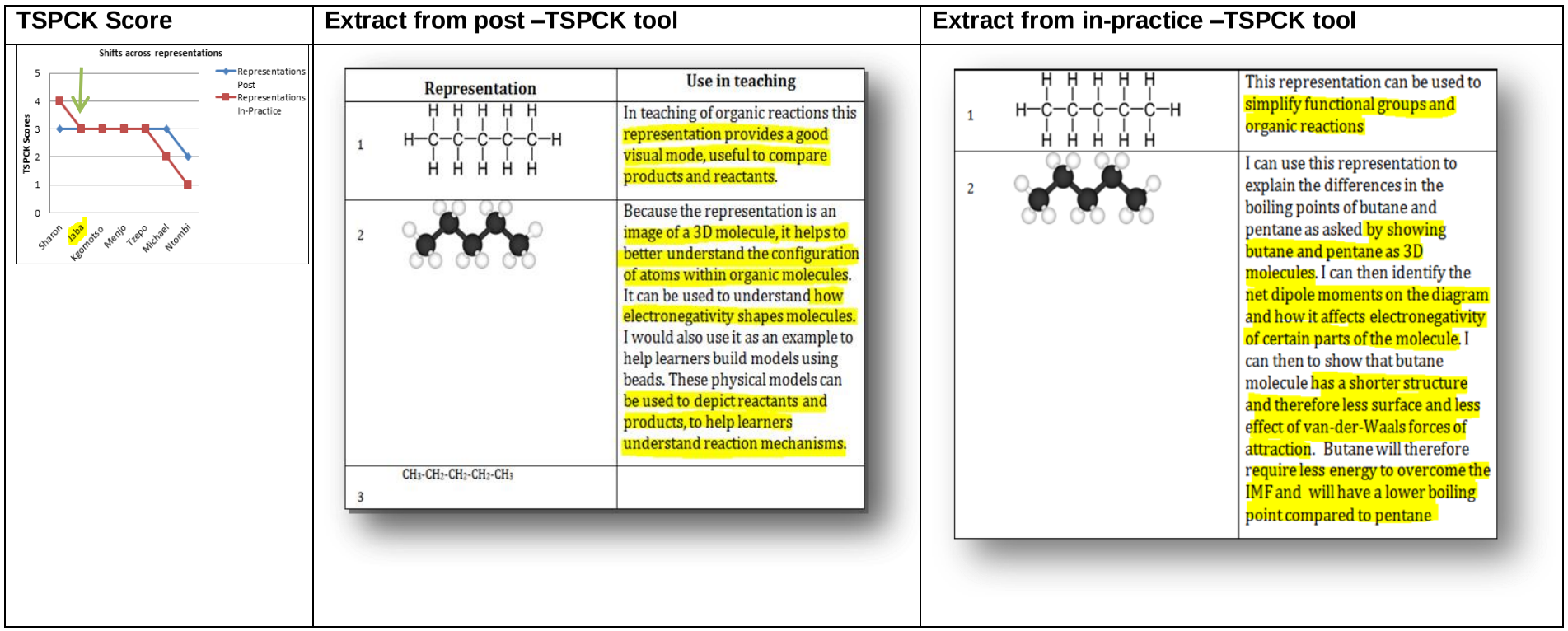


Figure 6.8: Responses from Jaba's post- (in-practice) TSPCK tests in the component of representations

As shown in Figure 6.8 above, the teacher selected the line diagramme structural molecule and a 3D molecule as the most useful representations for teaching organic reactions in the post-test. For the line diagramme structural molecule, the teacher explained that… *"in teaching organic reactions, the representation provides good visual mode, useful for comparing products and reactants to identify what took place.*" This aspect reflected the teacher's ability to point out the exact feature to be observed in a drawing, making clearer an aspect that is not easy to understand, namely how products are formed from reactants during chemical reactions. This was seen as an effort that indicates understanding of what makes concepts difficult for learners' understanding. He then identified the second representation as a molecule in a 3D orientation, which is widely reported to be desirable in helping learners to better understand configuration of atoms in organic molecules, thus drawing on an aspect of curricular saliency.

In the same statement, the teacher referred to electronegativity in the context of explaining the configuration of atoms that yield to the different shapes of molecules. This provides evidence of awareness of the foregrounding concepts, needed prior to teaching the topic of organic chemistry, which also indicate drawing on an element of the component of curricular saliency. So, taking the teacher's written response together, we see evidence of the component of representations used in a way that complements understanding the component of what is difficult to understand and curricular saliency. The teacher was assigned a score of three, which denotes the developing quality of TSPCK in the post-test.

In the in-practice test, the teacher clarifies upfront when to use each representation for teaching various concepts of the topic. For example, he notes that he would use the first line diagram structural molecule representation to simplify organic groups and reactions, while the second representation would be used in showing the nature of molecules in a 3D orientation.

The teacher then succinctly described how he would apply the second representation to explain the boiling points of butane and pentane, pointing out that he would use the selected representation to first depict both pentane and butane molecules in a 3D dimensional orientation. He would then use the representation to

identify the effect of the net dipole moments (intermolecular forces) on the electronegativity of parts of molecules. He further points out that the representation would help him depict butane molecule as having a shorter structure and therefore less surface area, and less effect of Vander-Waals forces of interaction than the pentane molecule. He went on to emphasise the core aspects of content knowledge demonstrated in the representation, by confirming that because butane has less Vander-Waals forces of attraction, it will require less energy to overcome the intermolecular forces (IMF) and therefore will have a lower boiling point.

In the teacher's explanation, we see an explicit link between the selected representations and the pre-concepts that need to be understood prior to teaching the topic, as well as specific aspect (s) of the concept being explained. This shows evidence of the interactive use of the components representations and curricular in the same teacher segment. According to Shulman, choosing suitable representations involves thinking through the main ideas in the lesson and identifying alternative ways of representing them to students (Shulman 1986, p. 16.). Teacher Jaba's scores were rounded up to a single whole number and located in the developing quality category of TSPCK in the in-practice test. The patterns observed between teacher Jaba's post- vs. in-practice tests reveal qualitative evidence of retention in the quality of TSPCK in the content component of representations.

(v) Example 5: Showing evidence in conceptual teaching strategy

The last example, where the GBTs retained the same quality of TSPCK between the post and in-practice tests was lifted from the component of conceptual teaching strategies. The two figures shown in Figure 6.9 below are graphical representations of individual intervention of GBTs' TSPCK person scores in the component of conceptual teaching strategies (the one on the right), and the collective average TSPCK scores for the component, shown on the left, presented together for comparison.

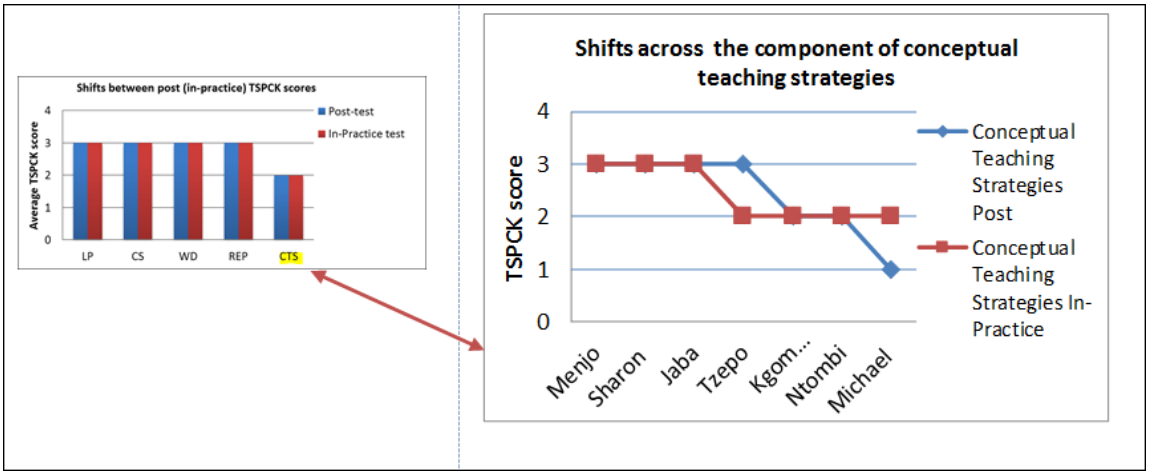


Figure 6.9: Post- (in-practice) TSPCK scores in the component of conceptual teaching strategies

The findings of the analysis of post (in-practice) TSPCK scores in Figure 6.9 above reveals that five intervention GBTs retained the same quality of TSPCK between the post and the in-practice TSPCK tests in the component of conceptual teaching strategies. It was however noted that one GBT, the teacher Tzepo, experienced a visible drop of one quality category level down, from the post- to the in-practice test. On the contrary, another GBT, the teacher Michael, experienced a positive gain of one quality category, moving from the limited to the basic category of TSPCK proficiency.

It was further noted that although five intervention GBTs retained the same quality of TSPCK between the post and in-practice tests, three of the GBTs retained the same quality of TSPCK in the higher quality category level of developing TSPCK. The other two intervention GBTs retained the same quality of TSPCK between the post and in-practice tests, but remained in the lower category of basic TSPCK proficiency.

During this analysis, the component of conceptual teaching strategy was seen to be the most difficult TSPCK component for the GBTs to engage with, registering an average score of two, in both the post and in-practice tests. It was thus of interest to this study, to consider two sample extracts; with the first representing the lower

categories of quality, and the second representing the higher categories of quality TSPCK for the component of conceptual teaching strategies.

Two examples of written responses captured from teachers Michael and Jaba's post (in-practice) tests were used as typical examples, showing the overall qualitative evidence of retention in the quality of TSPCK experienced by the intervention GBTs, representing the lower and higher quality categories of quality, respectively. In the discussion below, I start with a comparison of a sample of a weak extract from the teacher Michael.

a) Retention in conceptual teaching strategies – weak score

The same TSPCK tool in the topic of Organic Chemistry, which was administered to teacher Michael's class in 2014, as the topic of intervention was repeated two years later during the teacher's actual classroom teaching as a beginning teacher in 2016.

The question posed in this category was in two parts. The first part required the GBTs to explain how they would teach a lesson about the different ways of representing organic molecules to a class. In the second part, the teachers were asked to explain how they would conduct a revision lesson to assist learners who persistently show misconceptions in representing the number of bonds around a carbon atom, to correct their held errors and move towards correct answers (the full test tool is provided in Appendix F). Figure 6.10 below shows a comparison of teacher Michael's written responses between the post- versus in-practice TSPCK tests-representing the lower quality end proportion of the cohort.

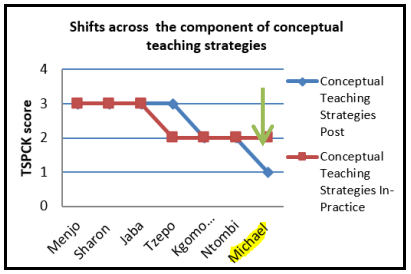
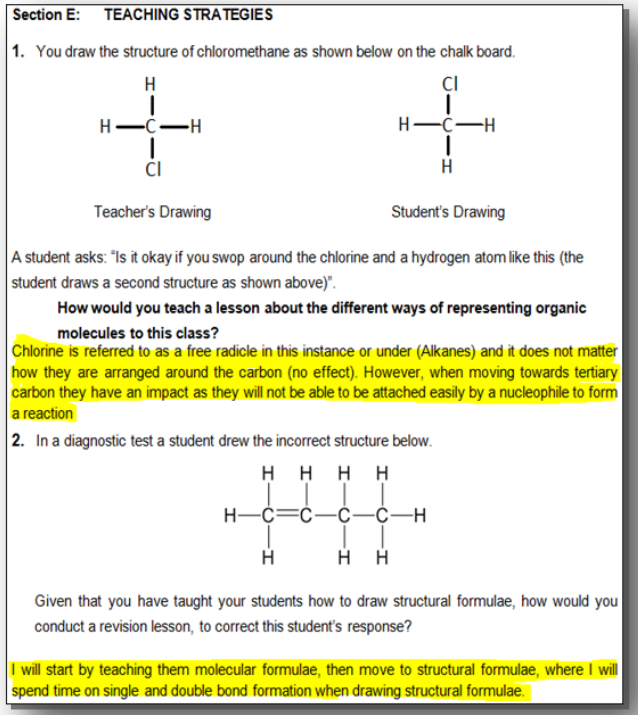
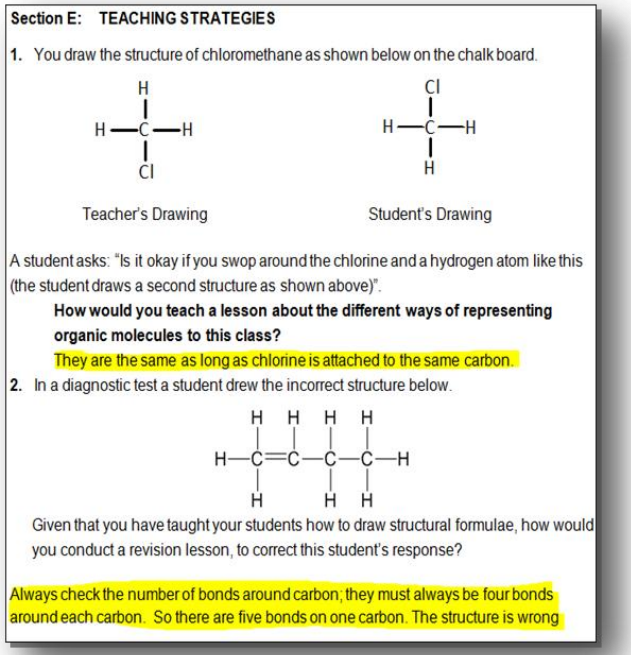
TSPCK score	Extract from post-TSPCK tool test tool	Extract from in-practice test tool
		

Figure 6.10: Teacher Michael's post- (in-practice) responses in the component of conceptual teaching strategies

Looking at Michael's written responses lifted from the post-test in Figure 6.10 above, we see the teacher failing to read through the learner's question, providing an irrelevant response. For instance, the teacher refers to chlorine as a free radical, when in fact it bonds to the methyl group as an ion. He goes on to discuss the nucleophile attack, an issue not under discussion, thus missing the learner's question, which had pertained to whether it is okay to swop the chlorine and hydrogen atoms around the carbon atom in a methane molecule. The teacher was subsequently assigned a score of one for failing to identify the problem and not responding to the learner's question.

In the second part of the question item, the then pre-service teacher simply states that he would start by teaching a molecular formula, and then move to structural formulae, without providing linking explanatory notes about how he would sequentially present the lesson. The teacher was likewise assigned a score of one for suggesting a weak conceptual teaching strategy without linking explanatory notes, or showing evidence of drawing interactively on the other TSPCK components.

The scores from the two parts of the question were subsequently rounded up and the GBT was assigned an aggregate score of one in the post-test, with all the enlisted raters in agreement. A score of one matches the limited quality of TSPCK proficiency in the scoring rubric, where a response with no evidence of acknowledgement of student prior knowledge or misconceptions is assigned the lowest score of one.

In response to the first part of the question item in the 'in-practice test' shown on the right-hand side in Figure 6.10, teacher Michael's response, like the one provided in the post-test, indicated that the position of the substituent atom around a molecule of methane does not matter, as long as it is attached to the carbon atom. This response represents correct SMK when teaching primary halogenoalkanes, because the compound in question has a single carbon atom. However, the teacher failed to emphasise the most important aspect, namely that it would be for instance different in case of hydrocarbons with multiple bonds between the carbon atoms. For the second part of the question, the teacher similarly indicates that the carbon bonds

must always be 4, and not 5, without providing linking explanatory notes to explain why the carbon atom must have four bonds instead of five. The teacher therefore failed to either provide a suitable confrontational strategy or relevant explanations related to the other components of TSPCK in response to the second part of the question. He was subsequently assigned an overall score of two in the in-practice-test. This score matches the criteria of the basic category of TSPCK, acknowledging the student misconception with no corresponding confrontational strategy or linking explanatory notes.

As mentioned above, the extracts compared in Figure 6.10 above were used as evidence of retention in the quality of TSPCK for the lower categories of quality in the component of conceptual teaching strategies.

It was of interest to this study to consider one example of the intervention GBTs who retained the same quality of TSPCK in the higher categories of quality in the same component. Teacher Jaba's written responses were thus used as a typical example of the intervention GBTs, who contributed to qualitative evidence of retention in the same quality of TSPCK in the higher categories of quality shown in Figure 6.9 above. The extracts lifted from teacher Jaba's post (in-practice) tests, are presented in Figure 6.11 below.

b) Retention in conceptual teaching strategies – high score

The question item asked under this category, as mentioned above, required the GBTs to show how they would apply the TSPCK component of conceptual teaching strategy to teach the different ways of representing organic molecules in a classroom context. They were further required to explain how they would conduct a revision lesson, to assist learners who persistently show misconceptions in representing the number of bonds around a carbon atom, move towards correct answers.

Teacher Jaba's written responses in the post- (in-practice) tests are presented in Figure 6.11 below for comparison.

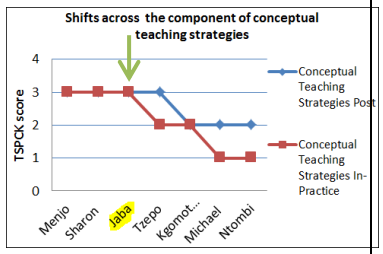
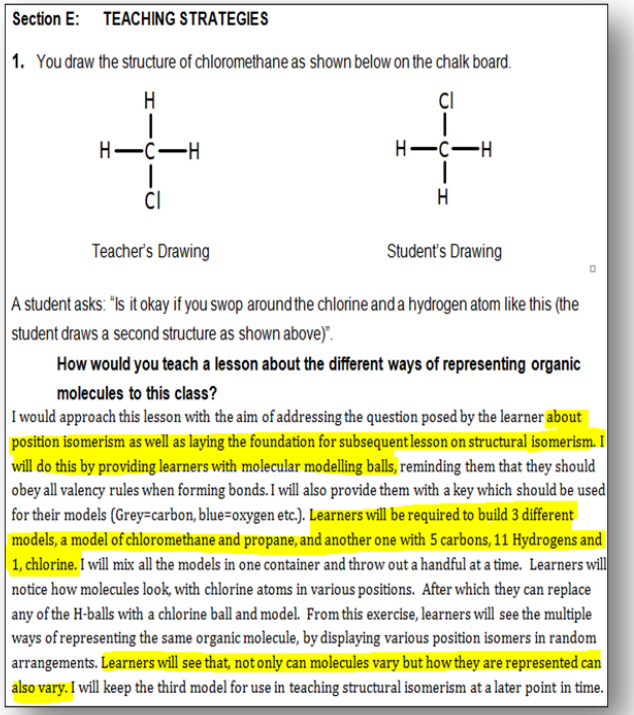
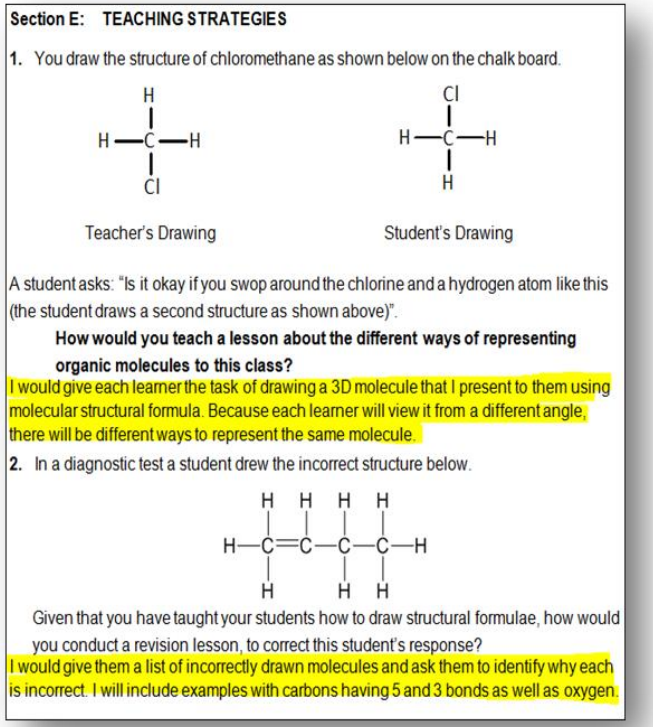
TSPCK score	Extract from post-TSPCK tool	Extract from in-practice –TSPCK tool
		

Figure 6.11: The teacher Jaba's post- (in-practice) responses in the component of conceptual teaching strategies

The responses shown in Figure 6.11 above reveal that the teacher Jaba was able to display evidence of drawing on different TSPCK components to teach about the different ways of representing organic molecules. For instance, in the post-test, the teacher points out in the opening statement that: *"I would approach this lesson with the aim of addressing the question posed by the learner about position isomerism, as well as laying the foundation for the subsequent lesson on structural isomerism."* In the response, we see evidence of understanding of the main concept to be addressed i.e., position isomerism, as well as what the teacher anticipates to teach in the subsequent lesson, on structural isomerism. The teacher's intention is confirmed towards the end of the extract, where he explicitly specifies that *"I will keep the third model for use in teaching structural isomerism at a later point in time."* According to Shulman (1986, p. 10) familiarity with the topics and issues that have been and will be taught in the same subject area during the preceding and subsequent school years, and the materials that embody them reflects knowledge of vertical curriculum. This aspect appears well-articulated by teacher Jaba, which is an indication of drawing on the component of curricular saliency. The teacher went on to outline the technique he would employ in presenting the lesson, by stating that he would provide learners with molecular modelling balls, where they will be required to build three different models, by displaying various groups of atoms in different positions around the basic carbon skeleton to display random arrangements of position isomers. He further notes that by displaying various positional isomers, *"learners will see that not only can molecules vary, but how they are represented can also vary."* The explicit emphasis on the interactive use of models to teach different ways of representing organic molecules in the extract indicates presence of the component of representation at macroscopic level.

In the explanation, we see teacher Jaba confirm an accurate understanding about different ways of representing organic molecules by drawing interactively on the components of curricular saliency and representations. However, the component of representations was found to bring multiple levels of component sophistication to the discussion. The teacher's response was categorised in the developing quality category in the TSPCK scoring rubric, with all raters in agreement. As alluded to in Chapter 3, the component of conceptual teaching strategy constitutes pulling all the

thoughts from the other four components and providing a description on how a lesson would unfold sequentially.

This may include the use of either macroscopic or symbolic representation with sub-microscopic representation to enforce understanding, drawing on at least two other components of TSPCK in the process, as was the case in the above extract.

In response to the same test item in the 'in-practice test' two years later as a beginning teacher, we see teacher Jaba equally draw on the component of representations at different levels of component sophistication to explain how to represent different organic molecules. For instance, in the opening statement shown on the right-hand side of Figure 6.11, the teacher indicates that *"I will give each learner the task of drawing a* (3D) *molecule that I present to them using molecular structural formula. Because each learner will view it from a different angle, there will be different ways to represent the same molecule."* For the second part of the question, which required the GBTs to explain how they would conduct a revision lesson to assist learners who persistently show misconceptions in representing the number of bonds around a carbon atom, the teacher noted, *"I will give them a list of incorrectly drawn molecules and ask them to identify why each is incorrect."* The interactive use of the (3D) illustrations, formulae as well as examples, to explain different ways of representing organic molecules and how to correctly represent bonds around a carbon atom, indicates the presence of the component of representations used at different levels of component sophistication.

The analysis from the extracts above show that despite the differences in the nature and sequence in which the component interactions occurred, the GBT was able to reason through the topic using representations linked to aspects of the component of curricular saliency in both the post and in-practice tests. This analysis confirms that the GBT was able to retain and apply the interactive use of the component of conceptual teaching strategies in actual practice, two years after the intervention programme.

Teacher Jaba was assigned an overall score of (3), which corresponds to the developing quality category of TSPCK proficiency in the in-practice test. This was for interactively drawing on the component of representations at different levels, as well

as aspects of the component of curricular saliency to explain how organic molecules are represented in space. The repeated use of the component of representations at different levels of component sophistication in both the post and the 'in-practice tests' was noted as critical in explaining chemistry concepts.

In summary, the in-depth qualitative analysis method used to provide insights into the fine grain that builds up to the average scores across the components revealed finer details of performance. In particular, it was noted that for each component, there are three subcategories of performance. The first is the majority of GBTs who retain the same score. The second is a small proportion, often one in seven, who improved while in practice; and lastly one or two who drop in the quality of their teaching. It is interesting to note that Michael improves and Ntombi drops in quality. So, while on a big scale the average scores point to retention, more valuable insights were established from the fine grain analysis, particularly those who dropped in quality. Thus, the next section takes a closer look at the qualitative evidence of a student who represent the majority who retained the quality of TSPCK across all the components of TSPCK. This is in line with the understanding that the quality of TSPCK is derived from all five components. I then look at one student who dropped in quality, and thus failed to retain the acquired TSPCK. In analysing both examples I collaborate their responses with their views from interviews.

In the following analysis, I look at the qualitative evidence of shifts and retention in the quality of TSPCK across individual GBTs.

6.3 Qualitative insights into the nature of retention of GBTs person average scores

The pattern derived from the shifts experienced across the individual person average scores in Table 6.1 above indicate retention of the quality of planned TSPCK, acquired at the end of the two year classroom intervention. This implies that when considering the shifts made across each of the five components of TSPCK for each participant, an overall retention in the quality of TSPCK in noted.

To observe the finer qualitative details of the GBTs' overall shifts experienced between the post- (in-practice) tests, the individual person average scores described in Table 6.1 were graphically represented as shown in Figure 6.12 below. The *x*-axis on the graph represents the intervention GBTs, while the *y*-axis represents the post-(in-practice) TSPCK person average scores.

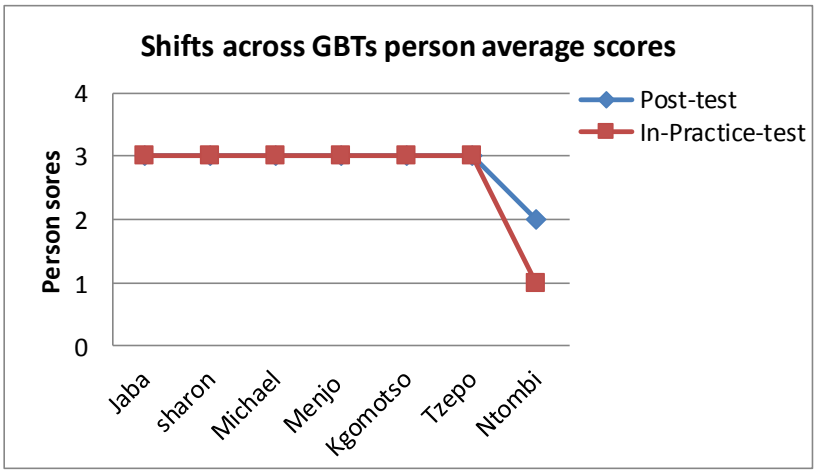


Figure 6.12: Post (in-practice) TSPCK person average scores

Each point on the graph in Figure 6.12 represents a quality of TSPCK, which is determined from the considerations of responses from all the five components of TSPCK.

The overall pattern emerging from the post- (in-practice) person average scores displayed in Figure 6.12 above indicates that the intervention GBTs retained the same quality of TSPCK between the post- vs. in-practice tests. However, a closer inspection of the analysis of individual GBTs person average scores reveals that although six intervention GBTs retained the same quality of TSPCK acquired at the end of the intervention programme, two years later into their actual teaching as beginning teachers, one intervention GBT, the teacher Ntombi, experienced a visible drop of a single quality category between the post- and in-practice TSPCK tests. Teacher Jaba was used as a typical example of intervention GBT who contributed to the overall retention in the quality of TSPCK across all five components of TSPCK, while teacher Ntombi represented a typical case of poor retention of TSPCK.

6.3.1 The typical profile of GBT who retained the quality of TSPCK across all five components

As mentioned in Chapter 5, when looking for evidence of shifts or retention in the quality of TSPCK for each participant, it is important to look for such shifts across all the five components of TSPCK in alignment with the theoretical framework used in this study. In Figure 6.13 below, I present a summary of the teacher Jaba's post- vs. in-practice TSPCK scores per component.

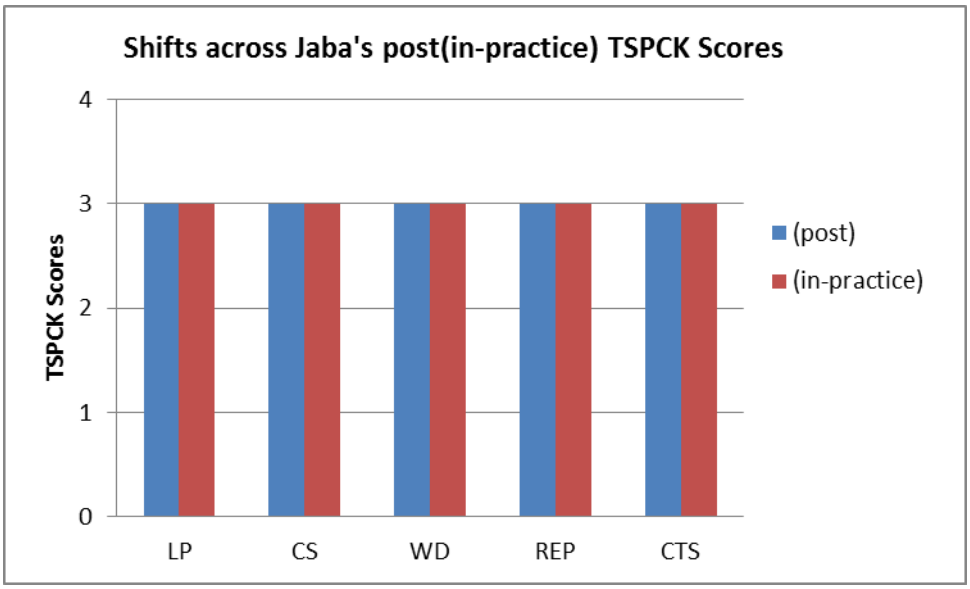
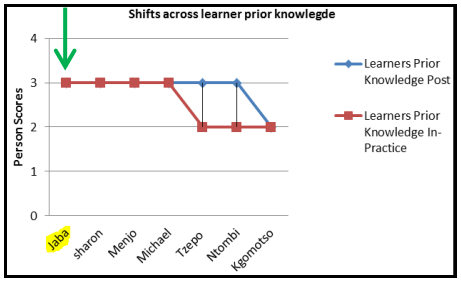
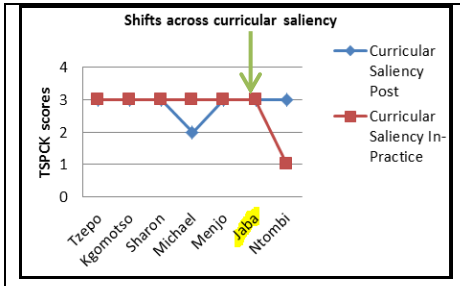


Figure 6.13: The teacher Jaba's post vs in-practice TSPCK scores per component

The finding displayed in Figure 6.13 above indicates that teacher Jaba retained the same quality of planned TSPCK across all the TSPCK components, between the post and in-practice tests. The observed retention of quality was located in the developing category of TSPCK proficiency.

To observe for the qualitative evidence showing retention of quality, a summary of the analysis of teacher Jaba's post vs. in-practice qualitative responses to the test items in each of the TSPCK components is presented in Figure 6.14 below. This example demonstrates analysis of depth that leads to the determination of a person's average score in the post vs in-practice TSPCK tests. The extracts were lifted from the topic of Organic Chemistry.

TSPCK Component and Score	Extract from TSPCK post-test	Extract from the in-practice TSPCK test
Learner prior knowledge  	While it is true that an –OH group bonded to an organic molecule denotes an alcohol, all functional elements need to be taken into account. I would use multiple line diagrams of other molecules to show the –OH symbol representations in other functional groups, to confirm accurate understanding. Learners perceive numbering on the longest straight chain. I will remind them to always number the longest possible chain that provides the lowest position number for branches or functional groups even if it's not straight. In this extracts, the teacher identifies the learner misconception, where the –OH group should be bonded to a carbon atom. He then confirms accurate understanding to enforce understanding, drawing on two other TSPCK components of curricular saliency and representations, when the focus of the discussion was on the component of learner prior knowledge.	To help learners distinguish between alcohols from other compounds, I will point out to the learners that an–OH group is not the only requirement for a compound to be an alcohol. For it to be an alcohol, it needs to be the only functional group on the carbon atom. I will go through each example and point out why it is/ isn't an organic molecule. I will remind them that the longest chain does not need to be a straight chain. If they still don't recognize it as pentane, I would tell them explicitly that there are 5 carbon atoms in the longest chain and challenge them to identify it. In the extract, the teacher identifies and the learner misconception, stating that the –OH group is not the only requirement for a compound to be an alcohol, before moving on to confirm accurate understanding drawing on three other TSPCK components of curricular saliency and representations and aspects of what is difficult to teach, when the focus of the discussion was on the component of learner prior knowledge to enforce learner understanding.
Currricular saliency		



The big ideas for teaching the topic are; naming organic compounds according to the IUPAC system, Different ways of representing organic substances and Functional groups, which tell us about different types of compounds. The pre-concepts that must be covered before teaching the topic are the atom, the periodic table, chemical bonding and electrochemistry. The topic is important because it helps learners identify different functional groups. The knowledge taught helps in naming organic compounds using IUPAC system

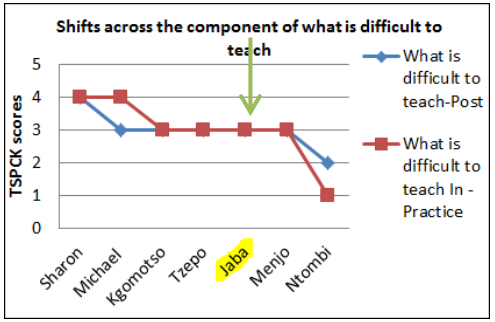
In the extract, the teacher identifies specific concepts with reasons related to conceptual development and understanding of the topic. The identified pre-concepts include those needed for the current topic like the periodic table and chemical bonding. The reasons provided for importance of the topic include reference to conceptual scaffolding of understanding of other concepts in the subject, like identifying different functional groups.

The big ideas for teaching this topic include; naming organic compounds according to the IUPAC system, Different ways of representing organic substances and Functional groups, which tell us about different types of compounds. The pre-concepts that must be covered before teaching the topic are the atom, the periodic table, chemical bonding and electrochemistry. The topic is for the importance in understanding the synthesis of plastics, how glue works and application of the topic to other concepts in the subject such as bond energy, electronegativity and valency.

In the extract, the teacher provides logical sequence of the two big ideas, (naming organic compounds according to IUPAC system, and different ways of representing organic compounds) and the subordinate concepts.

The reasons provided for importance of the topic, such as electronegativity and valency, are related to concepts of the current topic and link to learners' everyday experiences, like synthesis of plastics.

What is difficult to teach



What contributes to the difficulty in naming organic compounds is numbering of the molecules. Isomers are difficult to teach, because learners struggle to comprehend compounds with the same formulae having different names.

In this extract:

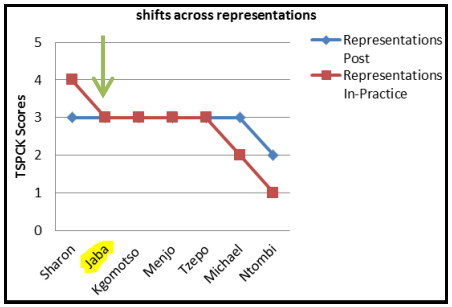
The teacher considers a mix of aspects that make concepts difficult to teach, like isomers, with algorithmic options like numbering of organic compounds.

The concepts that are difficult to teach in this topic include; structural formulae, where learners tend to ignore double bonds. Isomers, where learners assume that when a structure looks different, it must be a different molecule, as they cannot identify symmetry. Processes like substitution, addition and elimination as well as concepts like combustion and esterification reactions, appear difficult because they are abstract as learners cannot see the physical processes.

In the abstract,

The teacher identifies specific gate-keeping concepts that when not fully understood add to the difficulty of a concept as a mix of simple organic reactions like combustion reactions, which can be considered simply as broad and abstract concepts. As alluded to in Chapter 3, discussions on the component of what is difficult to understand moves beyond the abstractness of concepts, by pin-pointing the actual difficulty in teaching a topic. During the face-to-face interview, the teacher explained that his learners are very weak in mathematics and tend to struggle with mathematical computations for science. This is what, according to the teacher, leads him to focus on calculations at the expense of teaching for conceptual understanding.

Representations



In teaching organic reactions, the line diagram representation provides a good visual mode, useful to compare products and reactants. The 3D representation helps learners to better understand the configuration of atoms within organic molecules. It also helps learners to understand how electronegativity shapes molecules.

In this extract:

The then pre-service teacher identifies the importance of electronegativity as a pre-concept in understanding shapes of molecules. We also see evidence of use of scientific symbolic representation linked aspects of the concept being explained.

I can use the 3D representation to show that the butane molecule has a shorter structure and therefore less surface area and less Vander Waals forces of interaction compared to pentane. Because it has less Vander Waals forces of interaction, it will require less energy to overcome the IMF and therefore have lower boiling point.

In this extract:

The selected representation links key concepts needed prior to teaching the topic, with core aspects of content knowledge. For example, linking the energy required to overcome the intermolecular forces in determining differences in the boiling points between butane and pentane. The representation links the components of learner prior knowledge and aspects of curricular saliency.

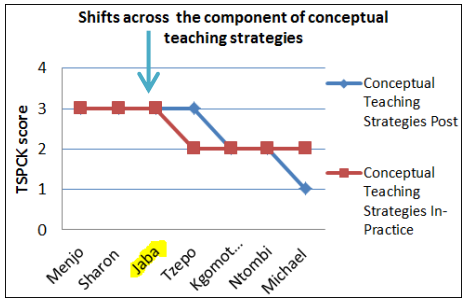
Concptuual teaching strategies		
	I will approach this lesson with the aim of addressing the question posed by the learner about position isomers as well as laying the foundation for the subsequent lesson on structural isomerism. I will then provide leaners with molecular modelling balls, where they will be required to build 3 different models, by displaying various groups of atoms in different positions around the basic carbon skeleton to display random arrangements of positional isomers. I will keep the third model for use in teaching structural isomerism at a later point in time. **In this extract:** The teacher confirms an accurate understanding, drawing on the components of curricular saliency and representations at different levels to explain how organic molecules are represented in space.	I will give each learner the task of drawing a 3D molecule that I present to them using molecular structural formula. Because each learner will view it from a different angle, there will be different ways to represent the same molecule. For correcting misconceptions about drawing correct structural formulae, I will give them a list of incorrectly drawn molecules and ask them to identify why each is incorrect. **In this extract:** The teacher draws on the component of representations at different levels of component sophistication, as well as aspects of curricular saliency, to explain how organic molecules are represented in space. In the post interview session, the teacher explained that he carries out few class demonstrations whenever necessary to help explain concepts that appear abstract.

Figure 6.14: Summary of teacher Jaba's post- (in-practice) responses across the five TSPCK components

6.3.2: Looking into a typical case of poor retention of TSPCK

The overall pattern emerging from the findings of the analysis of post- (in-practice) TSPCK scores in Table 6.1 above indicates that teacher Ntombi, consistently experienced a drop in the quality of TSPCK by at least one quality category level down across all the five TSPCK components discussed above from the post to the in-practice tests. It was of interest to this study to consider the teacher's written responses as a typical example of the intervention GBTs who contributed to the overall poor retention of planned TSPCK. Figure 6.15 below shows a graphical representation of the teacher Ntombi's post- vs. in-practice TSPCK test scores per TSPCK component.

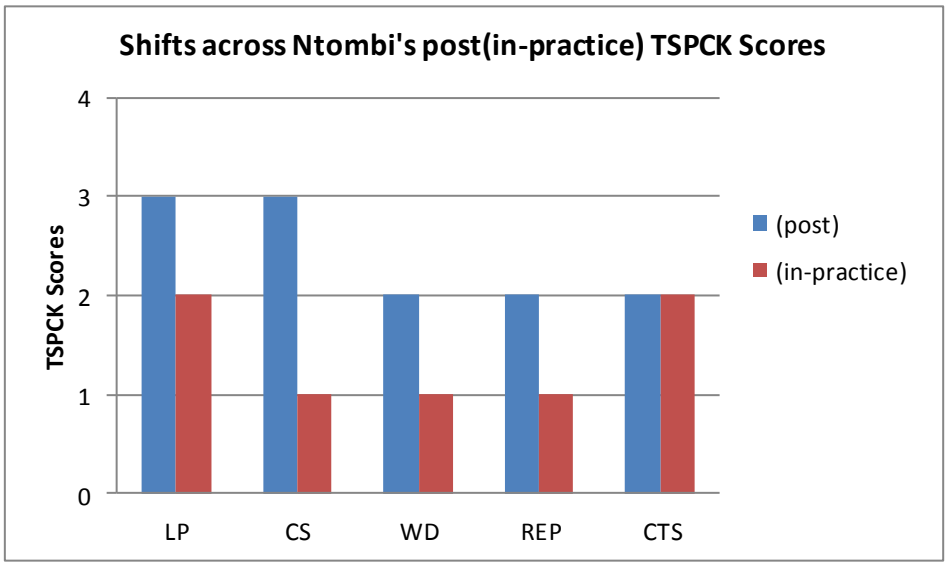
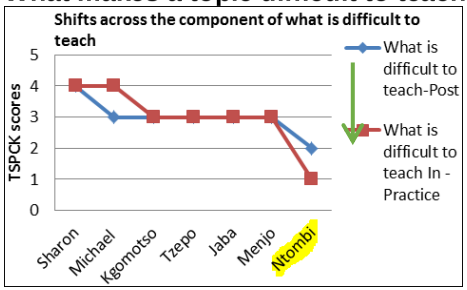
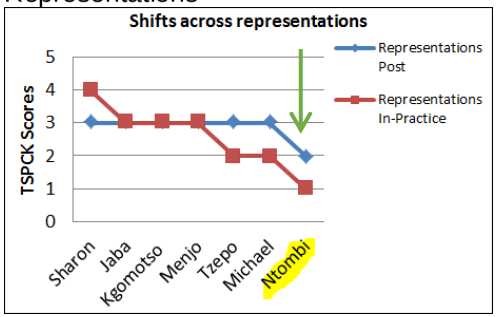


Figure 6.15: The teacher Ntombi's post- vs. in-practice TSPCK scores per component

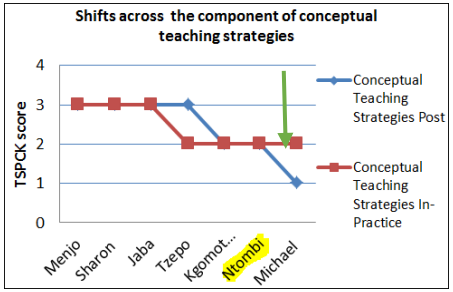
The overall pattern emerging from the finding displayed in Figure 6.15 above reveals that teacher Ntombi experienced a drop of at least one quality category level across all the TSPCK components from the post- to the in-practice tests. The most noticeable drop was in the component of curricular saliency, where the teacher experienced a visible drop of two quality category levels. It was, however, noted that the teacher was able to retain the same quality of TSPCK in the component of conceptual teaching strategies. However, the score remained in the lower quality category of basic TSPCK.

To observe for the finer details of qualitative evidence suggesting poor retention in the quality TSPCK, a summary of the analysis of teacher Ntombi's post vs. in-practice qualitative responses in the test items across three TSPCK components is presented in Figure 6.16 below. This example demonstrates analysis of depth that leads to the determination of poor person average score in the post-versus in-practice TSPCK tests. Teacher Ntombi's extracts were lifted from the topic of Organic Chemistry.

TSPCK component	Extract from TSPCK post test	Extract from TSPCK in-practice test
What makes a topic difficult to teach 	The concepts that are difficult to teach in organic chemistry include; IUPAC names, where leaners sometimes are inconsistent in grasping the names. Homologous series, where learners sometimes start counting the carbon atoms from the wrong side and at times place commas and dashes in the wrong positions. The other concepts found difficult to teach are the types of reactions like. substitution, addition and elimination, and this is because there is a lot of content to be covered **In the extract:** The teacher identifies a mix of specific gate keeping concepts that may be problematic, with broad generic concepts, without pin-pointing the actual sub-concepts that are problematic. Aspects like learners not grasping the names or counting from the wrong side are too general. The reasons provided for difficulty of the concepts are similarly broad and generic. For example, too much content to be covered is not reason for difficulty of understanding.	The concepts I find difficult to teach are functional groups. This is because there are a wide variety of them that look similar. Therefore because of the inherent difficulty in identifying the functional groups, it is also the reason why naming them becomes difficult. **In the extract:** The teacher identifies broad concepts without specifying the actual sub-concepts that are problematic. For example, having a wide variety of functional groups. The reasons provided like difficulty in identifying the functional groups are broad and generic. In the interview session held, the teacher explained that her learners are very weak in English and Mathematics. She further explained that the reason for her shift towards algorithmic reasoning is attributed to the demands of schools, where emphasis is often placed on preparing learners for their final examinations at the expense of teaching for conceptual understanding. The other reason according to teacher was the pressure of being a beginning teacher in a new school environment.

<table>
<tr>
<td>Representations

</td>
<td>I can apply the line diagram representation for naming organic compounds, as well as writing and molecular formula. I can then apply the 3D representation for identifying the longest chain, saturated hydrocarbons and intermolecular forces

In the extract: The selected representations suggest use of scientific symbolic representation without explanatory notes to make links to the aspects of the concept being explained.</td>
<td>I can use the line diagram representation when moving from formula to structure. The 3D representation is good when using the radmaste tool kit to teach.

In the extract: The selected representations are limited to the generic benefit of teaching the topic, with no reasons given for their importance. For example, the representation being good when using radmaste.
In the interview session, the teacher noted that she doesn't carry out practicals to explain abstract concepts due to a lack of resources. She only depends on the class textbook to teach.</td>
</tr>
<tr>
<td>Conceptual teaching strategies

</td>
<td>Learners should understand that there is only one isomer of methyl chloride, so it doesn't matter which side of the carbon bond the chlorine is attached.

In the extract: the teacher acknowledges student misconceptions with no suitable corresponding confrontation strategy to make learners understand substitution reactions of hydrocarbons.</td>
<td>It doesn't matter which side of the carbon, the chlorine atom is attached, in representing chlorine as a substituent group to methane. Learners need to know that where functional groups are attached must be mentioned in naming hydrocarbons.

In the extract: the teacher acknowledges student misconceptions verbally with no corresponding confrontation strategy. In the interview session, the teacher observed that topics like organic Chemistry ushers in new scientific terminologies, which learners have never come across. This makes it difficult to teach.</td>
</tr>
</table>

Figure 6.16: Teacher Ntombi's post (in-practice) responses across the five TSPCK components

Summary

In summary, the qualitative evidence showing retention of the quality of TSPCK observed in the topics of intervention from the post- to the in-practice TSPCK tests appear to suggest that the intervention GBTs were able to retain the acquired quality of planned TSPCK, developed at the time of the pre-service teacher intervention training programmes in their actual classroom practice. However, there were individual variations noted among the intervention GBTs, which could be attributed to other extraneous factors, like the different school contexts and individual teacher efficacy, among others.

In the chapter that follows I analyse the findings with respect to the advantage derived from an early exposure to explicit PCK development in specific topics attended by the intervention GBTs.

CHAPTER SEVEN

ANALYSIS OF ADDED ADVANTAGE ON PLANNED TSPCK

In the preceding chapter, I showed findings suggesting retention of the quality of TSPCK by intervention-GBTs two years into their teaching practice. In this chapter, I seek to analyse for any added advantage with respect to planned TSPCK in the teaching practice derived from the GBTs early exposure to TSPCK in specific topics at the time of the pre-service training programme. The participants in this analysis are three intervention GBTs who formed a subset from the total of seven. They were compared against a control set of three non-intervention GBTs, who did not experience the TSPCK based intervention programme in any form. Two sets of data were collected for analysis. The first sets of data were TSPCK tests from the same TSPCK tools in the respective topics of intervention freshly completed by both GBT sets. The second set of data were comprised of completed TSPCK test tools, in new topics, which were different from those used during the intervention studies, administered to both GBTs sets. It was also found beneficial to administer a copy of one test tool from the new topics to a single expert teacher, who was included to this sample as a reference on the likely quality of teacher expertise at the time. The scores generated between the intervention GBTs vs. the control GBTs in both topics of intervention and the new topics are then compared to determine for any added advantage in the reasoning and planning to teach a topic. I conclude this chapter by summarising the results of the findings.

7.1 Is the early exposure to TSPCK a friend or a foe to the quality of Planned TSPCK when in practice?

The main purpose of this chapter was to explore a response to the research question on whether there is any added advantage in the quality of planned TSPCK derived from the GBTs' early exposure to explicit TSPCK development in specific topics that could be seen in their early years of practice. It is the first component of the question, as it seeks to determine the possible existence of any added advantage in

the reasoning and planning element of the GBTs' teaching practice. The main reason to start the exploration with the planning aspect follows from Shulman (1987), who posited that the planning and particularly pedagogical transformation seen in the planning of the lessons before being actualised is as important as the delivery of the lesson itself. The second component to this question on classroom practice is explored in the next chapter.

In order to determine for a response to this question, a control group of three non-intervention GBTs was introduced. These were practicing teachers also in their 2nd year of practice from their year of graduation at a sister university in the same city. As first detailed in Chapter 3, they were considered comparable to the intervention GBTs, as firstly, they both majored in Physical Science taught in secondary school curriculum from institutions located in the same geographical space. Secondly, the 4th year Physical Science Methodology class, from which the participants were sampled in both universities, are taught by teacher educators and qualified PhD degree holders in science education (Chemistry), with many years of teaching experience. In addition, both institutes offer similar general pedagogy and discipline specific methodology courses in their professional teaching components, with a few minor differences in terms of the aims and objectives, as stipulated in their respective learning outcomes. For example, in both institutions, the undergraduate teacher preparation programme is structured in such a way that the content and the methodology components are delivered separately, but as parallel courses in the same Department. The topics for the content and the methodology components are taught simultaneously, using the concurrent (CC) Initial Teacher Education (ITE) model. Furthermore, the pre-service students at both universities are mostly black and largely from previously disadvantaged communities, historically associated with poor quality of school education, in particular science education (Zhang et al., 2015). Therefore, while the two-pre-service teacher programmes are not the same item-to-item, I argue that they are equivalent in the sense that they share the same location space; draw their students from the same catchment areas; offer their programmes in English as the medium of instruction; offer the same teacher qualification degree; share similarities in the targeted objectives, but different in the actual coverage and implementation of PCK. The major difference between them is thus the TSPCK

intervention programme, offered at my university. Moreover, the control GBTs graduated in the same year matching the intervention-GBTs. The sample of the control GBTs were therefore considered similar in major aspects, and it was reasonable to regard graduates from the sister university as a comparable control group for this study. The control GBTs are thus referred to in this study as comparable GBTs. The criteria for choosing the participants in the control group beyond equivalence, was practicing within the Johannesburg region and ethical willingness to participate in the study. Seven qualifying participants were approached, where initially four were agreeable, but one left in the middle of data collection, leaving a total of three non-interventions GBT with full data sets.

An equal number of three intervention GBTs were then selected from the original sample of seven intervention GBTs on the same basis, together with the comparable group to form a sub-set of a total of six participants considered a sample in this investigation (see Table 7.1). The use of an equivalent control group, as mentioned in Chapter 3, was to help screen off the noise and other intervening factors, such as the possible effect of knowledge gained from classroom experience over the years, among others. As argued in the literature, PCK develops over time, based on teachers' experiences of teaching a topic repeatedly (e.g. Henze & van Driel, 2015).

The move was to increase the chance to investigate within reason, where only the advantage derived from a direct result of the intervention programme received.

As alluded to in Chapter 3, data in the form of planned TSPCK tools that determined the quality of pedagogical transformation in reasoning and planning for teaching a topic was collected in two different contexts. The first was termed the 'familiar context'. In this context, the TSPCK tools were in the topics of intervention and administered to both groups; and the intervention GBTs would be expected to be familiar with the topic while the comparable GBTs would not, as they have not done any intervention on TSPCK and particularly in the topics of intervention. The second context was termed 'unfamiliar'. The TSPCK tools were in a new topic also administered to both groups and engagement with the specific topic with respect to pedagogical transformation was new to both groups. The new topics in this study, as alluded to in Chapter 3, refer to different topics from those used during the

intervention studies. As further mentioned in Chapter 3, the TSPCK test tools used in this study were designed to match the five content components of TSPCK set out by Mavhunga and Rollnick, (2013) for the quality assessment of planned TSPCK. The question items asked in the test tools were typical multiple choice objective questions, where the option to develop the best-answer rather than the correct-answer was adopted (Rohaan et al., 2009). The test items in all the categories were constructed in a similar format, except the category of conceptual teaching strategies, which comprised an open-ended question item format in all the topics, used during the intervention studies.

Prior to administering the test tools, the comparable GBTs were inducted on how to respond to the TSPCK test tools. I specifically emphasised the importance for the teachers responding in full to the best of their ability in all the spaces that required explanations supporting their selected options from the multiple-choice items. The GBTs were then given a time frame of one week, to respond to the test tools at their comfort.

The completed TSPCK test tools were analysed and scored using the same criterion based on the TSPCK rubric proposed by Mavhunga & Rollnick (2013) for scoring the quality of planned TSPCK and used in Chapter 6 to determine for retention of acquired TSPCK. The data analysed at this point were thus comprised of a combination of freshly completed TSPCK test tools that measured the quality of planned TSPCK in topic contexts considered familiar and unfamiliar for the intervention GBT set, and in both contexts unfamiliar for the control set. For the intervention GBTs, the data for the familiar context is the same as that collected and termed “in practice”, listed in the previous chapter that explored retention of the acquired TSPCK.

The TSPCK test tools were complemented with face-to-face interviews that were used to confirm the findings, and seek for reasons in the written comments provided by the GBTs in the completed TSPCK test tools.

The study also found it necessary to include one experienced Physical Science teacher, to the sample of the unfamiliar context. The reason for incorporating the experienced/expert teacher in the sample was to have a glimpse of additional

insights on the likely improvement in TSPCK of a typical example of expert practice at the time.

Table 7.1 below shows a summary of the structure for the data analysed to determine for any added advantage, derived from an early exposure to explicit PCK development in specific topics.

Table 7.1: Structure of the sample used for analysis of added advantage

TSPCK Tools administered	Intervention GBTs	Comparable-GBTs	Expert teacher
TSPCK tools in topics of intervention	3x beginning teachers	3x beginning teachers)	-
TSPCK tool in new topics	(the same 3x beginning teachers)	(the same 3x beginning teachers)	1x expert teacher

I looked for the advantage in the quality of planned TSPCK evident in the responses written in the completed test tools, starting with a postulation that the intervention GBTs had an added advantage over their comparable GBTs in the topics of intervention, having been exposed to explicit PCK development in the same topics earlier on during the pre-service intervention programme. I however expected no explicit advantage in the scores of the two groups in the new topics, as both groups were being treated to the new topics for the first time. This meant that any advantage observed from either group would reflect implicit personal development in the new topic.

In the following sections, I analyse the performance of three intervention GBTs versus an equivalent comparable sample of three GBTs who did not experience the TSPCK-based intervention programme in both topics of intervention and the new topics. The three marching GBT cohorts were randomly paired, based on the topic in which the particular GBTs were treated. In the first section (7.2), I start with the analysis of the quality of planned TSPCK in the topics of intervention. This is followed by the analysis of the quality of planned TSPCK in the new topics in the next section (7.3).

Section A: Familiar Context

7.2 Familiar Context: TSPCK in the topic of intervention between intervention vs. control GBTs

The same TSPCK test tools used in the parallel topics of intervention attended by the three intervention GBTs in Table 7.1 above collected as "in-practice tests" were similarly administered to the comparable group of the three GBTs and analysed.

Table 7.2 below shows the findings from the analysis of the TSPCK test tools responses within and across pairs of intervention-GBTs versus comparable-GBTs. The GBT cohort pairs are grouped according to the topic of intervention in which they were treated.

Table 7.2: Performance of intervention GBTs versus comparable GBTs in the topics of intervention on Planned TSPCK

Intervention (control GBT)	LP	CS	WD	REP	CTS	Person Average
Menjo(Dido)	3(2)	3(2)	3(2)	3(2)	3(1)	**3(2)**
Jaba(Mpho)	3(1)	3(2)	3(1)	3(1)	3(1)	**3(1)**
Tzepo(Thembu)	3(1)	3(2)	3(1)	2(1)	3(1)	**3(1)**
Group average score						**3(1)**

Note: The TSPCK test scores for the comparable-GBTs are shown in brackets. Pseudonyms have been used to conceal the identity of the GBTs involved.

The overall pattern emerging from the findings in Table 7.2 above indicates that the intervention-GBTs displayed an advantage over their comparable GBTs in the quality of planned TSPCK across all the TSPCK components in the topics of intervention. For instance, the calculated group average score of the intervention-GBTs was two quality category levels higher, when compared to the group average score of the comparable-GBTs. It is important to recall that the average score is a proxy score

reflective of the overall influences of the component interactions seen across the individual components of TSPCK.

To observe the finer features of the overall pattern emerging between the intervention GBTs vs. the comparable GBTs, the TSPCK scores in Table 7.2 above were graphically re-presented as shown in Figure 7.1 below. Figure 7.1 shows four graphs, the smaller three of which on the left indicate the TSPCK scores from each intervention GBT vs. the comparable GBT pair across the five TSPCK components in the topic of intervention of the partner GBT. The bigger graph on the right shows the collective proxy average person scores between the intervention GBTs versus the comparable GBTs. The *x*-axis on the bigger graph represents the intervention vs their comparable GBT cohort pairs, while the *y*-axis represents the person average TSPCK scores in the topics of intervention. The *x*-axis on the smaller graphs represents the five TSPCK components, while the *y*-axis represents the individual GBTs' TSPCK scores per TSPCK component.

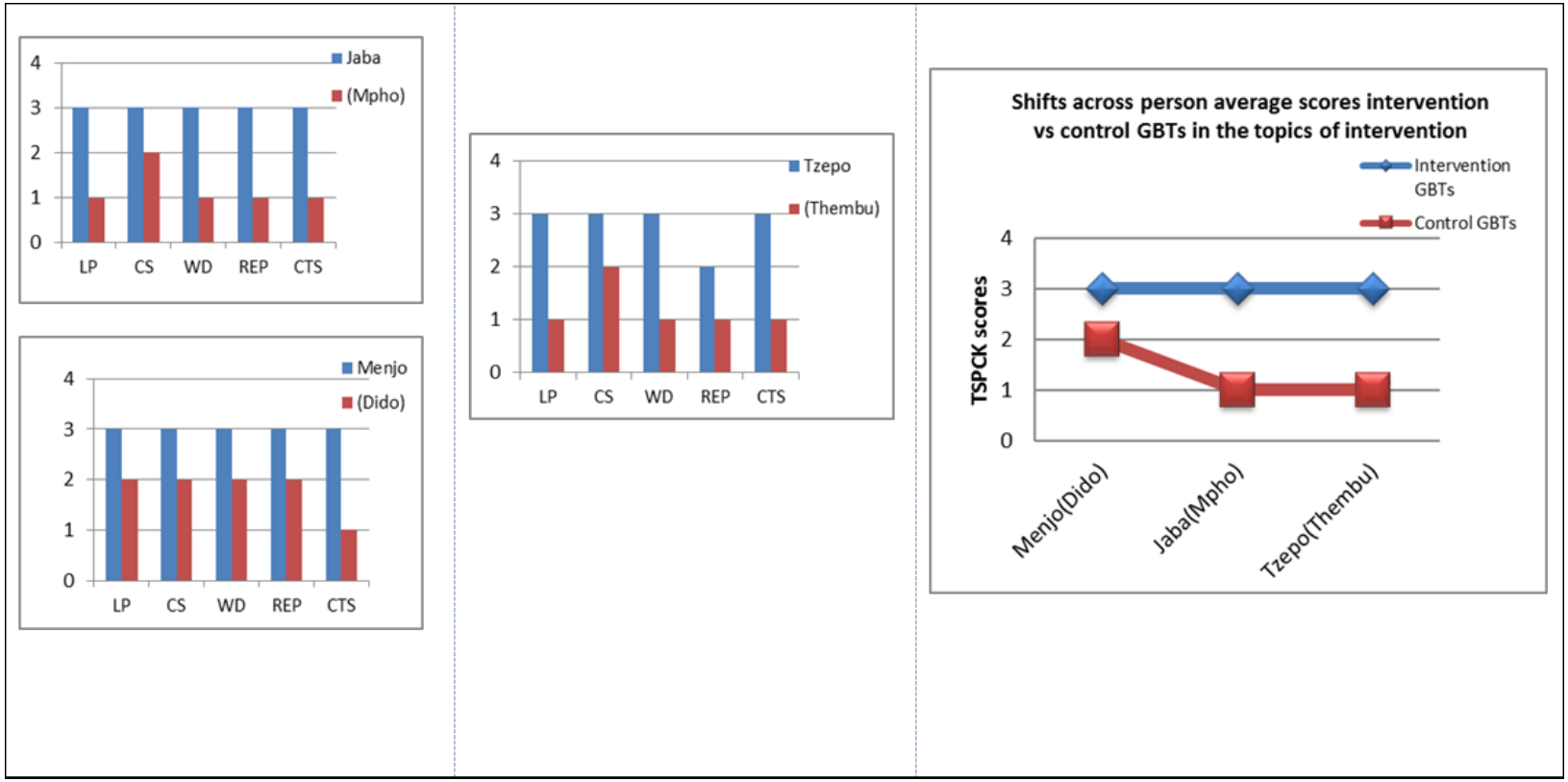


Figure 7.1: Comparison of Intervention versus Comparable GBTs' person average scores in the topics of intervention

Note: The comparable GBTs are shown in brackets

The overall pattern emerging from the bigger graph in Figure 7.1 above is that the intervention GBTs had an advantage of two quality category levels up in the quality of planned TSPCK in the respective topics of intervention over their comparable GBTs on average. In two of the three GBT pairs, viz. the teachers Jaba and Mpho, and Tzepo and Themba, an advantage of two quality categories was observed. One GBT cohort pair, teachers (Tzepo and Themba) demonstrated an advantage of one quality category level difference in the quality of TSPCK, in favour of the intervention GBT.

To determine the finer details of the TSPCK scores between the GBT cohort pairs, the scores generated per TSPCK component are graphically presented in the smaller diagrammes on the left of Figure 7.1 for comparison.

The pattern emerging from the TSPCK scores in the smaller graphs similarly reveals that the intervention GBTs demonstrated an advantage in the quality of planned TSPCK over their comparable GBT counterparts across all the TSPCK components.

This is evident from the high proportion of multiple scores that denote higher quality TSPCK, displayed by the intervention GBTs compared to their comparable GBTs. For instance, the pattern derived when looking at the average scores generated per TSPCK component indicate that both teachers (Menjo and Jaba) were assigned a score of three, which denotes the developing quality of TSPCK across all the components. Similarly, teacher Tzepo was categorised in the developing quality of TSPCK in four out of the five TSPCK components. On the contrary, all the comparable GBTs were assigned scores of one and two, which fall in the lower quality category levels of limited and basic TSPCK proficiency, respectively. It was however observed that none of the GBTs was scored in the exemplary quality category of TSPCK.

According to the initial postulatation of this study, the overall performance in the quality of TSPCK demonstrated by the intervention GBTs over their comparable GBT counterparts was expected. However, the extent of the advantage observed was not predicted. As mentioned earlier, the expectation was based on the understanding

that the intervention-GBTs had the added advantage of having been exposed explicitly to the same TSPCK test tools earlier, during their respective intervention studies. While the limitation of having a small sample is acknowledged, the pattern observed with the current sample indicate an added advantage by intervention GBTs over their comparable GBT counterparts. The extent of this advantage seemed to vary as we see two cases with two category level difference and one with a single category difference. Factors contributing to the difference were, however, not explored in this study. One major factor singled out by the qualitative design of this study is the explicit exposure to the development of TSPCK in a specific topic.

In the discussion below, I present examples of sample qualitative extracts showing insight into the nature of responses reflecting added advantage in the quality of TSPCK between the intervention GBTs vs. their comparable GBTs per component as indicated in Figure 7.1 above.

(i) Example 1: Extracts showing a two-quality category difference between the intervention vs. comparable GBTs in the topic of intervention

The first example explored the quality of planned TSPCK lifted from written responses between teacher Jaba (intervention GBT) and teacher Mpho (comparable GBT), where the intervention GBT had an added advantage of two-quality category level difference over the comparable GBT in the component of learner prior knowledge.

The same tool on topic-specific PCK in Organic Chemistry administered to the GBTs as the topic of intervention was freshly administered to teachers Jaba and Mpho in 2016. The question items asked under this category were presented in two parts. The first part required the GBTs to explain how they would help learners distinguish organic alcohols from other compounds. The second part asked how the GBTs would help learners to correctly name hydrocarbons according to the IUPAC rules (see Appendix F for the full tool). Figure 7.2 below, presents extracts lifted from the 1st part of the question. This is followed by extracts lifted from the second part of the question in Figure 7.3 thereafter.

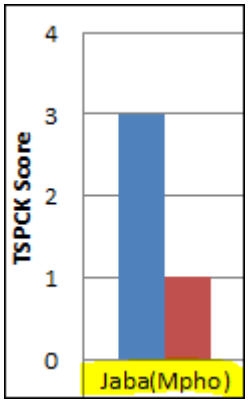
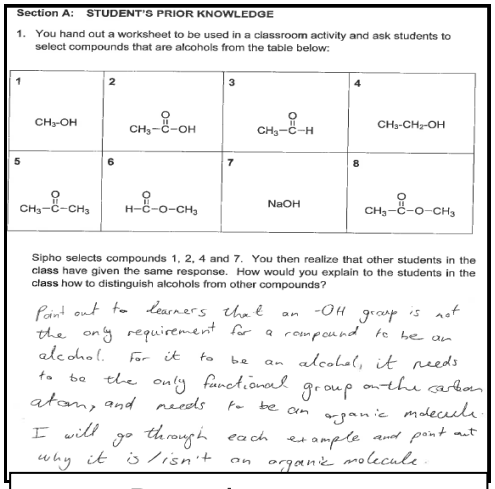
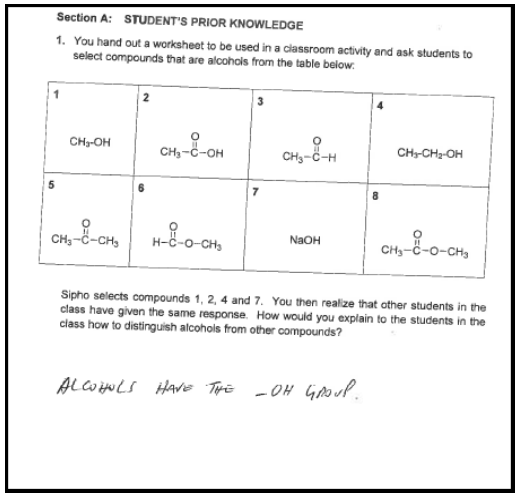
TSPCK score	Extract from intervention GBT	Extract from comparable GBT	Extract from stimulated recall interview
	 Section A: STUDENT'S PRIOR KNOWLEDGE 1. You hand out a worksheet to be used in a classroom activity and ask students to select compounds that are alcohols from the table below: 1 CH_3OH 2 $CH_3-\overset{O}{\overset{\|}{C}}-OH$ 3 $CH_3-\overset{O}{\overset{\|}{C}}-H$ 4 CH_3-CH_2-OH 5 $CH_3-\overset{O}{\overset{\|}{C}}-CH_3$ 6 $H-\overset{O}{\overset{\|}{C}}-O-CH_3$ 7 NaOH 8 $CH_3-\overset{O}{\overset{\|}{C}}-O-CH_3$ Sipho selects compounds 1, 2, 4 and 7. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds? Point out to learners that an -OH group is not the only requirement for a compound to be an alcohol. For it to be an alcohol, it needs to be the only functional group on the carbon atom, and needs to be an organic molecule. I will go through each example and point out why it is/isn't an organic molecule. **Re-typed comments:** Point out to the learners that an –OH is not the only requirement for a compound to be an alcohol. For it to be an alcohol, it needs to be the only functional group on the carbon atom and needs to be an organic molecule. I will go through each example and point out why it is/isn't an organic molecule.	 Section A: STUDENT'S PRIOR KNOWLEDGE 1. You hand out a worksheet to be used in a classroom activity and ask students to select compounds that are alcohols from the table below: 1 CH_3OH 2 $CH_3-\overset{O}{\overset{\|}{C}}-OH$ 3 $CH_3-\overset{O}{\overset{\|}{C}}-H$ 4 CH_3-CH_2-OH 5 $CH_3-\overset{O}{\overset{\|}{C}}-CH_3$ 6 $H-\overset{O}{\overset{\|}{C}}-O-CH_3$ 7 NaOH 8 $CH_3-\overset{O}{\overset{\|}{C}}-O-CH_3$ Sipho selects compounds 1, 2, 4 and 7. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds? ALCOHOLS HAVE THE –OH GROUP. **Re-typed comments:** Alcohols have the –OH group.	**Researcher:** You provided a response to this question that says "*Alcohols have the – OH Group.*" Is this what you would tell the learner in question? **Mpho**: Yes. **Researcher:** Can you give me some reasons for your response provided? **Mpho:** The learners course book, which guides us in teaching, states that the-OH is the functional group that differentiates alcohols from other compounds. **Researcher:** Given a chance to re-formulate your response is there any additional information you would like to explain or provide to the learner? **Mpho:** I would strees that the-OH group must always be attached to a carbon atom.

Figure 7.2: Excerpts showing two quality category level differences for Jaba and Mpho

In the opening statement, teacher Jaba states upfront that *"I will point out to learners that an-OH group is not the only requirement for a compound to be an alcohol."* This indicates teacher's awareness of a common learner misconception when naming organic compounds. In the same statement, the teacher helps to distinguish organic alcohols from other compounds, by stating that *"for it to be an alcohol, it needs to be the only functional group, on the carbon atom, and needs to be an organic molecule".* The understanding of when to refer to organic alcohols or not, based on the attachment of the (-OH) functional group, specifically to a carbon atom and not any other atom shows understanding of the key pre-concepts that need to be understood prior to teaching functional groups in Organic Chemistry. According to Geddis and Wood (1997), the understanding of concepts that are most important in a topic, and identification of key pre-concepts that need to be understood prior to teaching a particular concept, is an element of curricular saliency. In the teacher's response, we also see evidence of drawing on the component of representations, when he emphasises that… *"I will go through each example and point out why each is/isn't an organic molecule"* in the last sentence in the extract. Examples in this case referred to the use of line structural drawings given as options in the test item, that form part of the knowledge of a range of subject matter representations (Geddis & Wood 1997, p. 612).

According to Klafki (1958), the ability to engage with content through illustrations and examples lies in the return to the "original situation" (p. 26), an aspect well demonstrated by teacher Jaba. In the episode, we see the teacher confront a common learner misconception and confirm accurate understanding drawing interactively on the TSPCK components of curricular saliency and representations, when the focus of the discussion was on addressing the component of learner prior knowledge. The teacher was subsequently assigned a score of three, which matches into the developing quality category in the TSPCK scoring rubric.

Teacher Mpho, the comparable GBTs' written response to the same test item is shown on the right-hand side of Figure 7.2. In his response, we see the teacher acknowledge that *"alcohols have an–OH group."* However, the teacher does not provide linking explanatory notes to support his suggestion. He similarly fails to

identify the specific learner misconception, which learners may hold in distinguishing organic alcohols from other compounds. This is evident from the reasons provided during the stimulated recall interview, where the teacher repeats standard textbook definition without reference to any component of TSPCK, even after being prompted by the researcher, as shown on the far-right hand side in Figure 7.2 above. The teacher Mpho was assigned a score of 1, which matches into the limited quality category of TSPCK, for his failure to identify the common learner misconception and repeating standard textbook definition, without reference to any other component of TSPCK.

The responses captured from the GBT cohort pairs for the second part of the same question are presented in Figure7.3. The question asked required the participants to explain how they would respond to learners who in-correctly name hydrocarbons by inferring to the longest straight chain instead of the longest continuous chain.

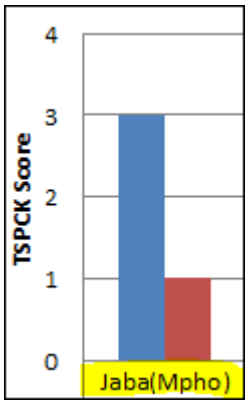
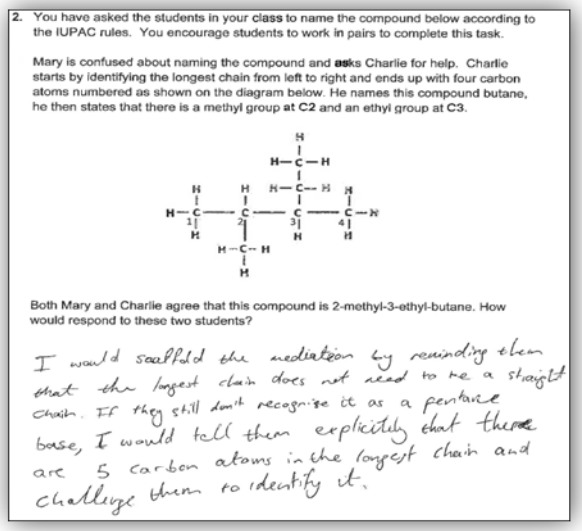
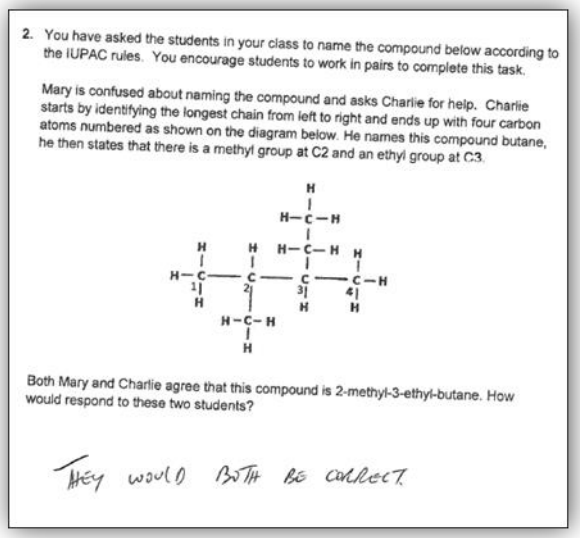
TSPCK score	Extract from intervention GBT	Extract from the control GBT	Extract from stimulated recall interview
	 **Retyped comments:** I would scaffold the mediation by reminding them that the longest chain does not need to be a straight chain. If they don't recognise it as pentane, I would tell them explicitly that there are five carbon atoms in the longest chain and challenge them to identify it.	 **Retyped comments** They would both be correct.	**Researcher:** Your response to this question suggests that both learners could be correct by naming the compound in the test tool as two-ethyl three, methyl butane. Given a chance to re-formulate your response is there any additional thing you would like to explain or provide to the learner? **Mpho:** Not really, I would request them to go and read and practice more on naming Hydro-carbons using examples from their text books and any other sources like the internet.

Figure 7.3: Extracts showing teacher Jaba vs teacher Mpho response in the topic of intervention

An examination of the written responses in Figure 7.3 above indicate that teacher Jaba correctly identifies the common learner misconception, by pointing out that; *"I would scaffold the mediation by reminding learners that the longest chain does not need to be a straight chain."* The teacher then confronts the misconception, by re-phrasing the explanation to confirm accurate understanding noting that; *"if they don't recognise it as pentane… I would then tell them explicitly that there are five carbon atoms in the longest chain and challenge them to identify it."* In the segment, we see the teacher first identify the misconception, before giving a hint to help confront the misconception by stating that the longest chain does not need to be straight, and only if the learners don't recognise it as pentane, would he then tell them explicitly that the compound has five carbon atoms in the longest continuous chain. The teacher draws on his subject matter knowledge, an element of curricular saliency to confront a common learner misconception, which indicates presence of the component of learner prior knowledge.

So, considering teacher Jaba's responses, we see evidence of drawing on the TSPCK components of curricular saliency and representations, when the focus was on the component of learner prior knowledge for this part of the question.

Teacher Mpho's written response to the same question item, shown on the right-hand side of Figure 7.3, reveals the teacher's own held misconceptions about the topic. From the teacher's written response, naming pentane as butane could both be correct; this indicates incorrect subject matter knowledge (SMK). The teacher equally repeated the same response, even after being reminded during the stimulated recall interview that his response suggests that *both learners could be correct in naming the compound as 2–methyl-3-ethyl-butane*. The finding from teacher Mpho's response agrees with Kruse and Roehrig (2005), who observe that practicing Chemistry teachers often demonstrate many misconceptions related to key Chemistry topics such as chemical reactions, the structure of matter etc. Teacher Mpho was also assigned an average score of one for this part of the question. After rounding up the scores from the different parts of the question to a single whole number, teacher Jaba was assigned an average score of three, which corresponds to the developing TSPCK proficiency in the topic of intervention during his actual

classroom practice as a beginning teacher. On the other hand, teacher Mpho was assigned an average score of one, which corresponds to the limited TSPCK proficiency.

Another example showing an average difference of two quality category levels in the quality of TSPCK between the GBT cohort pairs was captured from between teachers Tzepo (intervention GBT) versus Thembu (comparable GBT) in the component of conceptual teaching strategies.

(ii) Example 2: Extracts showing a two-quality category difference between intervention vs comparable GBTs in the topic of intervention

In this example, the GBT cohort pair responded to the TSPCK test tool in the topic of electrochemistry. The teachers were required to explain how they would assist learners in moving towards correct answers, by identifying and correcting their held errors. These are indicated in Figure 7.4 as extracts 1 to 4 under the category of conceptual teaching strategies (the full test tool is provided in Appendix G). Figure 7.4 also shows a comparison of extracts captured from the GBT cohort pairs' written responses.

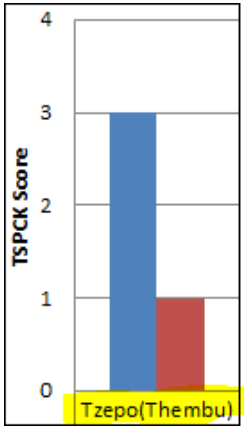
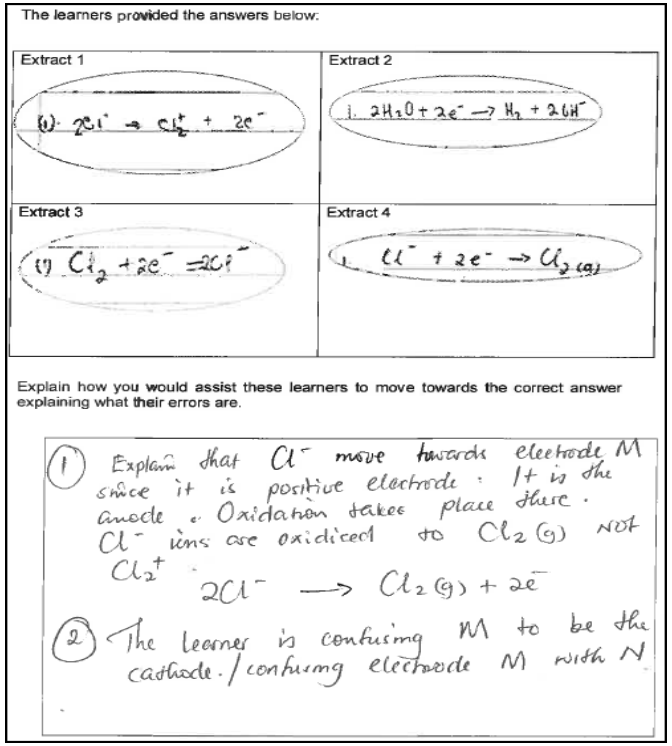
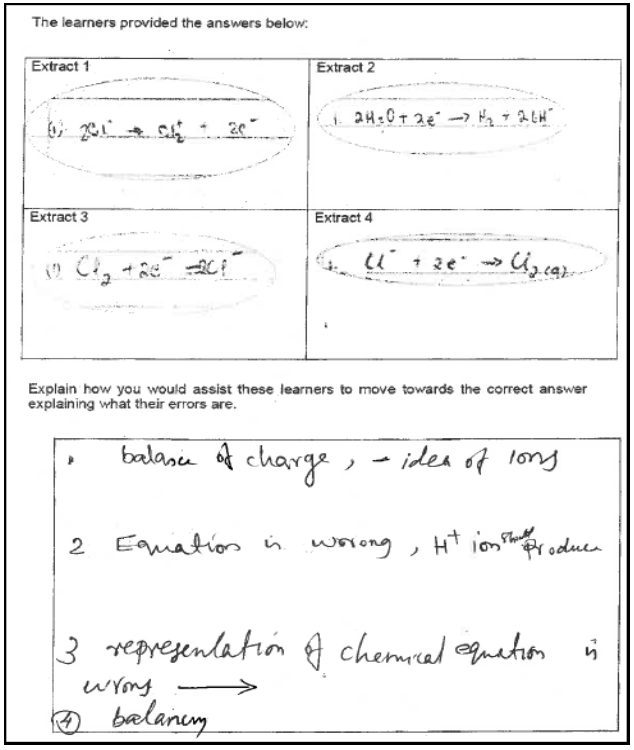
TSPCK score	Extract from teacher Tzepo	Extract from teacher Thembu
		

Figure 7.4: Extract on how to correct learners' errors: Tzepo vs. Thembu

Looking at the responses displayed in Figure 7.4 above, we see teacher Tzepo correctly identify the learners' error in extract 1, pointing out that the Cl^- ion moves towards electrode M (anode), noting that the electrode is the anode since oxidation takes place there (see test tool Appendix G Question 7). The teacher then confirms accurate understanding, using the correct representation, by stating that the Cl^- ions are oxidised to Cl_2 (g) and not Cl_2^+, thus providing correct SMK, which indicates presence of the component of curricular saliency.

The teacher further suggests enforcing learners' understanding using the correct equation: ($Cl^- \rightarrow Cl_2 + 2e^-$), which is an indication of the component of representations at symbolic level. He finally emphasises that learners confuse electrode M, the (anode), with electrode N, the (cathode), which signals knowledge of the common learner misconception regarding the charges assigned to these electrodes, as an aspect of the component of learner prior knowledge.

Teacher Tzepo was assigned an average score of three, which corresponds to the developing quality category of TSPCK, for use of scientific symbolic representation linked to the TSPCK components of learner prior knowledge and aspects of the component of curricular saliency, as a conceptual teaching strategy.

In teacher Thembu's response, shown on the right-hand side in Fig 7.4 above, we see the teacher acknowledge the learner's error, by pointing out that the equations in extracts two and three are both wrong (see test tool Appendix G). However, he fails to provide a corresponding confrontation strategy on how to assist learners move towards the correct answer. Teacher Thembu was consequently assigned a score of one, which corresponds to the limited quality category of TSPCK, for only referring to content knowledge (CK) by identifying the learner error, with no linking explanatory notes to aspects of the concept being explained.

(iii) Example 3: Extracts showing a single quality category difference between intervention vs comparable GBTs in the topic of intervention.

The third example was an extract showing a single quality category difference between teacher Menjo (intervention GBT) and teacher Dido (comparable GBT), lifted from the TSPCK component of curricular saliency.

Under the category of curriculum saliency, the question items asked were used to explore GBTs' knowledge about the big ideas in teaching various Chemistry topics at Grade 12. In the question items, the participants were provided with lists of a mix of the main concepts (big ideas), subordinate concepts, and concepts that were not related to the teaching of the different Chemistry topics used during the intervention studies. The participants were then asked to select three main ideas or concepts, which they consider important for teaching those respective topics. They were further required to select concepts which they believe must been covered before teaching the topics under discussion. Figure 7.5 below shows a comparison of written responses of selected big ideas (main concepts) for teaching the topic of chemical equilibrium. This is followed by extracts showing the topics that must be taught before teaching chemical equilibrium, and the reasons for selecting them in Figure 7.6.

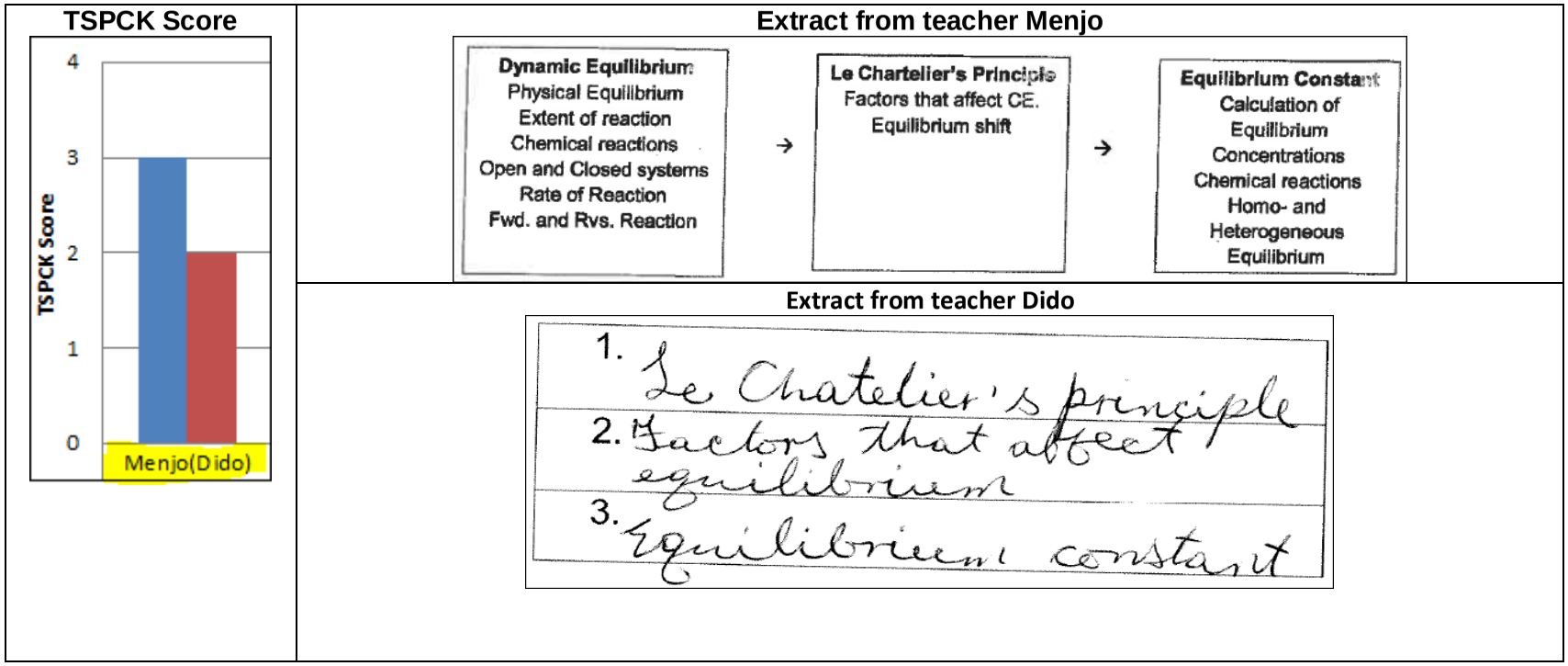


Figure 7.5: The main ideas for teaching electrochemistry teachers Menjo vs. Dido

From the listed concepts shown in Figure 7.5 above, teacher Menjo selected dynamic equilibrium, equilibrium constant and Le Chaterlier's principle in relation to factors that affect CE (chemical equilibrium), which correctly makes it a big idea.
This meant that the teacher had all the three big ideas correct. Teacher Dido, on the other hand, sees the two (Le Chaterlier's principle and factors that affect equilibrium) as different big ideas, which makes both concepts incorrect as big ideas. The teacher, however, correctly identifies equilibrium constant as one of the big ideas in teaching chemical equilibrium at Grade 12. Teacher Menjo was assigned a score of four, for identifying all the three big ideas, and providing logical sequence of the selected big ideas, while teacher Dido was assigned a score of one, for identifying only one big idea.
The second part of the question required the GBTs to select topics/concepts that must be covered in Chemistry before teaching the topic of chemical equilibrium. The question further asked the GBTs to provide reasons for the selected topics.

Figure 7.6 below shows a comparison of extracts between the GBT cohort pair, showing topics/concepts that must be covered in Chemistry and the reasons before teaching chemical equilibrium.

Extract from teacher Menjo (Intervention GBT)

3.3 What topics must have been covered in chemistry before you can teach chemical equilibrium?

List of Topics to be taught before Chemical Equilibrium	Place them in a sequence (the one to be taught first , place it as No. 1)	Provide reasons for the proposed sequence
Balancing Chemical reactions	1. Kinetic molecular theory of matter	These topics lay a good foundation for the teaching of chemical equilibrium.
Exothermic and Endothermic reactions	2. Balancing Chemical reactions	
Kinetic molecular theory of matter	3. Quantitative aspects of chemical change	
Rates of reactions	4. Exothermic and Endothermic reaction	
Factors that affect rate of reactions	5. Rates of reaction	
Quantitative aspects of chemical change	6. factors that affect rate of reaction	

Extract from teacher Dido (Comparable GBT)

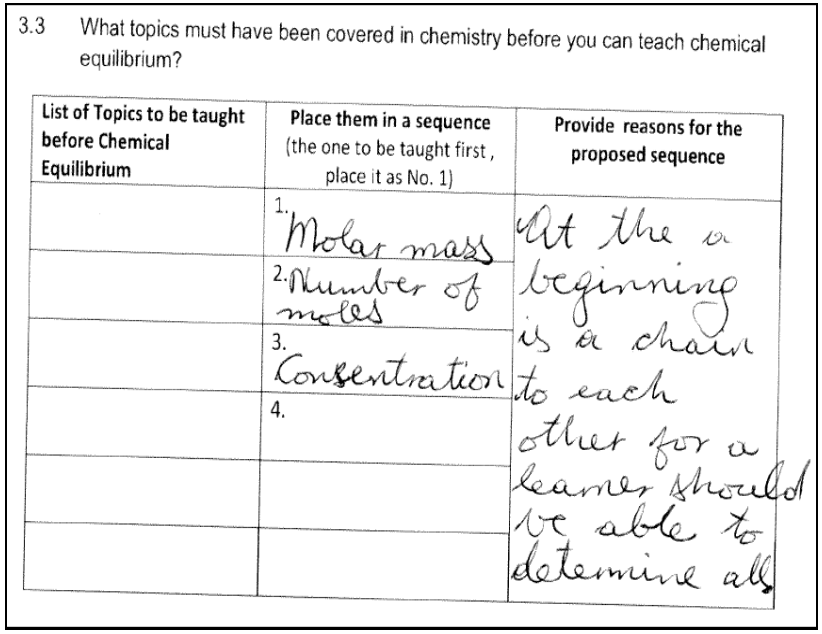


Figure 7.6: Extracts showing topics that must be taught before teaching chemical equilibrium teachers Menjo vs. Dido

Looking at the topics/concepts selected by the GBTs, we see both teachers identify a mix of concepts related to teaching the topic of chemical equilibrium, as well as those not relevant to the topic. For example, teacher Menjo correctly selected some concepts used to express equilibrium constant, such as; quantitative aspects of chemical change, rates of reaction and factors that affect rate of reaction. Teacher Dido likewise selected concentration, which is one of the pre-concepts related to teaching the topic of chemical equilibrium. The above choices demonstrate understanding of the knowledge needed prior to teaching the topic, which indicates an aspect of the component of curricular saliency. However, the inclusion of concepts related to different topics by both teachers was seen to constrain appropriate conceptual scaffolding and developmental understanding of the topic. For instance, teacher Menjo included exothermic and endothermic reactions, from thermodynamics. Teacher Dido similarly listed the number of moles and molar mass, which are concepts from stoichiometry that do not directly relate to the teaching of chemical equilibrium. Both teachers were assigned a score of two, for selecting a mix of concepts related to teaching of chemical equilibrium, as well as those not relevant to the topic. As alluded to earlier, the scores captured from the different sections of the question items asked were rounded up or down to whole numbers in order to locate the score in the appropriate category in the scoring rubric. The process of rounding up of individual scores resulted in classifying the intervention GBT in the developing category of TSPCK proficiency, while the comparable GBT was assigned an overall score of two, which corresponds to the basic category of TSPCK in the scoring rubric.

In summary, the nature of quality of planned TSPCK in the familiar context generated from the qualitative analysis and discussions captured from the topics of intervention above include aspects, where generally, the intervention-GBTs demonstrated: (i) knowledge of potential misconceptions and/or confusion by learners; (ii) improved structuring of the topics for teaching; (iii) identification of aspects regarded difficult to teach; (iv) use of representations; and (v) improved teaching strategies, which include reference to one or more of the other content components of TSPCK. On the contrary, the comparable-GBTs were seen to

generally struggle to provide convincing evidence of sophisticated connections between the content components of TSPCK, in their responses.

In general, the scores generated by the comparable group were lower compared to those of their intervention GBT counterparts. This means that the intervention GBTs had an added advantage on planned TSPCK in the topics of intervention. This was evident from the qualitative extracts, which revealed that, the comparable group lacked the ability to formulate explanations with reference to knowledge brought about by the TSPCK components. It was further observed that, although the comparable GBTs displayed correct content knowledge in the topics of intervention, they lacked what to talk about when explaining concepts. This was confirmed from the responses captured in the stimulated recall interview, shown in Figure 7.2, where I was required to spend a lot of time using specific prompts to make them respond concisely to the test items. For example, when asked on what else the teacher would tell the learner to help them differentiate organic alcohols from other compounds, it took me a great deal of time and persuasion to have the teacher recall that alcohols have an- OH group attached to a carbon atom and not any other atom. In addition, when asked whether, if given a chance to re-formulate his response the teacher, this would provide any additional information, the comparable GBT simply repeated known standard textbook definition about -OH as a functional group.

As mentioned above, the observed performance by intervention GBTs over their comparable GBT counterparts in the topics of intervention was expected. This was due to having been exposed to the same test tools earlier, during their respective intervention studies. However, the extent of the difference was not predictable before this analysis.

Therefore, to single out the likely impact of the intervention programme on the observed performance, the quality of planned TSPCK displayed between intervention GBTs versus the comparable GBTs in new topics was measured.

In section B below, I show extracts of qualitative responses reflecting the quality of planned TSPCK, between the intervention GBTs and the comparable GBTs in the unfamiliar context, with new topics.

Section B: Unfamiliar Context

7.3 Comparison of planned TSPCK between intervention GBTs versus comparable GBTs (new topics)

As alluded to earlier, the new topics refer to different topics from those used during the intervention studies. In the new topic, the intervention-GBTs were allowed to apply the interactive use of the five content components of TSPCK learnt at the time of the pre-service intervention programme to develop PCK across other physical science topics.

For the analysis in this section, one experienced and practicing Physical Science teacher was added to this sample. This was to provide additional soft insight into the likely quality of expert teaching at the time. The experience is considered soft as only one teacher was used. This insight was also useful as a reference projected from a likely future, when the beginning teachers (both intervention and comparable GBTs) would have turned into expert teachers, due to many years of experience in practice. The additional teacher did not experience the explicit training on TSPCK as a pre-service teacher, but was considered experienced based on the many years (10) of teaching Physical Science in various schools. The expert teacher first trained as a Physical Science and Mathematics Diploma teacher (Dip. Ed). He then taught for about four years before registering for a bachelor's degree in Science Education (B.Ed) through a correspondence course programme as a part time university student. By the time of the data collection exercise, the teacher had taught Physical Science and Mathematics for a total of 10 years at senior Grade/FET levels of education, in three different township secondary schools. It is argued in the literature that experience in practice influences proficiency in PCK, although the nature of the experience matters (Cooper & Loughran, 2015). It was therefore found beneficial to evaluate the reasoning and planning element in one of the topics, as well as the actual classroom teaching of the expert teacher's video recorded lessons of the same period as the GBTs, for purposes of comparison.

For clarity of the topics analysed, a summary of both the intervention topics analysed in the preceding section, and the new topics analysed in this section is provided in Table 7.3 below.

Table 7.3: Summary of the topics in which TSPCK was measured in the intervention vs. new topics

GBT cohort Pair	Topic of intervention – measured in section 7.2. above	New Topics measured in Section 7.3 below
Menjo (Dido)	Chemical Equilibrium	Organic Chemistry
Jaba (Mpho)	Organic Chemistry	Electrochemistry
Tzepo(Thembu)	Electrochemistry	Organic Chemistry
Expert teacher	-	Organic Chemistry

Note: the pseudonyms for the control GBTs are shown in brackets

The criterion based Mavhunga & Rollnick (2013) TSPCK rubric for scoring the quality of planned TSPCK was similarly used to score the responses captured from completed TSPCK test tools in the new topics. Table 7.4 below shows a comparison of performance in the TSPCK tests between the GBTs cohort pairs and that of the expert teacher on planned TSPCK in the new topics.

Table 7.4: Performance of intervention GBTs versus comparable GBTs on Planned TSPCK in the respective new topics

GBT pair	New Topic	LP	CS	WD	REP	CTS	Person Average
Menjo (Dido)	Organic Chemistry	3(2)	3(2)	3(1)	3(2)	2(1)	**3(2)**
Jaba (Mpho)	Electrochemistry	3(2)	3(1)	3(2)	3(2)	3(2)	**3(2)**
Tzepo(Thembu)	Organic Chemistry	3(2)	3(2)	2(1)	3(2)	3 (2)	**3(2)**
Group average score							**3(2)**
Expert teacher	Organic Chemistry	4	3	3	4	4	**4**

Note: the scores generated from comparable GBTs are indicated in brackets. Pseudonyms have been used to conceal the identity of the GBTs who participated in this study.

The overall pattern emerging from the findings displayed in Table 7.4 indicate that the intervention GBTs displayed an added advantage in the quality of planned TSPCK over their comparable-GBTs in the new topics across all the components by on average one quality category level difference. The intervention-GBTs' group average score was categorised in the developing TSPCK proficiency. On the contrary, the group average TSPCK score for the comparable-GBTs was categorised in the basic TSPCK proficiency.

The intervention GBTs added advantage in the quality of planned TSPCK over their comparable-GBTs in the new topics was not, however, exemplary as would be expected of experienced teachers. This was evident from the performance of the expert teacher, who was assigned a person average score of 4, which corresponds to the exemplary quality category in the planned TSPCK in the new topic.
The finer features of the GBT cohort pairs' TSPCK scores described in Table 7.4 above are graphically represented in Figure 7.7 below.

Figure 7.7 shows four graphs, the smaller three of which on the left indicate the TSPCK scores from each intervention GBT vs. comparable GBT pair across the TSPCK components in the new topic of the partner GBT. The TSPCK scores generated from of the expert teacher are shown in green. The bigger graph on the right shows the collective proxy average person scores between the intervention GBTs vs. the comparable GBTs in the new topic. Each point on the bigger graph represents the overall average score, which is a proxy score reflective of the collective influence of all the observed TSPCK component interactions, thus indicative of the quality of TSPCK. The GBT cohort pairs have been grouped according to the new topics they responded to.
The *x*-axis on the bigger graph represents the GBT cohort pairs, while the *y*-axis represents the GBTs' person average TSPCK scores in the new topics. The *x*-axis on the smaller graphs represents the five TSPCK components, while the *y*-axis represents the GBTs and the expert teacher's TSPCK scores per component.

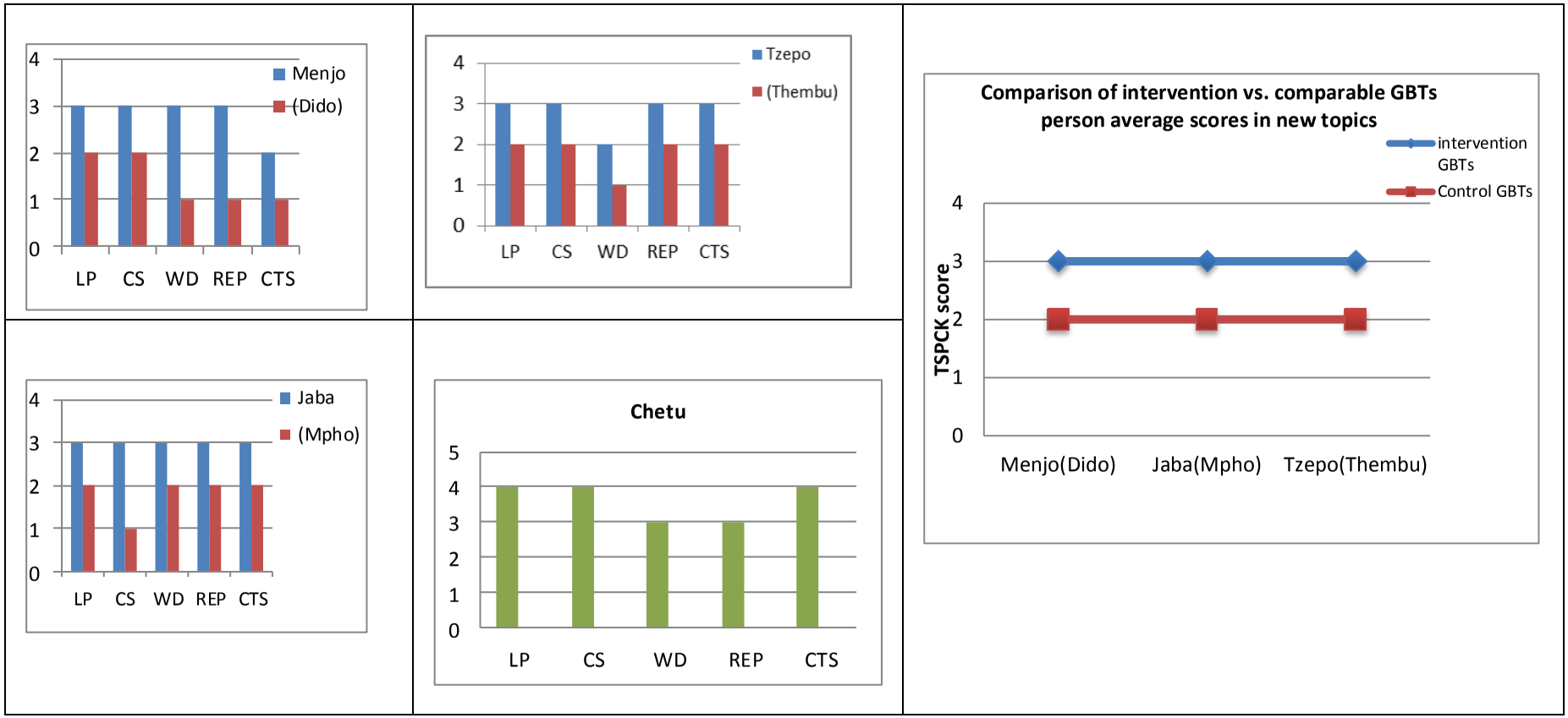


Figure 7.7: Comparison of participants' average person scores in the new topics

Note: The comparable GBTs pseudonyms are shown in bracket

The pattern emerging from the collective average TSPCK scores per component, between intervention GBTs vs. their comparable GBTs cohort pairs, in the smaller graphs in Figure 7.7 similarly indicate that the intervention GBTs showed an improvement of one quality category level across all the TSPCK components in the quality of TSPCK quality over their comparable GBTs.

This is evident by the high proportion of high quality TSPCK scores displayed by the intervention GBTs over that of the comparable GBTs. For instance, one GBT teacher (Jaba) was assigned a score of 3, which corresponds to the developing quality category of TSPCK in all the TSPCK components. Likewise, two intervention GBTs, teachers (Menjo and Tzepo) were both categorised in the developing quality of TSPCK in four out of the five TSPCK components. Teachers (Menjo and Tzepo) were, however, seen to struggle in explaining how to enact the TSPCK components of conceptual teaching strategies and what is difficult to teach in practice, with both teachers being scored in the lower quality category level of basic TSPCK, respectively. On the contrary, all the comparable GBTs were seen to struggle when it comes to how to enact TSPCK in the new topics across all the components. This is evident from the low scores displayed by the group, where the three GBTs were all classified in the lower quality category levels of basic and limited TSPCK proficiency across all the components in the new topics.

It was however, noted that a high proportion of high-quality TSPCK scores displayed by the intervention GBTs over the comparable GBTs were not as exemplary as could be expected of experienced teachers. This was evident from the expert teacher's TSPCK scores, which were all scored in the higher order quality categories of proficient (2) and exemplary (3) TSPCK proficiency across the (5) TSPCK components.

In the following section, I present examples of sample extracts showing qualitative insights into the nature of responses reflecting the added advantage displayed by the intervention GBTs, over their comparable GBT counterparts in the quality of planned TSPCK per component in the new topics.

I start by showing a typical example of written responses that demonstrates a two-quality categories level difference between the intervention GBTs versus their comparable GBTs.

The first example used to show a two-quality category level difference between the GBT cohort pairs was lifted from extracts of written responses captured from teacher Menjo (intervention GBT) and teacher Dido (comparable GBT), in the component of representations.

(i) Example 1: Extract showing a two-quality categories difference in the component of representations

As alluded to earlier, the analysis of question items under the category of representations was carried out at two levels. The first level was selecting representations found most useful in teaching, from a list of representations provided in the test tool. This was followed by proving reasons why the selected choices are considered useful. The second part involved how the selected representation(s) can be used to teach specific concepts in a topic.

For example, teachers (Menjo and Dido) were asked to select representations they find most useful in teaching the topic of Organic Chemistry from a list provided in the test tool (Appendix F) and explain how they can use the selected representation(s) to teach the differences in the boiling points of butane (0.5^0C) and pentane (36^0C). The topic of Organic Chemistry was considered new for this specific GBT cohort pair, because the intervention GBT (teacher Menjo) had been exposed to a different topic (Chemical equilibrium, as shown Table 7.3 above) during his pre-service intervention study.

Figure 7.8 below shows extracts captured from the GBT cohort pairs' written responses regarding when they would use each representation in teaching, as well as how to apply one of the representations to explain the difference in the boiling points of butane (0.5^0C) and pentane (36^0C), respectively.

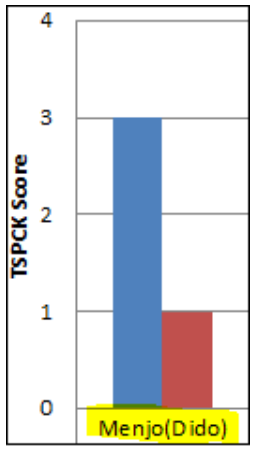
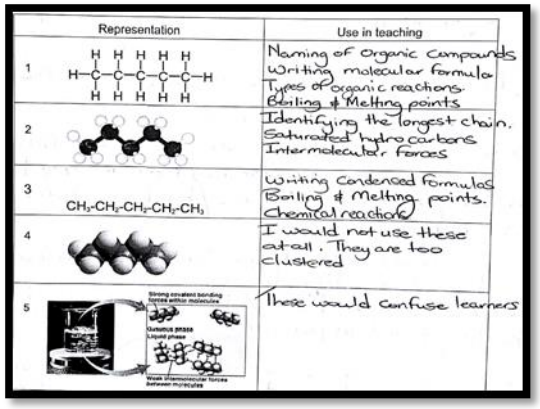
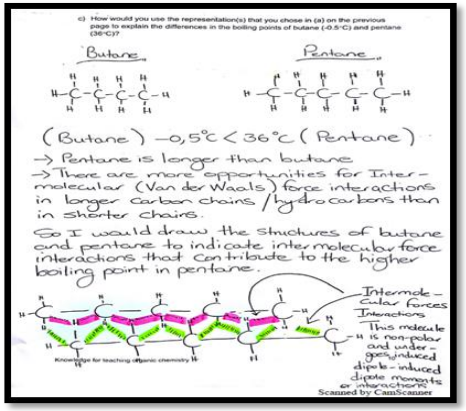
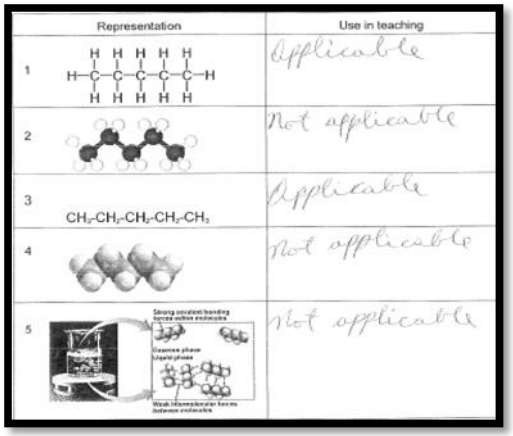
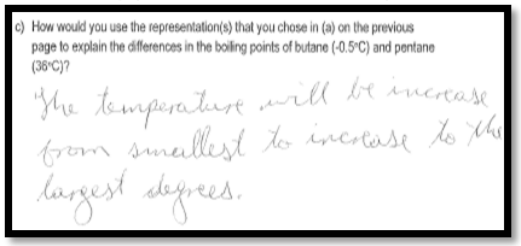
TSPCK score	Extract from teacher Menjo	Extract from teacher Dido	Extract from stimulated video
	 Use of representation to explain differences in the Boiling points between butane and pentane 	 Use of representation to explain the differences in the Boiling points of butane and pentane  **Re-typed:** The temperature will increase from the smallest to the largest in degrees	**Researcher:** In your response, you indicated that you would use only the 1st and 3rd representations in your teaching. Would you explain why the two would apply and not the other three representations? **Dido** The 1st and 3rd representations are suitable for teaching because they both depict line diagrams, which learners easily understand, compared to the 2nd and 5th representations, which depict organic diagrams in a 3D dimension that learners often find difficult to comprehend.

Figure 7.8: Teachers Menjo vs. Dido use of representations in teaching a new topic.

An inspection of the responses shown in Figure 7.8 above indicates that teacher Menjo listed specific concepts/sub-topics, where he would use the first three representations for teaching the topic of Organic Chemistry at Grade 12. The teacher however noted that he would not use the fourth representation at all, because it is clustered, while the fifth representation would confuse learners. The teacher went on to concisely describe how he would engage with the first three representations as shown in the second extract. In the explanation, we see the teacher engage with the selected representation at both symbolic and sub-microscopic, to enforce specific aspects of the concept being explained, specifically the effect of intermolecular forces on the boiling points of butane and pentane. This demonstrates an explicit link of core aspect of content knowledge with the representation.

The link is evident when the teacher's indicates the use of line diagrammes to explain the boiling points, by showing intermolecular forces using a drawing that could be interpreted as a 3D projection, which is explicit in the labelling. This aspect is revealed when the teacher notes, "*so, I would draw the structures of butane and pentane to indicate intermolecular force of interactions that contribute to the higher boiling point in pentane."*

As alluded to in the literature, identification of concepts that are most important in a topic indicates an aspect of the component of curricular saliency (Geddis & Wood 1997). The use of the TSPCK component of representations at different levels is noted as bringing a big difference in the explanation, making it to work complementary at multiple levels of component sophistication. According to Gabel (1998), an explanatory tool such as a diagramme or an image can provide the learner with a way of visualising the concept and hence develop a mental model for it. The use of representations at different levels and the natural consideration of aspects of curricular saliency was seen to reflect the inter-dependence of the two content components of TSPCK in working together to support understanding of a singular concept (Aydin, Demirdogen, Akin, et al., 2015). The teacher was assigned a score of three, which corresponds to the developing quality of TSPCK proficiency, for use of symbolic and sub-microscopic representation to enforce specific aspect(s)

of the concept being explained, and drawing interactively on the component of curricular saliency to support understanding of a singular concept.

Teacher Dido similarly indicated that the 1st and 3rd representations would apply at school level, and not the 2nd and 5th representations, as indicated on the right-hand side in Figure 7.8. The teacher did not, however, provide supporting explanatory notes to link the two selected representations with aspects of the concept to be explained. For instance, when asked why he would not apply the 2nd and 5th representations during the stimulated video recall interview, the teacher indicated that the 1st and 3rd representations depict line diagrammes, which learners can easily understand, compared to the 2nd and 5th representations that depict organic molecules in a 3D orientation. Teacher Dido's response was found to be not convincing enough with regards to the two representations not suited for learning at Grade 12. The teacher was subsequently assigned a score of 1, which corresponds to the limited quality of TSPCK following the criteria used in the scoring rubric, where limited use of a scientific representation without linking explanatory notes to aspects of the concept being explained is assigned a maximum score of 1. In the second part of the question that asked how the selected representation(s) would be applied to explain differences between the boiling points of butane and pentane, the teacher simply noted that *"the temperature will increase from the smallest to the largest."* This response displays the teacher's own lack of deep understanding and minimum effort to link the selected representation to understanding the concept being explained. Teacher Dido was subsequently assigned a score of 1, which marches into the limited quality category in the TSPCK scoring rubric for this part of the question. After rounding up the individual scores from the different parts of the question, teacher Menjo was assigned an average score of 3, which marches into the developing quality category in the scoring rubric. On the other hand, teacher Dido was assigned an overall score of 1, which corresponds to the basic quality of TSPCK.

The second example where the GBT cohorts experienced a two-quality categories level difference in the quality of planned TSPCK in the new topics was in the topic of electrochemistry. The sample extracts lifted from written responses captured

between teachers (Jaba and Mpho) in the component of curricular saliency are briefly discussed below.

(ii) Example 2; Extract showing a 2-quality categories level difference in the component of curricular saliency.

The topic of electrochemistry was considered new for this GBT cohort pair, because the intervention GBT (teacher Jaba) had been exposed to the topic of Organic Chemistry during the pre-service intervention programme. Under the category of curricular saliency, the GBTs were required to select at least three main ideas in the topic, from a list of a mix of big ideas and subordinate concepts and provide reasons why they considered the selected choices important for understanding by learners. Figure 7.9 shows a comparison of the GBTs' selected three big ideas and the reasons for teaching the topic of electrochemistry at Grade 12. This is followed by a comparison of the topics that must be taught before teaching the topic and the reasons why the GBTs consider the topics important for learners in Figure 7.10 (Appendix G shows a full copy of the test tool).

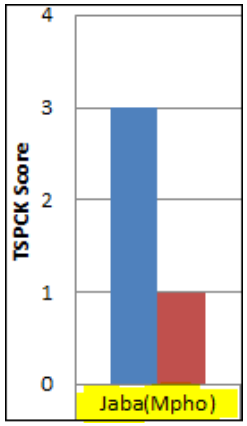
TSPCK Score in the component of CS	Extract from teacher Jaba on Big ideas		Extract from teacher Mpho on Big ideas		Extract from video recall interview
	Suggested big idea	Reasons	Suggested big idea	Reasons	
	Oxidation and reduction occur simultaneously Electrode potentials are linked to the energy of the half reaction Electrical neutrality is preserved in a cell	Oxidation and reduction occur simultaneously, therefore all electrons that are produced during oxidation are used during reduction and no free electrons are left around the cell. There is no build-up of electrons, but the cell neutrality is reserved by the ions in the salt bridge/electrolyte solution. The electrode potential is therefore not due to excess or deficit of electrons, but rather the energy of the reaction.	Energy from chemical reactions can produce electricity Electrode potentials are linked to the energy of the half reaction Equations must be balanced		**Researcher:** In your response, you did not indicate the reasons for your suggested three big ideas. Would you explain why? **Mpho** I understand the importance of the three concepts for teaching the topic, but the syllabus requires that we teach all the concepts equally.

Figure 7.9: The Big ideas for teaching electrochemistry: Teachers Jaba vs. Mpho in the new topic

Looking at the choices listed by the GBTs as the big ideas for teaching the topic of electrochemistry and the corresponding reasons provided in Figure 7.9 above, we see teacher Jaba correctly identify electrical neutrality, the link between electrode potentials and the energy of half equations, and redox reactions. All the selected concepts can be considered big ideas for teaching electrochemistry.

Teacher Mpho similarly selected energy from chemical equations as sources of electricity and the link between electrode potential and energy of half reactions, as big ideas for teaching electrochemistry. The teacher however included balancing equations as the third big idea in teaching the topic. As alluded to earlier, concepts like balancing equations, carry no explanatory power in teaching electrochemistry, but only serve to predict aspects related to the main ideas of the topic, hence should be considered subordinate to the big ideas. The observed mix of the main ideas and subordinate concepts by teacher Mpho demonstrates confusion in structuring the topic concepts for sequential development and understanding of other concepts in the topic. Teacher Jaba was assigned a score of 4 for correctly identifying the three big ideas of the topic, while teacher Mpho was assigned a score of 1, for identifying a mix of big ideas and subordinate concepts for this part of the question. Teacher Jaba went on to correctly suggest the reasons for selecting cell neutrality as one of the main concepts for teaching the topic, pointing out that learners need to understand the flow of electrons in the cell and how electrical neutrality is maintained. The teacher further noted that some of the learners think that free electrons are left within the cell. He then confirmed accurate understanding, stating that: *"there is no build-up of electrons, but cell neutrality is reserved by ions in the salt bridge/electrolyte solution …the electrode potential is not due to excess or deficit of electrons, but rather the energy of the reaction."* The explicit emphasis of the electrode potential not resulting from an excess or deficit of electrons, but the energy of the reaction, indicates knowledge of/and confrontation of an aspect considered difficult for learners' understanding about electron build-up in a galvanic cell**,** which indicates knowledge of a key gate-keeping concept about the topic, an element of the component of what is difficult to teach. Teacher Jaba was assigned an overall score of 3, which corresponds to the developing TSPCK proficiency, for providing correct reasons for one of the identified

big ideas that links to conceptual development and understanding of the topic. Teacher Mpho did not provide any reason for the selected concepts for this part of the question and was assigned a score of 1, following the criteria used in the scoring rubric, where any question without a response is assigned a maximum score of 1.

On probing why the teacher did not provide reasons for his selected big ideas during the stimulated video recall interview, we see evidence that the teacher may simply be following what is prescribed in the syllabus guidelines, without in-depth interrogation of the concepts taught.

As mentioned above, the last two question items required the GBTs to list topics that must be covered in Chemistry before teaching electrochemistry, and provide reasons why electrochemistry is important for learners. Figure 7.10 below shows the selected topics and the reasons why the topics are important for learners at Grade 12 for comparison.

Extract from teacher Jaba on topics that must be taught before teaching electrochemistry	Extract from teacher Mpho on topics that must be taught before teaching electrochemistry
Stoichiometry Reactions in aqueous solutions Solubility (Grade10) General redox (Grade 11) Molecular structure (atoms, ions, molecules) Grade 10)	Redox reactions Chemical change
sThe importance of learning electrochemistry	**Importance of learning electrochemistry**
Electrochemistry is a very important aspect in chemical industry The idea of cell potential helps learners understand the relationship between electrical energy and chemical energy	To understand the working of batteries To understand purification of metals like copper, extraction of aluminium and electroplating

Figure 7.10: Selected topics and the reasons why the topics are important for learners at Grade 12

An examination of the extracts of written responses shown in Figure 7.10 above reveals the GBT cohort pairs' understanding of topics/concepts that must be covered in Chemistry before teaching the topic of electrochemistry. In addition, the reasons provided by the GBT cohort pair for importance of the topic include sequential scaffolding for understanding of other topics in the subject, as well as in everyday life applications. In the extracts, we see both teachers link understanding of the topic to other related fields outside the classroom, especially in industry and daily life applications such as electroplating and extraction of metals. Teacher Jaba went further to link the topic to understanding the relationship between electrical energy and chemical energy.

According to Shulman (1986), the ability of a teacher to relate the content of a given course or lesson to topics or issues being discussed simultaneously in other classes and related fields, exemplifies knowledge of lateral curriculum, an aspect well demonstrated by both teachers. After rounding up the individual scores from the different parts of the question, teacher Jaba was assigned an average score of 3, which matches into the developing quality category of TSPCK. Teacher Mpho was assigned an aggregate score of 1, which corresponds to the limited quality category of TSPCK.

The examples shown above, presented sample extracts showing a two-quality categories level difference between the intervention GBTs and their comparable GBT counterparts. In the discussion below, I present an example, where the GBT cohort pairs experienced a single quality category level difference in the quality of planned TSPCK in the new topics.

The extracts of written responses used here as a examples representing a single quality category level difference in the quality of planned TSPCK in the new topics were taken from teachers Tzepo (intervention GBT) and Thembu (comparable GBT) in the topic of Organic Chemistry, under the category of the component of conceptual teaching strategies.

(iii) Example 3: Extract showing a single quality category level difference in the component of conceptual teaching strategies

As mentioned in Chapter 3, the question items asked under the category of conceptual teaching strategies retained an open-ended question format. The TSPCK test tool on Organic Chemistry was administered as a new topic to the GBT cohort pair named above. This is because teacher Tzepo, the intervention GBT had been exposed to the topic of electrochemistry at the time of the intervention programme. The question item asked under this category required the GBTs to explain how they would teach a lesson about different ways of representing organic molecules.

Specifically, the question required the teachers to explain how they would help students to correctly represent organic structures, when the learners consistently presented incorrect structural formulae, even after being taught (Appendix F shows full test tool). The extracts lifted from the GBT cohort pairs written responses are shown in Figure 7.11 below for comparison.

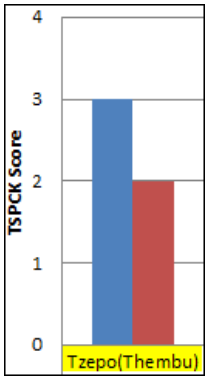
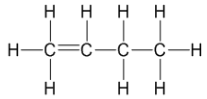
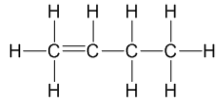
TSPCK score	Extract from teacher Tzepo	Extract from teacher Thembu	Extract from recall interview
	**1.** You draw the structure of chloromethane as shown below on the chalk board.  Teacher's Drawing Student's Drawing A student asks: "Is it okay if you swop around the chlorine and a hydrogen atom like this (the student draws a second structure as shown above)". **How would you teach a lesson about the different ways of representing organic molecules to this class?** In teaching the sub-topic of isomerism, I will clarify that there is only one structure of methyl chloride. So it doesn't matter which side of carbon bond is the chlorine **2.** In a diagnostic test a student drew the incorrect structure below.  Given that you have taught your students how to draw structural formulae, how would you conduct a revision lesson, to correct this student's response? I will take the learners back to the periodic table; we shall discuss the valence electrons to show them that in group 4 the carbon atom has 4 bonding electrons.	**1.** You draw the structure of chloromethane as shown below on the chalk board.  Teacher's Drawing Student's Drawing A student asks: "Is it okay if you swop around the chlorine and a hydrogen atom like this (the student draws a second structure as shown above)". **How would you teach a lesson about the different ways of representing organic molecules to this class?** I will just show the learners that the chlorine atom can be in any position on the carbon atom as long as there are 3 hydrogens and one chlorine in the carbon chain. **2.** In a diagnostic test a student drew the incorrect structure below.  Given that you have taught your students how to draw structural formulae, how would you conduct a revision lesson, to correct this student's response?	**Researcher:** In your explanation, you indicated that whichever side of the carbon bond the chlorine is attached to does not matter. Given a chance to re-formulate your response, is there anything else you would like explained to the learner? **Tzepo** Yes, I would explain that carbon compounds are formulated with four covalent bonds to each carbon, regardless of whether the combination is with carbon or chlorine. In methyl chloride, the hydrogen atom is attached to one carbon with a single bond and the bond angle is the same in whatever position.

Figure 7.11: Different ways of representing organic molecules: Teachers Tzepo vs. Thembu

The findings from the written responses captured from the extracts above indicate that both teachers correctly observed that the position on which a substituent group is attached in representing organic molecules is immaterial. For example, in his written response, teacher Tzepo notes that "*it doesn't matter which side of the carbon bond the chlorine atom is attached*." Similarly, teacher Thembu indicated, "*I will just show the learners that the chlorine atom can be in any position, so long as there are three hydrogens and one chlorine in the carbon chain*."

Both teachers demonstrated sound knowledge about reactions of halogenoalkanes, an aspect of the component of curricular saliency. For instance, when asked during the stimulated recall interview on how the teachers would explain the same concept given a chance to re-formulate their responses, teacher Tzepo succinctly pointed out that the hydrogen atom is not affected if swooped around the methane molecule, emphasising the importance of maximum number of bonds on a carbon atom, before explaining how halogens are positioned around a single carbon, as shown in Figure 7.11 above.

In the second part of the question, teacher Tzepo suggests taking learners back to discuss the periodic table and valence electrons, to show that carbon has 4 bonding electrons, and not 5. The teacher's reference to aspects of content knowledge learnt earlier, in a previous Grade level, to help build understanding about the current topic indicates drawing on an aspect of learners' prior knowledge. Teacher Thembu did not however respond to the second part of the test tool. When asked why he did not respond to the second part of the question, during the stimulated recall interview, the teacher simply indicated that learners have been taught that carbon has four covalent bonds, and not five. The teacher thus failed to provide any insights on how he would conduct a revision lesson for learners understanding.

Teacher Tzepo was assigned an average score of 3, which corresponds to the developing quality category of TSPCK for acknowledging student question and providing a corresponding confrontation strategy, in the process drawing on the components of learner prior knowledge and aspects of curricular saliency. Teacher Thembu was assigned a score of 2 for equally acknowledging student question,

hence drawing on aspects of curricular saliency, but failing to provide a corresponding confrontation strategy. Teacher Thembu's conceptual teaching strategy was, however, viewed as weak, for failure to respond to the second part of the question asked.

The examples above show sample extracts, where the GBT cohort pairs experienced both a 1 and 2 quality categories difference in the quality of planned TSPCK in the new topics**.**

7.4. Summary

In summary, the findings generated from the analysis above indicate that the comparable GBTs had a chance to show their knowledge in two different topics, but they performed poorly in both cases. The intervention GBTs' person average score was found to visibly differ from that of the comparable GBTs' group average score, in both the topics of intervention and the new topics.

For instance, the intervention GBTs maintained the same person average score of 3, which denotes the developing TSPCK proficiency in both topics of intervention and the new topics, what I refer to as the familiar and unfamiliar contexts, respectively. On the contrary, the scores generated from the comparable GBTs were largely categorised in the lower quality category levels of basic and limited TSPCK proficiency, maintaining a person average score of 1, in both the familiar and unfamiliar contexts.

In addition, the intervention GBTs group average score in both the familiar and unfamiliar contexts, which is 3, was found to be the same score the group attained at the end of the intervention programme as pre-service teachers then, in the post-TSPCK test tools as shown in Chapter 5.

It is important to recall that the group average score is a proxy score reflective of the overall influences of the component interactions seen across the individual components of TSPCK.

This finding means that the intervention GBTs were able to export the ability to learn both the knowledge of the five components of TSPCK, as well as their combined interactive use in formulating explanations and responses to questions on teaching a topic in the same perspective with new topics in actual classroom practice.

This understanding is developed while teaching the topics of intervention during the pre-service intervention studies, and used to pedagogically engage with the same topics as well as new topics in actual practice.

In Chapter 8, I discuss findings on the added advantage derived from an early exposure to TSPCK in core Chemistry topics across other physical science topics, for the development of PCK in new topics during real classroom teaching.

CHAPTER EIGHT

ANALYSIS OF ADDED ADVANTAGE ON ENACTED TSPCK

The previous chapter presented findings on the added advantage on the quality of planned TSPCK derived from the early exposure of GBTs to an explicit PCK development in specific topics during their final year as pre-service teachers. In this chapter, I present the second part of the detailed analyses this time on the impact the explicit intervention may have had on the GBTs' quality of enacted TSPCK in real classroom teaching, in the early years of their careers as professional teachers. The previous chapter, together with this one, provide the opportunity to witness TSPCK as a construct both in planning and in practice, holistically. In this chapter, the sample remained similar to that of the previous chapter, as a subset of three intervention-GBTs, three comparable-GBTs, and one expert teacher. The data collected were comprised of video-recorded lessons in the topic of choice, as well as sets of pre- (post-) lesson interviews. A newly developed and validated classroom rubric for scoring TSPCK in action was used to score and grade the participants' enacted TSPCK in real classroom teaching. I conclude this chapter by summarising the findings.

8.0 Introduction

The main purpose of this chapter was to explore the added advantage on the nature of the quality of enacted TSPCK in real classroom teaching of GBTs exposed to an explicit TSPCK intervention during their pre-service teacher training programmes. The chapter is a sequel and a complementary analysis to the findings of the added advantage in the quality of planned TSPCK presented in the previous chapter. Planned TSPCK refers to TSPCK seen in the context of planning to teach, while enacted TSPCK refers to TSPCK seen in classroom teaching. According to Shulman (1986), the pedagogical reasoning process for teachers extends beyond the planning stage to include the actual act of teaching. It is also argued that PCK,

which I extrapolate to TSPCK, is not only limited to what teachers know, but is also embedded in "what a teacher does, and the reasons for the types of actions they take in relation to teaching a specific topic" (Rohaan et al., 2009, p. 158). This posit suggests that the process of capturing and portraying TSPCK is a challenging endeavour and not sufficient when expressed only from one particular context of planning or enactment (Aydeniz & Kirbulut, 2014). The implication from the above understanding is that while planned TSPCK can help science teachers to design lessons that reflect best practice, enacted TSPCK, which refers to the type of TSPCK that can be observed during the teaching of a specific topic, manifests in a unique way during teaching.

In this chapter, the nature of the quality of enacted TSPCK was measured by assessing the GBTs' real classroom teaching in topics of their own choice. The reason for assessing lessons in topics of the teachers' own choice was informed by the fact that the research question asked required an understanding of the nature of the quality of enacted classroom teaching not necessarily in the topic of intervention.

This referred to the description of the typical nature of TSPCK in their current teaching. Following deliberations on this issue, I was convinced that the highest level of the quality of TSPCK could be observed when the GBTs were teaching a topic of their choice. This was a topic in which the respective participants appeared to possess sufficient content knowledge mastery and confidence, and a likely chance to display their best quality in teaching. Furthermore, several research studies contend that content knowledge is a pre-cursor to PCK (e.g. Halim & Meerah, 2002; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008) and TSPCK (Mavhunga, 2014). Therefore, seeing the GBTs in a topic they like to teach had a better chance to demonstrate their enacted TSPCK. According to Abell (2008), there is a need to investigate teachers' PCK in relation to specific topics, because PCK is typically considered to be topic-specific.

As alluded to in Chapter 3, teachers' classroom practice provided the main platform for witnessing and capturing enacted TSPCK. The analysis was rested on the evaluation of the quality of TSPCK episodes identified in two consecutive video recorded lessons. The lessons each lasted 45 minutes, making a total of 90

minutes. These were lessons from the same subset of GBTs and one expert teacher described in the previous chapter, Chapter 7. All the participants taught Grade 11 classes, in schools considered comparable (see Chapter 3). The three comparable GBTs did not experience the TSPCK intervention programme, and were thus used as a control to shield off other intervening humanity and contextual factors and nuances. The design helped to single out within reason the only factor under investigation, which was the advantage derived from an early exposure to explicit TSPCK development on the GBTs enacted classroom teaching. Similarly, the expert teacher was used for purposes of developing insights on the likely quality of TSPCK in the current teacher expertise. The seven participants observed during their real classroom teaching therefore formed seven separate mini-cases.

The data analysed at this stage reflected enacted TSPCK and was comprised of data captured from: (i) planning for lessons, collected from pre-lesson interviews; (ii) video recorded lesson observations of actual classroom teaching; and (iii) stimulated video recall post lesson interviews on reflections on the enacted lessons. All these teacher tasks are considered to be within the realm of enacted PCK, in the Refined Model of PCK (Carlson & Daehler, 2018). Researcher's think notes captured from salient features observed during the lesson sessions were also used as data supporting the patterns emerging from the observed lessons.

8.1 Analysis

To measure the quality of enacted TSPCK classroom teaching, the observed video recorded lessons captured from each GBT and the expert teacher were first transcribed verbatim into a textual format. The analyses and coding process involved independent watching of the recorded video lessons vis-à-vis the textual transcripts, and looking for evidence of moments that demonstrate presence of TSPCK episodes by a team of three independent raters, including myself as the fourth rater. The analysis of the identified TSPCK episodes followed, similar to Park and Chen (2012), a process of qualitative in-depth analysis of explicit TSPCK. The process was followed by matching the identified TSPCK episodes displayed in the

video recorded lessons into pre-determined categories of quality in a newly-developed and validated TSPCK classroom rubric for scoring TSPCK in action (see Chapter 4). The new rubric, which was specifically developed for this study, is comprised of three categories of quality that captures and displays episodes of TSPCK and the level of their complexity. It is notable that the rubric had been used in a separate study by a different researcher on enacted stoichiometry (Malcom, 2018) before this analysis. The rubric enables the capturing and portraying of the different quality TSPCK episodes demonstrated in a lesson and the subsequent display of these in a pictorial analytical tool that I have called TSPCK teaching profile (explained with examples below). The generated TSPCK teaching profiles allow comparisons across the teachers' lessons in terms of total quantity of TSPCK episodes present, the nature of their proportional quality distribution across the quality categories in the TSPCK rubric used, and the sequence in which they emerged in a lesson.

8.1.1 In-depth analysis for TSPCK episodes

In-depth analysis for TSPCK episodes, similar to that of Park and Chen (2012), started by identifying TSPCK episodes in the video recorded lesson. A TSPCK episode was described to indicate a specific teaching segment that displays the interactive use of two or more components of TSPCK. Components can be observed to work together to support an explanation of a single or pair of related concepts. The next step involved analysis of the identified TSPCK components by identifying the types of TSPCK components present and how they related to each other. The nature of the teacher task segment from which the presence of the component interactions emerges was also determined (Mavhunga, 2018). The result of the analysis was visually presented as a TSPCK map. A TSCK map was constructed by using solid circular lines around each TSPCK component that was clearly distinguishable and found to be interacting in a TSPCK episode. Where the components were observed to interweave with each other, they were presented as overlapping circles; while in cases where components were found to have a distinguishable linear sequence, they were represented with a solid linear arrow line

pointing out the sequence in which the components had emerged in the TSPCK maps. TSPCK maps have been used in the enacted lessons of teachers Menjo, Dido and the expert teacher in section 8.2.1, as a sample of part of the analysis done. The analysed TSPCK episode would then be ready for scoring using the TSPCK rubric described in Chapter 4.

As mentioned above, the generated rubric scores were peer validated by a team of three independent raters, in addition to myself. An inter-rater reliability agreement was calculated at a Cohen Kappa value of 0.822, which was considered substantial. The kappa value was calculated as described in Chapter 3, and first applied in Chapter 4, for validation of the TSPCK classroom rubric and in Chapter 5 and 6 for validation of retention of acquired TSPCK. Any differing scores observed between individual independent rater's scores and my scores were debated and resolved by consensus. Inductive analyses of the pre- (post-) lesson-interviews held were also analysed as content supporting analysis of the identified TSPCK episodes. Post-lesson interviews were conducted as video-stimulated recall sessions, where the video-recorded classroom lessons were re-played in front of the teacher. This analysis was done first with all the six GBTs to establish added advantage, and their analysis referred to that of the expect teacher for likely insight of current typical teacher expertise. Table 8.1 below shows a summary of the spread of the data collected for enacted TSPCK in the topics of participants' choice.

Table 8.1: Enacted TSPCK in topics of participants' choice

Data collected in actual teaching practice in 2016		
GBT Cohort year of Graduation	**Intervention GBTs video Lessons**	**Comparable GBTs Lessons videos**
2014	✓(1x teacher Menjo) Electromagnetism in a ▪ Straight wire and Circular wire ▪ Faradays law	✓(1x teacher Dido) ▪ Introduction to organic Chemistry ▪ Primary, secondary & tertiary alcohols
2014	✓(1x teacher Jaba) ▪ Endothermic and Exothermic reactions ▪ Acids and Bases-Ionization and precipitation reactions	✓(1x teacher Mpho) ▪ The three states of matter ▪ States of matter (Diffusion)
2014	✓(1x teacher Tzepo) ▪ Mechanical energy ▪ Solubility of salts	✓(1x teacher Thembu) ▪ Chemical bonding ▪ Doppler Effect
Expert teacher year of graduation 2006	✓ (1x teacher Chetu) • Matter & Materials-Atomic combinations	

In the discussion below, I present findings of the GBTs enacted classroom teaching that helped me respond to research Question 3.

8.2 Findings

The findings of the observed video-recorded lessons of the sampled six GBTs, expert teacher's enacted classroom teaching were analysed to measure the quality of enacted TSPCK. As alluded to in the literature review Chapter 3, the quality of PCK in a topic is demonstrated by the extent of the synergistic interactions of the specific components of PCK (Aydin, Demirdogen, Akin, et al., 2015; Park & Chen 2012), and by extension TSPCK. According to Goodrick (2014), the use of typologies, tables, diagrammes or matrices can capture and summarise information collected and facilitate examination of similarities and differences across the cases studied.

(i) Identification of TSPCK episodes in lessons

The different TSPCK episodes identified in the classroom teaching of the six sampled GBTs, and that of the expert teacher were presented by indicating the TSPCK sequence from which the component interactions emerge for ease of presenting the TSPCK Maps. As discussed in Chapter 4, the components that emerged in the identified TSPCK episodes following each other in a linear sequence are denoted with a (-), while those emerging as interwoven component interactions are represented by a forward slash (/). For purposes of clarity, the components of TSPCK were abbreviated in this analysis as follows: learner prior knowledge = LP; curricular saliency = CS; what is difficult to understand = WD; representations = RP; and conceptual teaching strategies = CTS.

Table 8.2 below shows the overall pattern of the types of TSPCK episodes seen in the classroom teaching of the six sampled GBTs and that of the expert teacher.

Table 8.2: Identified TSPCK episodes in classroom teaching per participant

Teacher	Type of School	Simple TSPCK Episodes	Proficient TSPCK Episodes	Sophisticated TSPCK Episodes	Total
Average lesson period 90 minutes					
Intervention GBTs					
Menjo	Township	CS/RP (2) RP-CS (2)	RP/LP/CS LP/WD-CS RP/WD-CS	RP/LP/WD/CS-RP/CS	**8**
Jaba	Former Model "C"	CS/RP RP/CS CS-LP RP-LP	RP/CTS/CS CS-RP/WD	CS/RP-WD/LP/CS	**7**
Tzepo	Township	CS/LP CS/RP(2) RP/LP RP/WD	LP-RP/CS		**6**
Comparable GBTs					
Dido	Adult Education Centre	LP-RP LP/RP CS/RP	RP/CTS/CS LP/RP-CS LP-RP/CS		**6**
Mpho	Township	RP-CS (2) RP/WD			**3**
Thembu	Township	RP-CS(2)			**2**
Expert teacher					
Chetu	Township	RP/CS CS/RP/CS	LP-CS/RP/LP/CS RP/CTS/CS CS/RP/CS/LP CS/RP-CS/WD	RP/CTS/WD/CS	**7**

Note: The number of repeating TSPCK episodes in a lesson are shown in brackets

The first column in Table 8.2 indicates the GBTs pseudonyms. The second column shows the type of schools the GBTs and the expert teacher were teaching at the time of the data collection exercise. The successive columns show the GBTs TSPCK episodes displayed across the three categories of simple, proficient and sophisticated quality TSPCK in the newly developed and validated classroom rubric for scoring TSPCK in action. As alluded to earlier, each individual GBT was considered to be a separate case. This is, unlike in Chapters 6 and 7, where comparisons were made across pairs. Part of the reason for considering the participants as separate cases in this analysis, was due to the fact that each of them taught a topic of his own choice. For the purposes of making the patterns clearer,

the information in Table 8.2 above was re-represented in Figure 8.1 below, to show the distribution of the identified TSPCK episodes within each enacted lesson.

(ii) Distribution of the identified TSPCK episodes within each lesson

Figure 8.1 below presents a closer in-depth analysis where the scored TSPCK episodes identified in the individual video lessons are plotted against the time in which they appeared across the 90 minutes teaching period. The plots portray a TSPCK teaching profile for each GBT.

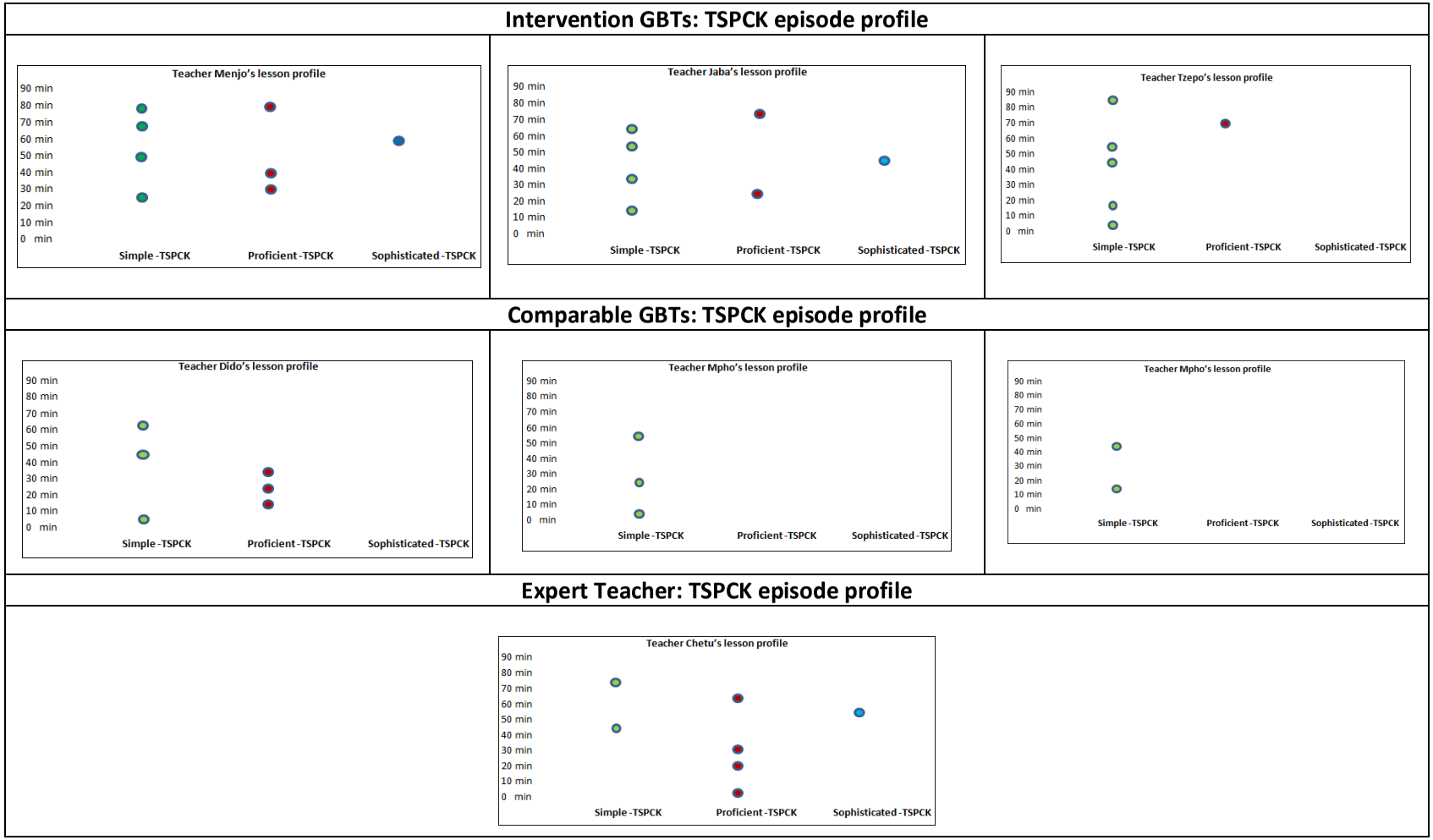


Figure 8.1: Distribution of the identified TSPCK episodes within each lesson

Table 8.2 and Figure 8.1 present several patterns about the nature of TSPCK episodes found in the video-recorded lessons of intervention vs. the comparable GBTs.

Observations with respect to the nature of quality of TSPCK episodes displayed revealed that firstly, all the GBTs displayed the presence of simple TSPCK episodes in their teaching. These episodes contain only two components of TSPCK that are interacting in a complementary manner. They are classified in the lowest quality category of TSPCK as per the enactment TSPCK rubric used in the study. It was also observed that intervention GBTs displayed a slightly higher quantity of these simple TSPCK episodes than the comparable GBTs. Secondly, in contrast to comparable GBTs, where only one teacher (Dido) displayed proficient TSPCK episodes, all intervention GBTs in addition to simple TSPCK episodes further displayed evidence of episodes of TSPCK that could be categorised in the proficient quality category, a higher order quality of TSPCK. Furthermore, two intervention GBTs teachers (Menjo and Jaba) displayed evidence of one sophisticated TSPCK episode each in their teaching. It is further noted that for the intervention GBTs, the distribution of the identified TSPCK episodes spreads were across the entire lesson period, as compared to comparable GBTs, where the emergence of TSPCK episodes seem to end at about halfway the lesson or just slightly more than halfway (see Dido).

When the TSPCK episode profiles of lessons by all the GBTs are compared to that of the expert teacher, it was noted that the observed higher quality TSPCK seen in the classroom teaching of the intervention GBTs was, however, a little less than that of the expert teacher. This was evident from the higher quantity (a total of five) of TSPCK episodes that denoted a higher order quality TSPCK in the category levels of proficient and sophisticated TSPCK, across the length of the expert teacher's enacted classroom teaching. In the next section, I present a further detailed in-depth qualitative analysis where in addition to the identification of TSPCK episodes, and the sequence in which they emerged, I describe the nature of the teacher tasks from which the episodes emerged. As Mavhunga (2018) pointed out, the identification of such tasks informs science educators on the tasks that promote the emergence of

TSPCK, which is evident of the desired pedagogical transformation of content knowledge.

8.2.1. Detailed lesson analysis per participant - teaching profiles

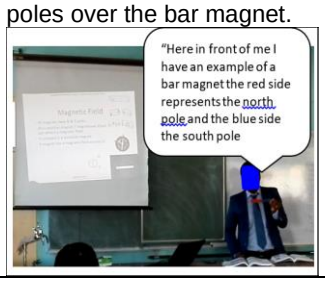
The analysis was done per participant, independently, as a standalone mini-case.
As the analyses of the lessons are very long, I present herein the step-by-step analysis of only the intervention GBT and the comparable GBT who registered most sophisticated TSPCK episodes in their teaching. I also included that of the expert teacher. The reason for sampling GBTs from each cohort with most sophisticated TSPCK episodes is that they reveal a full range of different kinds as opposed to showing those with low quality episodes. However, the same analysis process was conducted for the rest of the participants, and their analysed lessons are included as Appendices, I, J, K and L. Each of the GBTs and the expert teacher's lesson analysis is summarised through a pictorial presentation reflecting the individual's detailed TSPCK teaching profile.
The detailed analysis of teacher Menjo's (intervention GBT) enacted lesson is first provided below.

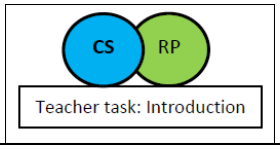
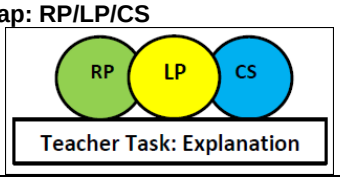
(i) Overview of Teacher Menjo's enacted lesson

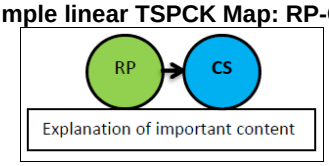
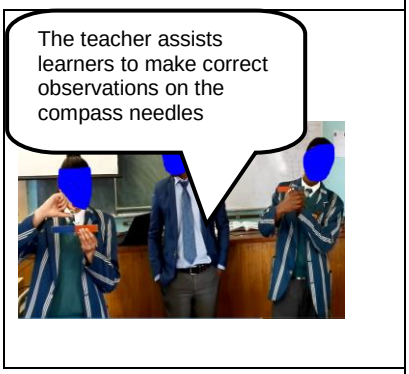
Teacher Menjo's lessons were both captured in a physics topic, which is a different subject learning area from the one in which the teacher was exposed to during the intervention programme (Chemistry). The teacher's first lesson was an introduction to electromagnetism, focusing on how to draw the direction of the magnetic field and the direction of the current for a straight wire. The second lesson was a sequel to the first lesson, focusing on the magnetic field around a circular wire and Faradays Law of Electromagnetic Induction.

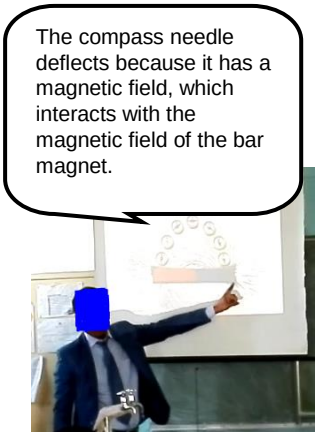
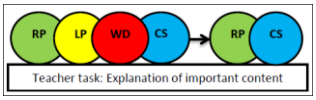
In his response during the pre-lesson interview, teacher Menjo indicated that for the first lesson he intended his learners to "*…know that a straight wire, with a current*

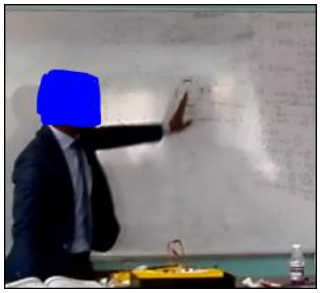
flowing through it creates a magnetic field". The teacher explained that he expected his learners to be able to draw the direction of the current and magnetic fields using the right-hand rule. These intentions were seen to relate to a big idea on the relationship between magnetism and electricity. The teacher further explained that learning about the relationship between electricity and magnetism would enable his learners to be able to relate and apply the theoretical explanations of Faradays Laws to their daily life appliances. He noted that understanding such a relationship would help the learners realise the importance of the topic. He then indicated that he would use a combination of class demonstrations, slide shows, and question and answer methods as the strategies to achieve his intended learning purposes. The details of teacher's enacted lesson are presented below.

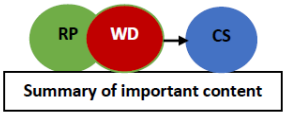
Time	Class action in sequence	Comments	Qualitative in-depth analysis
0-5min	**Teacher:** "*who would like to tell me what they understand by the term electromagnetism, what comes to your mind when you hear the term electromagnetism?*	The teacher repeats the question several times, urging learners to raise their hands and respond.	Acknowledging that teacher sought for learner prior knowledge, however this by its own is not a TSPCK episode.
5-10	**Learner:** *"electric current passing through the wire and creating a magnetic field"*	The teacher commended the learner and repeated what the learner had said to the whole class.	Here we see teacher making emphasis of most important understanding in the topic which is an element of curricular saliency, but the statement by itself is not a TSPCK episode.
10-15	**Teacher**: *"that is a good point; he is saying that he thinks of an electric current passing through the wire and in turn creates a magnetic field-very good."*	He went on to point out that "the term electro-magnetism basically deals with the relationship between electricity and magnetism", noting that this was going to be the primary focus for the day's lesson, before displaying a visual slide showing the same statement as written text.	The ground is laid here by projecting the same important statement, but not a TSPCK episode by itself.
15-20	**Teacher:** *"if you look at this slide, there are several points we need to look at to help us understand the current topic better."*	The teacher read the first point on the slide.	There is no TSPCK episode, as the teacher is still explaining the important content of the topic
20-25	**Teacher:** *The first point says that "all magnets have a north pole and a south pole* (CS)…." **Teacher**: *"here in front of me I have an example of a bar magnet the red side represents the North Pole and the blue side represents the south pole".*	He picks up a bar magnet and holding it in his hands, explains the opposite poles, by indicating the poles over the bar magnet. 	The use of 'big idea' statements, i.e. "All magnets have a north pole and a south pole", indicates understanding of prior concepts needed before teaching the topic, an aspect of (**CS**). The teacher then helps learners to recall this understanding by simultaneously, physically demonstrating using a magnetic bar while describing the concept. The use of a visible magnetic bar is an element of representations at the macroscopic

Time	Class action in sequence	Comments	Qualitative in-depth analysis
			level (**RP**). **Simple interwoven TSPCK Map: CS/RP** 
25-30	**Teacher**: *"now we also know that if I were to place any ferromagnetic material close to this magnet, it would be attracted to it because the ferromagnetic material will be magnetized and so get attracted to this bar magnet. We also know that it is the magnetic force that exists around the bar magnet that causes this attraction with the ferromagnetic material."*	The teacher reminds learners that certain materials that are ferromagnetic will be attracted to the magnetic bar by a magnetic force. 	The teacher builds on the previous statement repeating the explanation of the aspects represented by the magnetic bar (**RP**). He recalls learner prior knowledge about ferromagnetic material being magnetised (**LP**). He then makes a connection to the magnetic force that causes attraction of ferromagnetic materials (**CS**). Here there are three TSPCK components interacting in a complementary manner – making this a three-component TSPCK episode. **Proficient interwoven TSPCK Map: RP/LP/CS** 
30-35   <

Time	Class action in sequence	Comments	Qualitative in-depth analysis
	ferromagnetic material to be so special."		
40-45 45-50	**Teacher:** *"I want you to draw a bar magnet in your books and indicate the direction of the magnetic field around a bar magnet"* (RP). **Teacher:** *Okay what important aspect of magnetic field lines around a bar magnet do you remember?* **Learners:** *"They don't cross."* **Teacher: "***Very well they never cross and they do not touch. In which direction do they move?"* (CS). **Learner:** From north to south. **Teacher:** *"So, roughly, each of you should be having something like this..."*	The teacher instructs learners to draw a bar magnet in their exercise books and walks around the class observing and assisting individual learners. Meanwhile, he poses a question. He commends the learners' and repeats their response, for emphasis (CS). He then depicts an illustration of a bar magnet indicating the North Pole and South Pole and the direction of the magnet field lines on the chalkboard (RP). 	In this segment, the use of an illustration of a bar magnet by learners, indicating the direction of the magnetic field lines is evidence of an aspect of representations (RP). The teacher then poses a question about an important aspect to be added into the representation about a concept that he explained earlier (the features of the magnetic field lines). This is an element of curricular saliency (CS) even though posed as question, as it places explicit emphasis on one of the most important concepts and it links to a discussion made in the lesson few minutes prior. The teacher closes the activity with a diagram that he expected from learners re-drawn on the chalk board with the direction of the magnetic field lines shown and repeated their character (CS). Here we see the interaction of the RP and CS TSPCK components repeated. **Simple linear TSPCK Map: RP-CS** 
50-55 55-60 60-65	**Teacher:** "*I want you to rotate the compass in the same position and observe what happens to the compass needle* (RP)… *What is happening to the compass needle?"* **Learners:** *"The needle remains in the same position, as the compass is rotated."* **Teacher:** *"Remember around the bar magnet, there is the magnetic field. When they placed the compass in the magnetic field, it deflects, it's moving."* He posed a question. ***Teacher:*** *"Who can tell us what causes it to move? What is so special about the compass that causes it to move?"* (WD). **Learners:** (silence) **Teacher***: "The compass needle*	The teacher called on two learners to come forward and perform a simple demonstration. Both learners were given a bar magnet and a magnetic compass and asked to place the compass close to the bar magnet and explain what was happening. 	In this teaching segment, the teacher calls on two learners to come forward and carry out a simple demonstration (RP). He then repeatedly probes for what was causing the compass needles to deflect (LP). Informed by the learners' non-response, the teacher states that 'The needle is ferromagnetic, and goes on to emphasise that, if it was just a needle of plastic, it wouldn't deflect. The explicit emphasis of the compass needle being ferromagnetic and not just a needle of plastic is evidence of understanding the need to highlight the main gate keeping concept that causes difficulty in learning (WD). He explains this observation from the interference/interaction of the magnetic fields (CS), which come about as a consequence of the devices being ferromagnetic. Here the teacher makes the connections between ferromagnetism and the behaviour of the magnetic field

Time	Class action in sequence	Comments	Qualitative in-depth analysis
	is ferromagnetic. *If it was just a needle of plastic, it wouldn't deflect. So, the reason why the compass needle deflects is because it has a magnetic field; it's interacting with the magnetic field of the bar magnet."* He then goes on to emphasise the following: **Teacher: "***An important property for the needle to deflect is that it is ferromagnetic. The needle's position lies at a tangent to the magnetic field lines of the power magnet. That is very important.*" He then moved on to explain a slightly different concept.	He then explained what was causing the compass needles to deflect over a visual slide depiction, displaying the compass and a bar magnet. 	lines. Talking over a representation (RP) he further points to another new important point about the position of the needle of the compass being at a tangent to the magnetic field (CS). **Sophisticated linear/interwoven TSPCK Map: RP/LP/WD/CS-RP/CS** 
65-70	**Teacher:** *"I now want to talk about a magnetic field that is produced or created around a straight electricity conducting wire. I am going to demonstrate"* (RP). **Teacher:** "*You notice that, if I take a magnetic compass and bring it close to the straight line conducting electricity, it deflects*. *The demonstration proves that electricity and magnetism have a relationship*." He then reads from the visual slide. **Teacher:** "*An electric current creates a magnetic field and the change in the magnetic field creates a flow of current* (CS). *This relationship between electricity and magnetism has been studied extensively resulting in the invention of many devices useful to humans like, cellular phones, radios and televisions."*	The teacher read the text on the next slide, ushering in a slightly different idea about the interaction between charges, current, the electric and magnetic fields. He positioned four magnets around a straight wire, connected the battery and closed off the circuit. He called on one learner to come forward and observe the movements of the compasses and inform the rest of the class the different directions the four campuses were pointing. 	In this teaching segment, the teacher introduces a slightly new aspect into the discussion by performing a demonstration to show direction of a magnetic field that is produced or created around a straight electricity carrying wire (RP). He then builds on the understanding from the demonstration to explain the relationship between the two core concepts of electricity and magnetism (CS). **Simple linear TSPCK Map: RP-CS.** 

Time	Class action in sequence	Comments	Qualitative in-depth analysis
70-75	**Teacher:** "*you should note that in this closed circuit, my positive is on the right and my negative on the left and it has been shown to us that as long as there is current passing, the different points around the wire the compass seem to be pointing in different directions. Why is this so?"* **Learner:** *"Because of the current."* **Teacher:** *"What is the current doing... what is so special about this current that it is causing these compasses to be deflected exactly the same way as the magnet? When electricity is passed through a ferromagnetic material and certainly there is deflection what is deflecting the compasses?"* **Teacher:** *"When the current was removed, or the circuit opened, the compasses pointed in the original direction, why is this so?"* **Learner:** (A learner attempts to answer but failed to get the correct explanation) **Teacher:** "*The reason why the compasses deflect when the circuit is connected is because of the magnetic field that was created by the straight conductor, at a right angle to the direction of current*" (WD).	The teacher probes for the reasons why the compasses were pointing in different directions. However, on realising learners were struggling to explain this observation, he moved on to clarify the concept by illustrating the direction of current and compass around the circuit on the chalk board. 	In this teaching segment, the teacher first poses several probing questions regarding why the compasses were pointing in different directions, so long as current were flowing. He however realises the difficulty learners have in explaining this concept (WD). Here we see the component of WD used as a standalone component and therefore, there is no episode observed.
75-80	**Teacher;** "*If you want to know the direction of the magnetic field, you use the right-hand rule for a straight wire. The rule represents an easy way that physicists use to remember the directions that things are supposed to point, based on underlying physics, which relates magnetic fields and the forces that they exert on moving charges"* (CS). *"In using the rule, the right-hand thump is used to represent the direction of the current. Everybody thumps up…* *Yes and the fingers represent the direction of the magnetic field. This is the right-hand thump rule"* (RP).	He then summarised this part of the lesson by demonstrating how the right-hand thump rule works. 	The teacher summarises how to represent the direction of the current and the magnetic field, one of the key concepts in the topic (CS), by demonstrating the analogy of the right-hand thump rule (RP). Analogies form part of representations in teaching Science. **Simple interwoven** **TSPCK Map: CS/RP** 
80-85	**Teacher:** "*What happens when an electric current is passed through a circular wire?"*	The teacher moved to a slightly different aspect by first informing the class that the next part of the lesson	In this segment, there is no TSPCK episode as the teacher is merely checking what learners know.

Time	Class action in sequence	Comments	Qualitative in-depth analysis
	Teacher: *"Can you create electricity using magnetism or a magnetic field around you? …This is the question that Faraday basically asked. In his investigation, Faraday took a solenoid and a galvanometer. Remember, (shows learners a coil) a solenoid is basically a coil of wire around this cylindrical plastic. Faraday had a galvanometer, what is a galvanometer known to do?*" **Learners:** measure *current*	would be on investigating what happens when a magnet is moved inside a solenoid and Faraday's Law. He then posed a question.	
	Teacher; *"**Yeah, you know a galvanometer is very special in a sense that it can even measure very small amounts of current. So, Faraday, made a circuit-like this (shows the circuit). He then* took *magnets and inserted them into the solenoid.*" (Teacher conducts the demonstration by inserting the bar magnet continuously in and out of the solenoid) **Teacher;** "*Did you see what happened? There's current flowing but there is no battery"* (RP). *We know from our knowledge of electricity in Grade 10, we know that there are two things that are required in a circuit for a current to flow: there is the power source (the battery) and the circuit must be closed. Alright… Does this mean our magnets are batteries?" (*WD). **Learners**: "No." **Teacher**: *"It is because the magnet induces the current to flow. But not that the magnet has current flowing through it* (WD). *This was basically Faraday's law of electromagnetic induction. That a magnet can induce a current when placed in a solenoid"* (CS).	He displayed a circuit and moved on to perform a simple demonstration, on Faraday's law of electromagnetic induction. He asked the learners to just sit and observe what happens, as he carried on with the demonstration (RP).  Teacher summarises the lesson by repeating the same statement, emphasising that it is the magnet that induces the current to flow, and not the current flowing through the magnet.	In this segment, the teacher introduces a new concept, passing an electric current through a circular wire by performing a demonstration (RP), to show that current can flow without being connected to a battery, a key gate keeping concept deemed difficult to understand (WD). He then explained that a magnet can induce a current to flow, but not that the magnet has current flowing through it. The explicit emphasis of the meaning of a magnet to induce a current to flow and not the current flowing through it indicates teacher awareness of potential learner difficulty in understanding Faraday's law of induction. He finally re-emphasised that this constitutes the substance of Faraday's Law. The act of emphasising what is core in an explanation is a crucial aspect of curricular saliency (CS). **Proficient linear/interwoven TSPCK Map: RP/WD-CS** 

To summarise the sequence in which the TSPCK episodes emerged, the pictorial map shown in Figure 8.2 below was developed to depict the GBT's teaching profile.

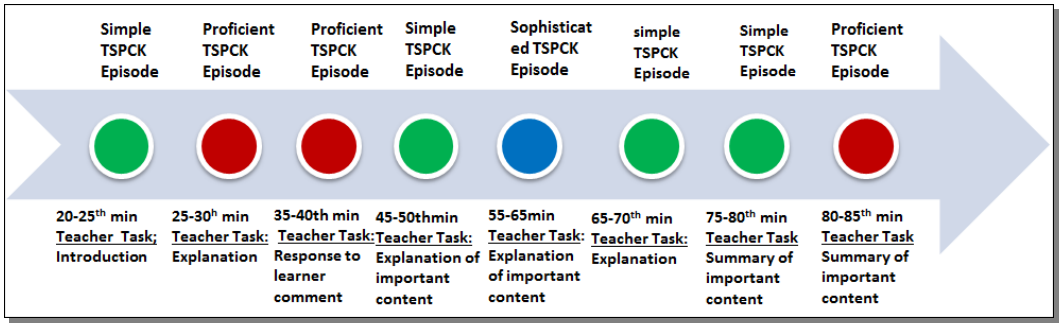


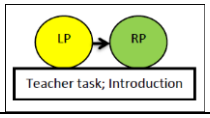
Figure 8.2: Teacher Menjo's TSPCK teaching profile

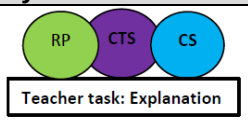
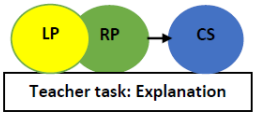
The next example is a qualitative description lifted from the teacher Dido, who is the comparable GBT who had most TSPCK episodes in his lesson.

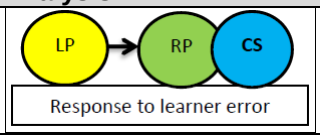
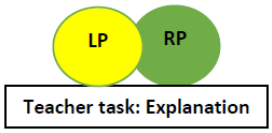
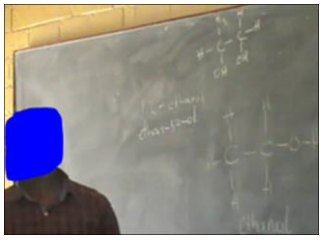
(ii) Overview of teacher Dido's enacted lesson – (comparable GBT)

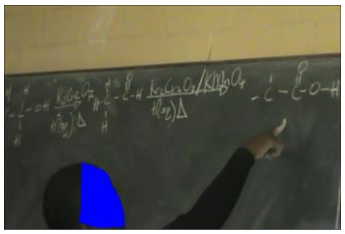
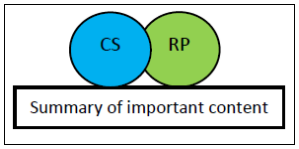
The teacher Dido's first lesson was introduction to Organic Chemistry, focusing on naming of organic compounds. The second lesson was a sequel to the first lesson, focusing on primary, secondary and tertiary alcohols.

In response to the pre-lesson interview held, teacher Dido indicated that he intended his learners to know how organic compounds react. The teacher pointed out that it was important for students to learn about this topic, because they should know how organic compounds react. He explained that he would engage learners in question and answer sessions, as well as formative assessment exercises throughout the lesson as his teaching strategy. In response to the difficulties about students' thinking, that would influence his teaching, the teacher commended that some learners believe that Organic Chemistry is a very difficult topic to understand and that was the reason why he would involve them in the question and answer sessions throughout the lesson.

Time	Class Action in sequence	Comments	Analysis
1-5	**Teacher:** *"Who can define for me the meaning of a hydrocarbon?"* **Learners:** (responded in a chorus to the first question). **Teacher "***who can give me an example of a Hydrocarbon, or define for me the term un-saturated hydrocarbon?"* **Learner**: Compound containing carbon and hydrogen.	The teacher began by posing a simple question. He repeated the same question, re-phrasing it, which the learners now understood. The teacher commended the learner and wrote the definition of hydrocarbon on the chalk board.	In this teacher segment, we see no TSPCK episode, as the teacher is simply probing for learners understanding with questions and providing standard text-book definition.
5-10	The learners correctly depicted illustrations of the first two members of the alkane homologous series on the chalkboard (RP). **Teacher:** *"Who can give me the names of the first third and four members of the alkane homologous series?"* (LP). **Learners:** (respond in chorus) **Teacher:** *"I want everybody to participate, please raise up your hands to respond."*	He then called on two learners to come forward and draw the structures of the first two members of the alkane homologous series and give their corresponding names on the chalkboard. 	In this teacher task segment, the teacher probes for learners' understanding about alkanes, an aspect of the component of learner prior knowledge (LP). He then helps the learners to recall what they previously learned in the normal schools, by involving them in illustrating examples of members of the alkane homologous series on the chalkboard (RP). **Simple linear TSPCK Map: LP-RP** 
10-20	**Teacher:** "*The straight-chain alkane- homologous series begins with methane. In that series, successive members differ in mass by an extra methyl unit. This is the reason why the first four alkanes are gases at room temperature. The solid alkanes do not appear until we have about 17 carbons in the chain."* (CS)	He then explained the meaning of straight chain alkanes and developed a table matrix on the chalk board, on which he wrote the names of the first four members of the alkane homologous. He then, together with the learners, filled up the table (RP) by explaining the relationship between increasing number of carbon atoms in the chain and vs. increasing molecular masses of the molecules, over the developed table.	In this teacher task, the teacher developes a table matrix, as a representation (**RP**), over which he applies an aspect of the variation theory to fill up the table, by use of patterns of variation, to help learners discern similarities and differences (**CTS**) of the increasing members of the alkane homologous series (**CS**). The simultaneous comparison of similarities and differences indicates presence of the component of (CTS). **Proficient interwoven TSPCK Map: RP/CTS/CS**

Time	Class Action in sequence	Comments	Analysis
			
20-30	**Teacher:** "*what do you understand by the terms alkene?"* (learners respond in chorus) **Learner:** (Depicts the structure of But-2-ene, naming it) (RP).  **Teacher:** *"Remember, alkenes are referred to as unsaturated hydrocarbons because of the double bonds found between their carbon atoms"* (CS).	He moved to the sub-topic of alkenes. He replaced the alkanes in the table with ethene, propene, and butane. He then wrote the general formulae for alkenes and alkynes on the chalkboard and following the same approach as for alkanes called a different learner to come forward and draw the structure of butene. The teacher pointed out the main difference between alkenes and alkanes, as the double bonds found in alkenes, before moving to examples of cyclic alkenes.	In this extract, the teacher helps learners to recall structures of alkenes, a different class of hydrocarbons, (LP), by involving them in depicting illustrations (RP) of exemplars of this class of hydrocarbons on the chalkboard. He then points out the difference between alkenes and alkanes as resulting from the double bonds found in alkenes (CS). **Proficient interwoven/linear TSPCK Map: LP/RP-CS** 
30-40	**Teacher:** "*who can draw the structure of cyclo-hexane and write its molecular formula?"* (LP). **Learner:** (attempted to draw the structure of cyclo–hexane, but used incorrect bonds). **Teacher:** *"Make sure when numbering the carbon atoms in the chain, you must always start with the carbon from either side with the double bond nearest the end"* (CS).	The teacher realised the learners were facing a challenge in drawing the structure of cyclo-hexane and quickly moved in to help him draw the correct structure pointing to the importance of correctly numbering and representing the carbon chain  The teacher's constant engagement of the teacher with learners, drawing on their potential misconceptions as a form of formative assessment on what had just been taught, seemed to strongly to be an approach to teaching rather	In this segment, the teacher acknowledges learner error (LP) and immediately brings in a response. The use of illustrations to explain how the structure of cyclo-hexane is drawn indicates drawing on the component of (RP). He then emphasises the importance of numbering the carbon atoms from either side of the carbon chain with the double bond nearest the end. Emphasis of important content in a topic is an element of (CS). **Proficient linear/interwoven TSPCK Map: LP-RP/CS**

Time	Class Action in sequence	Comments	Analysis
		than the task, which credited him with higher quality TSPCK episodes	
40-50	**Teacher:** *"who can represent for us the first two members of the alkyne homologous series?"* **Learners:** (Two leaners voluntarily moved forward and correctly represented the structures of butyne and ethyne, respectively)	The teacher moved to the third category of hydrocarbons, the alkynes. Using the same approach, he posed the first question. He commended the learners and wrote the names of first four members of the alkyne homologous series in the original table matrix, but did not explain any aspect of the compounds.	In this teacher segment, we see the teacher help learners to recall structures of alkynes, another class of hydrocarbons, which shows an aspect of (LP). The use of illustrations to depict structures of alkynes is an element of (RP). **Simple LP/RP TSPCK Map** 
50-60	**Teacher:** "*who can give me an example of an alcohol or any carbonyl group that you came across in your Grade 11?*" **Learners** (Did not immediately respond. Teacher depicts the structure of ethan-1, 2 diol on the chalkboard). **Teacher:** "*I want one of you to come and write only the name of this compound on the chalkboard."* **Learner:** (wrote ethan-1-ol) The teacher then wrote: **Teacher: *"****The correct name is ethan-1, 2 –ol, not ethanol."*** The teacher however overlooked to include the IUPAC name, missing the –dio*l* prefix, thus provding learners with the wrong SMK.	The teacher introduced the concept of oxidation of primary alcohols by asking learners to name examples of alcohols or carbonyl compounds they had come across. With no response from the learners, the teacher referred to his prepared notes and depicted the structure of (ethan-1, 2 diol) on the chalkboard and asked one of the learners to come forward and write its name.  The teacher did not realise the wrong IUPAC name of ethan-1, 2 diol.	In this teacher segment, there is no TSPCK episode, as the teacher is still laying the ground on a new class of organic compounds. The wrong naming of ethan-1, 2 diol as ethan-1, 2 -ol, however, indicated inadequate preparation by the teacher.

Time	Class Action in sequence	Comments	Analysis
60-70	**Teacher:** *"Primary alcohols can be oxidised to either aldehydes or carboxylic acids, using strong oxidising agents. In the case of formation of carboxylic acids, the alcohol is first oxidised to an aldehyde, which is further oxidised to the corresponding organic acid*" (CS).	The teacher introduced the last part of the lesson, on oxidation of primary alcohols by explaining upfront what the sub-topic entails. He then used a series of equations to explain the steps followed during oxidation of alcohols to form the corresponding carboxylic acids, over heated acidified $KMnO_4$ catalyst. 	In this extract, the teacher introduces a new class of organic compounds, namely oxidation of primary alcohols; which signals the presence of the component of (CS). He then uses equations, an aspect of (RP) at symbolic level to explain the process followed during oxidation of primary alcohols. **Simple interwoven TSPCK Map: CS/RP** 
70-80	**Teacher:** "*I want you to use the remaining time to discuss oxidation of secondary alcohols in acidified solution of $K_2Cr_2O_7$ or $KMnO_4$ as a catalyst."*	He then gave out a class activity and walked around the class, attending to individual groups.	

The following pictorial map summarises the sequence in which the TSPCK episodes in teacher Dido's teaching profile emerged.

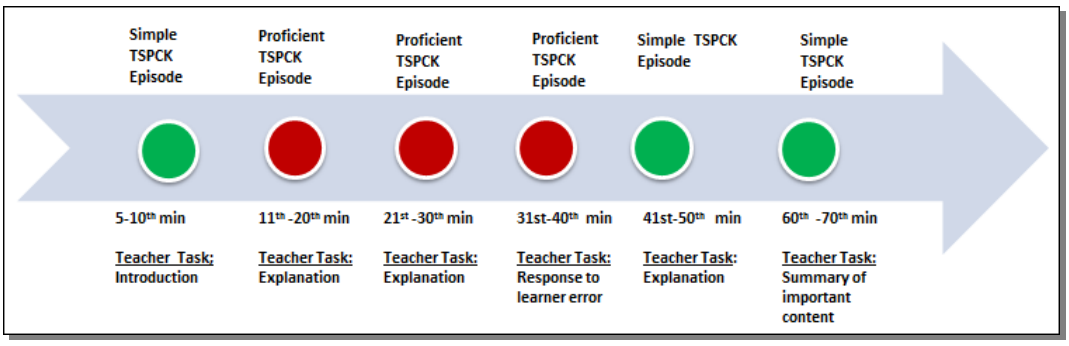


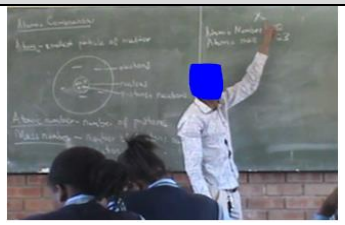
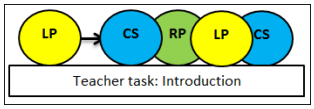
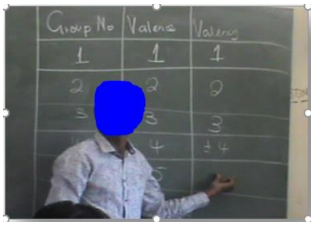
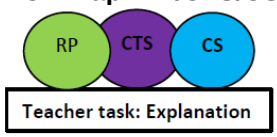
Figure 8.3: Teacher Dido's lesson profile showing TSPCK Episodes

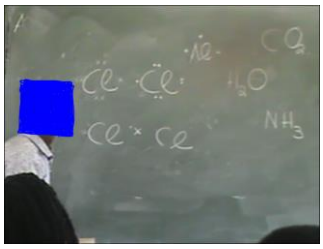
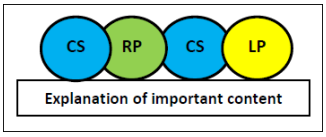
The third example is the analysis of the expert teacher's observed classroom teaching.

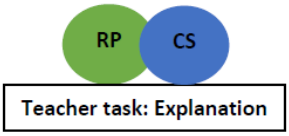
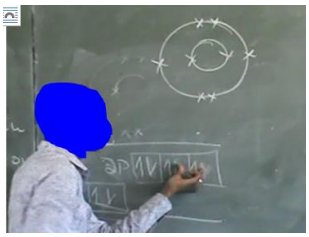
(i) Overview of teacher Chetu's lesson

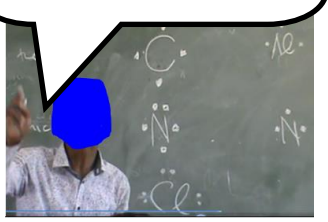
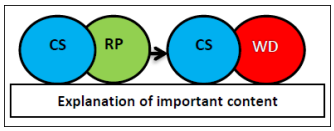
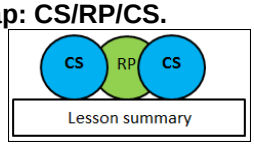
The expert teacher was observed teaching the topic of Matter and Materials. From the responses captured during the pre-lesson interview, the expert teacher indicated that, he planned to achieve only one lesson purpose, which was drawing Lewis diagrams. The teacher explained that this concept was important for learners because it would help them to know how compounds are formed. He then suggested use of the same strategy he uses for teaching sets in Mathematics to teach Lewis diagrams, noting that the concept is about sharing of electrons. He further explained that Lewis diagrams ideally show the bonding between atoms of a molecule and the lone pairs of electrons that may exist in molecules. The understanding of how to link Lewis dot structures to teaching sets in Mathematics demonstrates the teacher's ability to relate the content of a given topic with concepts taught in other subjects/disciplines, which demonstrates aspects of the component of curricular saliency. According to Shulman (1986), the teacher's ability to relate the content of a given course or lesson to topics or issues being discussed simultaneously in other classes embodies knowledge of lateral curriculum. The teacher then acknowledged the difficulties in learners' thinking that may influence his teaching, as learners blindly assigning electrons around atoms without clearly understanding the scientific meaning involved.

Time	Class Action in sequence	Comments	Analysis
5-10	**Teacher**; *"before we start this lesson, who can tell me what an atom is".* He gives learners time to respond before posing another question. **Teacher**: "*What is atomic number?"...* "*Look at the Hydrogen atom in the periodic table chart in your books*" (**LP**). **Learner:** (atomic number is the number of protons in an	The teacher began the lesson by posing two successive questions to the class. He commended the learner who responded and immediately depicted the structure of the Bohr atom on the chalkboard, over which he explained characteristics of protons, electrons and neutrons, the three sub-atomic particles found in atoms of elements.	In this teacher task segment, the expert teacher begins by probing for learners understanding about the topic (LP). He provides time for learners to respond before building on their responses to explain characteristics of the sub-atomic particles-protons, electrons and neutrons, an aspect of (CS). The explanation is done over an illustration of the Bohr diagramme, depicting all the three sub-

Time	Class Action in sequence	Comments	Analysis
	atom). **Teacher:** "*Very good*, *the atomic number of refers to number of protons, while mass number is the total mass of protons and neutrons"* (CS). *"The mass of an atom is not defined in terms of electrons... but the number of protons and neutrons* (LP). *Therefore, neutral atoms have the same number of protons and electrons, because protons have a single positive electrical charge, equal and opposite to that of the electron. The opposite charges therefore cancel out in neutral atoms. Is that clear? This is important to understand"* (CS).	 He then explained the difference between valence and valency electrons.	atomic particles, (RP) at the symbolic level. He emphasises the meaning of atomic mass, not to refer to the number of electrons but the number of protons and neutrons, which indicates understanding of common learner misconception about the topic, (LP). He finally explains neutrality of atoms, an element of (CS). **Proficient Linear/ Interwoven TSPCK Map: LP-CS/RP/LP/CS** 
15-20	**Teacher:** *"Valence electrons are the electrons in the outermost energy level or shell of an element, while valency electrons are the number of electrons that an atom gains or losses to attain the nearest noble gas structure* (CS). *In some atoms, the number of valence electrons is equal to the number of valency electrons. For example, look at the first three elements of the periodic table* (teacher shows illustration on chalkboard). *The group of the element, the number of valence electrons and number of valency electrons are all the same. However, this is not the case for non-metallic elements because they accept electrons to achieve the electron configuration of the nearest noble gas. Their valency is calculated by subtracting the total valence electrons from 8. Am I making sense?* **Learners**: *Yes.*	The teacher developed a table matrix as a representation (RP), over which he explained the differences between group valence and valency electrons (CTS) using the first six elements of the Periodic Table.  The simultaneous comparison of group of element, valence and valency electrons over the Table indicates presence of a conceptual strategy, as the teacher was seen to use of a combination of conceptual principles and rules of a topic as tools to confront potential misconceptions about known importance of pre-concepts.	In this teaching segment. the teacher developes a table matrix, as a representation **(RP**) to help visualise the patterns between Periodic Table, group, and valence electrons. Through the use of the Table, he depicts the first six elements to help explain the differences between the group of an element and both valency and valence electrons, as aspect of (CTS). The three are key pre-concepts needed prior to teaching the topic, an aspect which falls under the component of (**CS**). **Proficient interwoven TSPCK Map: RP/CTS/CS** 

Time	Class Action in sequence	Comments	Analysis
25-30	**Teacher:** *"We use valence electrons to draw the Lewis dot structures"* (CS). "*The octet rule helps depict electron in atoms and molecules."* **Teacher**: *"You must remember to always establish the atomic number of the atoms in the molecule, which informs us about the valency, before depict ing the the Lewis dot structures. For example, the atomic number of chlorine atom is what?"* **Learners:** *"Seventeen".* **Teacher**: "*It will require how many more electrons to fill up its outer octet? Remember in neutral atoms the number of electrons and protons are the same. How do we establish the valency?"* **Learners:** *"It is 1."* **Teacher**: "*Very good, therefore it has a valency of… -1, not 1, 7-8 = -1. This means it lacks one electron, which it will accept or share with the other chlorine atom to satisfy the octet rule. This is the valency or bonding electron not valence but valency electron"* (LP).	He then introduced the Lewis dot structures to explain how molecules share electrons to attain the octet of the nearest noble gases using the question and answer technique.  The teacher involved the learners, as he used the examples of the Cl_2 and CO_2 molecules (RP) to explain the Lewis dot structures (CS).	In this extract, the teacher introduces the idea of valence electrons, to explain how the octet rule applies in illustrating the Lewis dot structures (CS). Together with learners, he uses the examples of Cl_2 and CO_2 molecules (RP) to explain the how the octet rule works. The act of emphasising how the octet rule helps in depicting the Lewis dot structures as he talks/explains over the illustrations is an aspect of (CS). The emphasis the teacher places on the terms valency and valence as used in the topic signals presence of a likely learner misconception about the topic, an aspect of (LP). **Proficient interwoven TSPCK Map: CS/RP/CS/LP** 
35-45	**Teacher**: "*One more example, I want you to draw* the *Lewis dot structure* for the ammonia *molecule* (RP). *The central atom is nitrogen. You need* (8) *electrons around each atom except Hydrogen". Let us start with the valency of Nitrogen."* The teacher then depicted electrons around both atoms using dot (·) and cross (x) symbolic representations	The teacher uses the example of ammonia molecule to demonstrate the Lewis dot structures  He positioned (3) electrons around the nitrogen atom and together with the learners, filled up the outer energy levels of both the Hydrogen and Nitrogen atoms fulfilling the octet rule.	In this extract, the teacher uses ammonia, a more complex example to enforce understanding of the Lewis dot structure, (RP). An indication of moving deeper into developing conceptual understanding of the main concept under discussion (CS). As mentioned earlier, the understanding of the most important concepts in the topic is an element of (CS). **Simple linear TSPCK Map: RP/CS.**

Time	Class Action in sequence	Comments	Analysis
	(CS).		
45-55	**Teacher:** *"I want a volunteer to come and draw the dot and cross structure of NO_2."* **Leaner:** "*The first learner to volunteer depicts one of the oxygen atoms in the molecule as having* (10) *valence electrons*." **Teacher:** *"Let us try to fit NO_2 in our earlier table. Nitrogen is in Group 5, so it has five valence electrons. Oxygen has six valence electrons. You should however note that the NO_2 molecule is one of the structures that violate the octet rule* (WD). *We shall be looking at this aspect in detail later*" (CS)".	He then called on one learner to come forward and draw the Lewis dot structure of NO_2. He commented the learner and inserted the valence electrons of both oxygen and nitrogen atoms in the table matrix developed earlier. He then depicted the NO_2 dot and cross structure, pointing out that some molecules violate the octet rule. The teacher applies a more complex example of NO_2 where learners will follow the newly learnt rule and discover the rule can be broken/or does not always hold. This indicates drawing on a combination of conceptual principles and rules of a topic as tools to confront potential learner misconceptions.	In this teacher segment, the teacher introduces a more a complex example into the explanation, on structures that violate the octet rule, a concept regarded difficult to understand (WD). He however informs the learners that they would be learning about the concept in detail later on. The use of an example that exemplifies use of a newly learnt rule and at the same time discover the new rule can be broken and does not always hold, indicates knowledge of drawing on a combination of conceptual principles and rules of a topic as tools to confront known areas of difficulty or potential misconceptions, which indicates presence of the component of (CTS). He however informs the class that they would be learning about molecules that violate the octet rule later on (CS). **Sophisticated interwoven TSPCK Map: RP/CTS/WD/CS** 
55-65	**Teacher: "***There is another way of writing electron configurations called "Box and Arrow" or orbital configuration. In this method, we use the up and down arrows to represent electrons. So, if an electron is paired up in a box, one arrow is up, and the second must be drawn facing down okay"* (CS). **Teacher**: "*Here you must also, identify the group to*	The teacher introduced the Hund's rule, and explains its link with Lewis dot diagrammes, using the example Hydrogen and magnesium atoms. 	In this teacher segment, we see many aspects linked. For instant, the teacher introduces Hund's rule, a new concept (CS), by depicting illustrations of (H) and Mg atoms, which indicate an aspect of (RP) at symbolic level. He then helps learners to link the Lewis dot diagrams and Hund's rule by re-visiting the Bohr atom. The act of introducing a new

Time	Class Action in sequence	Comments	Analysis
	which the atom or atoms in a molecule belong, as I said earlier, this helps us to establish the valency." The teacher revisits the Bohr atom stating that "you *must first identify the group to which the atom belongs, before establishing its valency"* (**LP**).  **Teacher;** *"According to Hund's rule electrons always enter an empty orbital before they pair up . This is because, as I said at the beginning of this lesson, electrons are negatively charged therefore they repel each other". Unpaired electrons will therefore have the same spin, while paired electrons spin in opposite directions. Is that clear?"*	He requested learners to practice Hund's rule by filling up the S and P orbitals for the atoms of carbon, nitrogen and aluminum in their notebooks (WD). He then moved around the class and notices that some learners were struggling to correctly represent the structures. This observation forced him to re-visit the Bohr atom again (CS).	rule by re-visiting an important concept that has just been taught, informed by learner interactivity is an element of (CS). He then summarises Hund's rule, by explaining how the effect of the charge on electrons affect pairing of electrons in orbitals. This is a typical example of a key gate keeping concept that is difficult for learners understanding (WD). **Proficient linear/ interwoven TSPCK Map: CS/RP-CS/WD** 
75-85	**Teacher "***It is important to understand the properties of the three fundamental particles of an atom. These are electrons, protons and neutrons. Each element on this periodic table chart (moves to the Table- RP) is defined by the number of protons found in its nucleus* (CS). *The total sum of protons and neutrons in the nucleus of an atom gives us the atomic mass. Electrons are negatively-charged and almost weightless particles that orbit around the nucleus in specific energy levels. As we shall see later, valency electrons are responsible for the reactivity or un-reactivity of all chemical reactions* (CS).	The teacher summarises the important content of the lesson over the Periodic Table, as the main teaching resource. He then hints at the importance of the topic for future content to be taught later about chemical reactions. This exemplifies knowledge of vertical curriculum (Shulman, 1986).	In summary, the teacher re-emphasises the key concepts of the topic (CS), over the Periodic Table chart, as a representation (RP). He then hints at the importance of how the lesson links to future content in the same subject area, which as mentioned earlier is an aspect of (CS). **Simple linear TSPCK Map: CS/RP/CS.** 

To summarise the sequence in which the TSPCK episodes emerged, the following pictorial map was developed to depict teacher Chetu's teaching profile.

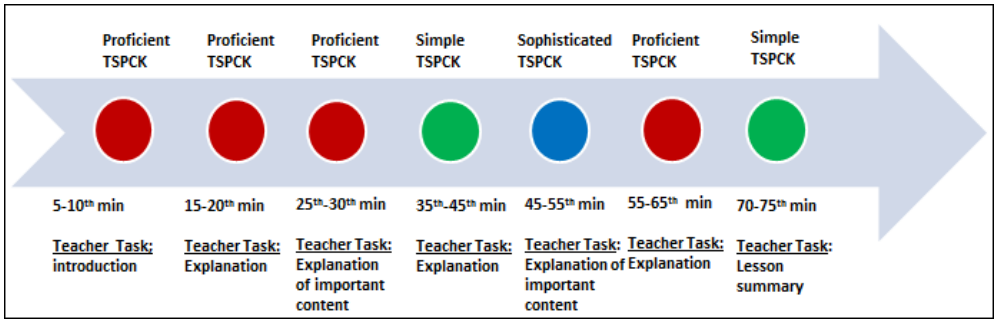


Figure 8.4: Teacher Chetu's lesson profile showing TSPCK Episodes

Figure 8.5 below shows a summary of the pictorial maps of the teaching profiles in which the TSPCK episodes for all the six GBTs and the expert teacher emerged.

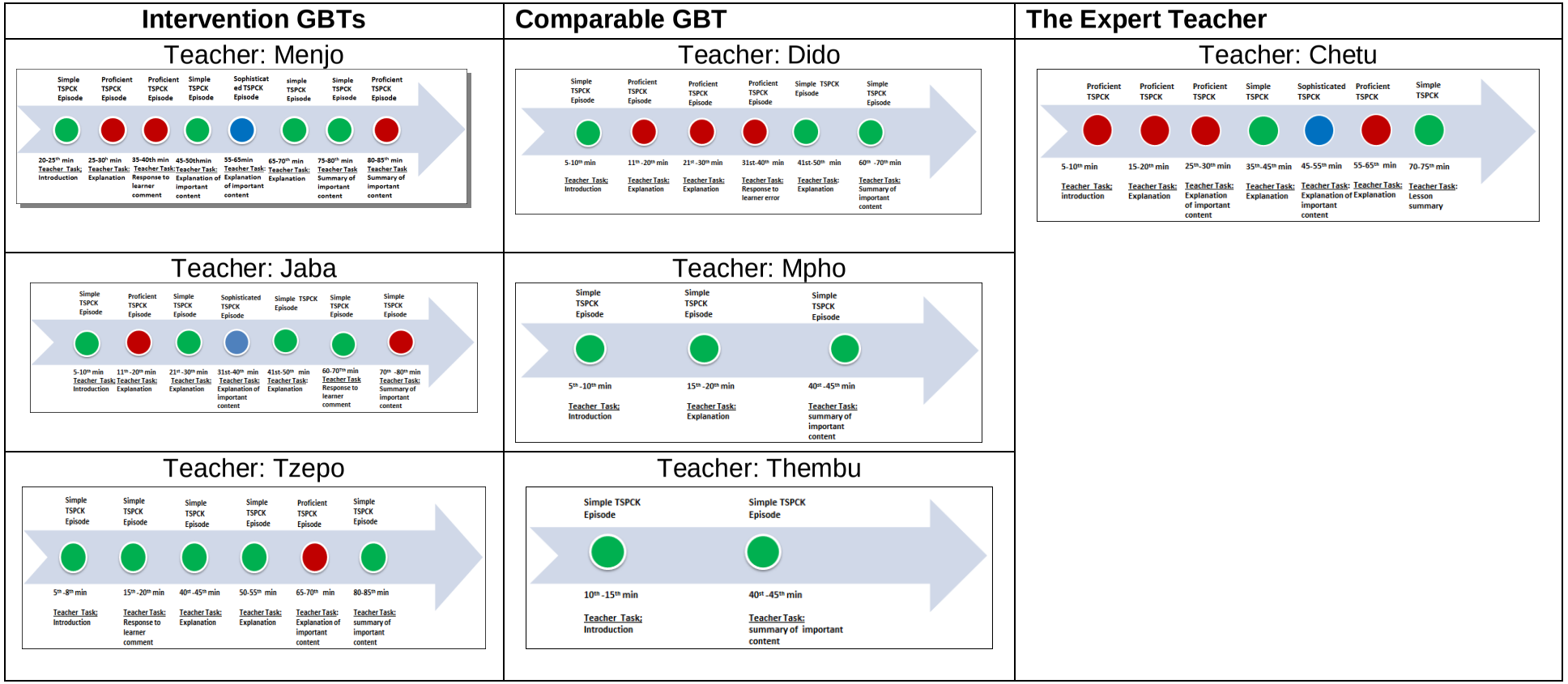


Figure 8.5: TSPCK teaching profiles of all the participants

The analysis above displays an additional element, viz. the kind of teacher tasks that promoted the emergence of TSPCK episodes. The overall pattern emerging from the summary of the TSPCK teaching episode profiles across the enacted lessons in Figure 8.5 repeats the patterns seen in Figure 8.1 above, where:

(i) All the intervention GBTs with the exception of Dido displayed a combination of both simple and higher order quality TSPCK episodes across the length of their teaching period, as compared to the comparable GBTs who displayed only simple TSPCK episodes across the profiles of their enacted lessons.

(ii) The distribution of the identified TSPCK episodes for the intervention GBTs across the lessons seem to be spread across the full lesson vs. comparable GBTs that seemed to stop midway the lesson period.

(iii) The pattern emerging with respect to teacher tasks indicate that the specific teacher tasks that seem to promote emergence of most TSPCK component interactions are; summary and explanation of the most important content knowledge in a lesson. For example, the teacher task that appeared to be associated with sophisticated TSPCK episodes was explanation of important content in the lesson for both the GBT teacher Menjo (min 55-65) and the expert teacher (min 45-55). These episodes were made visible as both teachers reflected on the important concepts in their respective enacted lessons. In addition, all the GBTs were observed to display simple TSPCK episodes in their lesson introductions.

8.3 Summary

In summary, the findings from the analysis with respect to the quality of GBTs enacted TSPCK in real classroom teaching above reveals that the intervention-GBTs advantageously exhibited a higher quantity of TSPCK episodes in their classroom teaching that denoted higher quality TSPCK compared to the comparable GBTs. For instance, the findings with respect to the nature of quality TSPCK episodes displayed reveal that firstly, all the GBTs displayed the presence of simple TSPCK episodes in their teaching. Secondly, in contrast to comparable GBTs, where only one teacher (Dido) displayed proficient TSPCK episodes, all intervention GBTs in addition to

simple TSPCK episodes further displayed evidence of episodes of TSPCK that could be categorised in the higher order quality of proficient TSPCK.

The finding further showed that the specific content components of TSPCK in the identified episodes were observed to interact with each other in a variety of clearly distinguishable combinations that appeared complex and idiosyncratic, similar to PCK (Mavhunga, 2018; Ayidin et al., 2014; Park & Chen, 2012).

The generated component interactions were found to differ by the type of components present, as well as the quantity and the sequence in which the components emerge in a TSPCK episode. In some episodes, some of the components were found to be repeated more than once, thus adding more depth to the explanations. The displayed component interactions were observed to interact with each other in either a linear standalone sequence, or an interwoven structural format; or would comprise both linear and interwoven sequence structural formations.

An example of this scenario is seen in the eight different TSPCK episodes generated by teacher Menjo, shown in Table 8.2, and represented pictorially as TSPCK Maps in the teacher's enacted lesson. For example, three out of the eight TSPCK episodes generated by teacher Menjo have three components of TSPCK interacting. The TSPCK episodes are, however, expressed in different formats as: RP/LP/CS, LP/WD-CS, and RP/WD-CS. While the three TSPCK episodes have the same quantity of components in an interaction, they however emerge differently from one another.

The findings further revealed that the more complex component interactions seem to emerge from specific kinds of teacher tasks. For example, teacher Menjo's three-component proficient TSPCK episode (minute 30-35) was captured when the GBT was explaining a key concept about ferromagnetism, in response to a learner comment. In the explanation, the teacher begins this segment by probing for learners' understanding as to what makes ferromagnetic material special, such that they can be magnetised as an element of the component of learner prior knowledge. He then repeatedly questions learners as he probes for their understanding as to what gives ferromagnetic materials magnetic properties. The repeated questioning in the excerpt indicates the teacher's awareness of potential learner difficulty in

understanding the new concept, hence gets re-phrased with a gate-keeping concept made explicit (WD). The teacher finally expands on the learner's response to explain the meaning of ferromagnetism, which illustrates evidence of the component of (CS).

The second overall finding is that the component interactions in the identified TSPCK episodes seem to be dependent on the teacher task and location of the task in the lesson among both groups of the GBTs. The teacher task segments that seemed to promote emergence of most TSPCK episodes among both groups are: explanation of important content knowledge in a lesson, and summary of the important content knowledge, as the GBTs reflected on the important concepts in a topic.

However, when compared to the TSPCK episode profile of the expert teacher, it was noted that the observed higher quality TSPCK seen in the classroom teaching of the intervention GBTs was a little less than that of the expert teacher. For example, the expert teacher was the only participant observed to activate proficient TSPCK episode interactions across the entire lesson, irrespective of the location of the teacher task in the lesson.

For instance, at minutes 55-65, the teacher was seen to re-visit an important concept that had just been taught, thereby seizing this opportunity to link a concept just taught to explain new content, informed by learner interactivity. The expert teacher was thus seen to exemplify the ability of reflection-in-action (Scion, 1987) within a stretch of time within which it was possible to make a difference to the outcomes of classroom action.

The above findings are consistent with the contention of Sickle (2012) that an explicit attention for relating subject and topic-specific PCK is the key to enriching teachers PCK for teaching specific topics. I acknowledge the small sample size used in this study, which cannot be sufficient for generalisation of these research findings. However, the emerging patterns signal the likely impact of the TSPCK intervention programme on the GBTs actual classroom teaching.

In Chapter 9, I provide a summary of the discussions of findings from the preceding chapters. In the chapter, I link the proposed theoretical framework to empirical findings of the study.

CHAPTER NINE

DISCUSSIONS AND IMPLICATIONS

This chapter provides a discussion of the findings from the preceding chapters. The chapter links the research questions to findings and further unpacks the proposed theoretical framework to empirical findings. The first part re-situates the study within the theoretical framework of PCK, particularly the relatively new literature on TSPCK. This is followed by a presentation of the new contributions to literature through responses and the corresponding discussions to the research questions. I then reflect on the main goal of the study and the main research question, which explores the possible advantage derived from the early exposure of GBTs to explicit PCK development in specific topics during their years of training as pre-service teachers. I also reflect on the research design used and the establishment of trustworthiness of the findings. I contextualise the findings within the limitations of the study. The chapter ends with an examination of implications of the findings for teacher education programmes and recommendations emanating within the South African context.

9.1 Introduction

I began this study by acknowledging the validity of Topic Specific Pedagogical Content Knowledge (TSPCK) as a theoretical construct. The construct is now also acknowledged in the newly Refined Model of PCK (Carlson & Daehler, 2018). I also acknowledged its limitation in scope, as it refers exclusively to PCK within specific topics. By virtue of being within topics, TSPCK is defined in relation to a set of types of knowledge that are specific to the content of a given topic (Geddis and Wood, 1997). These content knowledge components are: learner prior knowledge; curricular saliency; what is difficult to teach; representations; and conceptual teaching strategies. According to Shulman, (1987), the key benefit of PCK in any location (therefore TSPCK) is the pedagogical transformation of content knowledge for understanding by learners. At a topic level, such transformation emerges from the

complementary interactions of the listed content knowledge components (Ayidin, 2015; Park & Chen, 2012). Several independent studies have explored the notion of TSPCK used in initial teacher development programmes to develop teacher professional knowledge of science pre-service teachers. Most of these studies have reported, similar to the original study by Mavhunga and Rollnick (2013), an improvement in the quality of pre-service teachers' TSPCK in the topics of intervention (Ayidin, 2015; Potgieter et al., 2017; Malcom, 2018). This study was fundamentally built onto this proven understanding as a foundation. This understanding was the baseline from which I explored the possible added advantage derived by GBTs from such an early exposure to TSPCK, two years into their teaching practice. It is also important to point out that the study was nested within several new findings about TSPCK. More relevant to the study was the finding that there is a generic competence that is developed by pre-service teachers in using the TSPCK framework (Mavhunga, 2016). By the TSPCK framework, I refer to their developed understanding of what content knowledge components to use, and their understanding that the components are to be used interactively in formulating teacher explanations. Mavhunga (2016) presented empirical evidence pointing to the competence of pre-service teachers exposed to an intervention on TSPCK in particulate nature of matter, transferring their learnt understanding of the TSPCK framework for pedagogically transforming content knowledge of a new topic and a more difficult topic chemical equilibrium. In this new finding, Mavhunga (2016) insisted that the observed transfer was not a transfer of TSPCK, since there was evidence that the pre-service teachers were required to struggle and generate new and different knowledge in the new topic. Mavhunga (2016) called this competence 'pedagogical transformation competence' (PTC). The observed transfer was therefore not a transfer of TSPCK, but a transfer of PTC, which is the competence reflecting the knowledge of what content specific components are needed, and the manner in which they are to be used in order to develop TSPCK in a new topic. This interpretation of the finding was in line with the widely established understanding that PCK and also TSPCK observed in one topic is not transferable to another topic (Ayidin et al., 2014). It was therefore important to acknowledge this finding, noting that the transfer observed in the study by Mavhunga (2016) was in the context of pre-

service teachers reasoning and planning about teaching a particular topic. This study, while also exploring transfer, concerns itself with a new and succinct focus on the possible advantage seen from the early exposure to TSPCK into real teaching practice, especially in the first few years of practice by the TSPCK intervention graduate beginning teachers (GBTs). It was important to follow the graduates of the TSPCK programme as the initial rationale for exploring TSPCK in science pre-service teachers (Mavhunga, 2012) was to fast-track the development of their professional knowledge that would have otherwise naturally required many years in practice.

At the inception of this study, a theoretical proposition was made, namely that if the early exposure of pre-service teachers to TSPCK development has value, then there would be an added advantage in the reasoning and teaching practices of the TSPCK intervention GBTs compared to their counterparts (comparable-GBTs). The discussion below provides a reflective summary of the process undertaken to explore this proposition and the resulting findings. I first reflect on the process of developing a new tool for capturing and measuring the quality of TSPCK observed in classroom enactment. This tool was necessary for this study, and original in the sense that no existing tool was found suitable for measuring TSPCK in action. I then touch on the process of establishing a reliable base confirming that the pre-service teachers explored as a sample in this study, indeed acquired TSPCK in their respective explicit interventions. I then highlight the new contribution to knowledge established in the empirical discussions. Within this, I answer each research question asked, as informed by the findings. I provide a discussion on each empirical finding and summarise by answering the major research question. This is followed by implications and recommendations within the South African context, as well as my own personal view. I finally reflect on the theoretical framework with respect to the qualitative research design method used, the establishment of trustworthiness and the limitations of the study.

In the section below, I reflect on the process of development and the reliability of the newly developed tool for this study. While the development of the tool is a

contribution to new knowledge, I however, reflect on it separately here for ease of focusing on new knowledge from the key research questions later.

9.2 The development of a tool to capture TSPCK in classroom enactment

PCK and the related constructs, such as TSPCK, is a challenging target for study because it is tacit in nature and is partly an internal construct that exists in the mind of the instructor, where it may not be evident through observation or in written work alone (Baxter and Lederman, 2001; Aydeniz & Kirbulut, 2014). Aydeniz and colleagues (2014) therefore argue for a combination of tools exploring the construct in both the reasoning in planning and the enactment context for a holistic picture. This study was driven by research questions that explored for acquired TSPCK of pre-service teachers in both the reasoning in planning and enactment teaching contexts. Tools specially designed for exploring TSPCK in specific topics at the planning to teach level could be drawn from previous studies such as organic chemistry (Vokwana, 2015) stoichiometry (Malcolm, 2015), etc. However, there is generally paucity in the literature for tools capturing PCK or the related TSPCK construct in classroom enactment. This explains the need to develop a new tool in this study as shown in detail in Chapter 4. Unlike the processes of developing a written-in tool in a planning to teach context, the tool developed for capturing TSPCK in action is in the form of a rubric, which serves to capture and portray the different moments in the teaching of a lesson that displays evidence of pedagogical transformation of content knowledge. Such moments were termed TSPCK episodes, and displayed in form of a teacher teaching profile (e.g. Figures 8.5 in Chapter 8). Thus, it is more appropriate for use when measuring pattern differences or shifts in the captured performance, such as in this study, than serving studies with goals for determining a single measure of quality value.

The tool was developed from an inductive qualitative process of extracting qualities observed from the teaching actions of expert teachers. Three expert teachers were teaching the same topic and concept, a mole at the same school grade, Grade 11. As alluded to in Chapter 4, the use of expert teachers was based on the

understanding in the literature that PCK is professional teacher knowledge associated with expert teachers. Care was taken to identify and selectively mine the teacher qualities from the perspective, the lens of the TSPCK theoretical framework. Such a lens sifts and enables interpretation of the observed teacher actions from a set of five content-specific components and their use as interactions among each other. This excluded teacher actions related to pedagogical knowledge, such as general classroom management. In addition to aligning with the TSPCK framework, the rubric was developed in cognisance of two principles that undergrid the features of good criteria. The first is the importance for the criteria to spell out the qualities that need to be displayed and regarded as reflecting proficient performance (Moskal and Leydens, 2000). The second is that the criterion needs to spell-out the extent of proficiency of the performance from spelling out the desirable behaviour of the components of the construct being measured (Ariel-Attali and Liu, 2015). These two principles fitted well with the TSPCK framework, as the performance could be described from the perspective of the five TSPCK components present, as well as their behaviour in terms of the extent of the interactions observed. The analysis of the video recorded lessons of the expert teachers yielded to a rubric that had five (5) categories of quality, which were subsequently streamlined into three (3) distinct categories of TSPCK in action. These were presented with sample anchors demonstrating performance in each quality category see Appendix B.

The key rationale for streamlining and reducing the number of categories in the rubric was based on the observation of TSPCK episodes that had a fixed number of different TSPCK components in interaction, with one of the components being repeated. The repeated component brought additional emphasis that was, however, not necessarily new. For example, an expert teacher would speak to different aspects of curricular saliency, or describe different aspects of representation at different points of the same explanation. For instance, in the video extract showed in Figure 4.7, where teacher Laurent was observed to introduce his lesson by displaying a visual slide depiction, showing different volumes of gases formed during electrolysis of water, which indicates representations component at sub-microscopic level. He then applied an equation to link the reacting mole ratios of reactants and

products to the resulting molar gaseous volumes of the products, an element of representations at the symbolic level.

This observation was acknowledged as having the particular component of representations interactions at different levels; its extended use was however counted as not enough alone to warrant a new category. Furthermore, the need for rubrics to save time and be conscience (Brookhart, 1999) further counted against keeping an additional category. The validation of the rubric for trustworthiness with a sample comprised of practicing teachers and pre-service teachers was achieved by borrowing from the theory of construct validity (Kane, 2006). The process of construct validity is more common, with mixed methods as it requires a statistical or calculated quantitative argument as well as a qualitative or interpretive argument. As a 'borrowed' concept into this study that has a qualitative design, the borrowing was limited to using the qualitative version of calculated rater agreement as a proxy for a quantitative solid statistical calculation. This was compared against an interpretive argument that defined TSPCK, and drew on the literature citing practicing teachers to have better quality of the construct than pre-service teachers. The congruency between the rater agreement (a qualitative version of calculations) and the findings proved the understanding developed in the literature regarding practicing teachers holding a higher quality of TSPCK than pre-service teachers to be the case with the sample used was an indication of acceptable trustworthiness of the tool. Additional data pointing to the trustworthiness of the tool was illustrated by a separate study by another researcher (Malcolm, 2017) that used the tool to capture and portray the TSPCK of expert teachers with acceptable rater agreement of Cohen-Kappa value of 0.82.

It was further noted from the use of the tool with both the sample in the validation study, as well as with the actual GBTs, that no instance was recorded where raters using the rubric could not locate or grade a TSPCK episode identified in a video recorded lesson. This observation was welcomed as an indicator of sufficiency of the rubric for the sample at hand, and stands as a novel contribution to the TSPCK literature.

With a proven reliable tool to capture and portray the quality of TSPCK seen in classroom enactment, the next important thing was the need to establish a trustworthy data baseline for exploring the possible retention of the acquired quality of TSPCK and the added advantage derived from the early exposure to TSPCK, if any.

9.3 Establishing a reliable data baseline for measuring possible retention and added advantage in practice

As alluded to above, the starting point of this study was based on the proven proposition that an explicit exposure to a TSPCK based intervention leads to improvements in the quality of pre-service teachers' TSPCK in the topic of intervention. However, it was important to confirm this proposition for the sample of pre-service teachers used in this study as to establish trustworthiness in the baseline data from which all analysis is inferred. This is in line with the argument in the literature that it is always important to re-calculate reliability of the research tools anew with each new study, even when such has been previously established (Stemler, 2004).

The findings in Chapter 5, confirmed a noticeable improvement between the pre- vs. post-intervention TSPCK tools completed by the Chemistry Methodology class cohort of 2014. This improvement was first confirmed by re-scoring and analysing the tools which were completed retrospectively at the time. The confirmation was seen in the total class of N=24, but analysed in detail in Table 5.1 was only for the subset of seven GBTs, who met the sample selection criteria for the study. The findings indicated a noticeable improvement in the quality of TSPCK as seen from the overall persons scores which were initially at a category denoted 'Limited' (score 1) that shifted to a higher one 'Developing' (score 3). There was a positive shift of two quality categories. The close qualitative analysis of the participants' responses across the pre/post-intervention tests indicate a visible depth in thought in the post-tests. For example, Sharon's extracted response in Figure 5.3 had a noticeable shift from an algorithmic reliance on calculations in the pre-test, even though she seemed to be aware of its limitation, but still used it for conceptual emphasis in the post-test. In the post-test, Sharon is seen to first articulate the common learner misconception

of relating equal mass of different compounds to equal amounts. She delivers a corrective explanation by making clear links of the conceptual relationships between atomic sizes of different substances, hence their different atomic masses and how all are linked to different molar masses. A similar observation of a visible shift in the quality of TSPCK is seen in the analysis of the extracts of Jaba in Figure 5.5. Jaba's responses in the post-test clearly articulate connections between a 3D representation at sub-microscopic level and the theoretical concepts such as electronegativity and change of reactants to products in chemical reactions that are linked to the manner in which the atoms are arranged in the representation he chose to use. Such links are often difficult for learners to make by themselves. According to Bingölbali and Coşkun (2016) the essence of knowledge lies in the way in which knowledge is structured, as well as where the relationships that are established between the ideas are highlighted. Connections are important to foreground different perspectives, complex meanings, and the interdependence and significance of individual concepts. Jaba's extract and the subsequent information emerging from his stimulated recall interview discussed below further pointed to an additional benefit derived by the pre-service teachers from the explicit intervention. The intervention provided the pre-service teachers with both the understanding of making connections between concepts as well as the wisdom to explain their reasoning. Jaba indicated that at the beginning of the intervention, he did not know how to explain his correct intuitive preference for using a particular representation over another. Braaten and Windschitl (2010) argue that the single most powerful conceptual tool for advancing science teachers' practice is to provide a way for teachers to distinguish between descriptive and explanatory endeavours in science, moving from an emphasis on "what" towards an emphasis on the "how" and "why". Jaba's constructed explanation of his reasoning behind using the specific representations is evidence of the power of emphasis on "how" and "why", which by his own admission he did not have prior to the intervention. More of such explanations are seen across all TSPCK components in the post-tests, such as in Figure 5.11, which shows insights across all TSPCK component of a single participant, Sharon.

The observed improvement in the quality of TSPCK confirmed in the sample of intervention-GBTs used in this study was expected, but important to establish. It is a

finding reported widely in several similar studies mentioned earlier, but important in this study, as it confirmed the trustworthiness of the data-base from which findings from the exploration of a possible advantage in practice could be interpreted. The acceptable agreement of a Cohen kappa value of 8.0 between the raters who scored the completed pre/post-intervention tests was also assuring. The finding further adds more evidence supporting the call for the nationalisation of the explicit TSPCK intervention in pre-service teacher programmes (Mavhunga, 2017).

Sections 9.2 and 9.3 above are my reflections on the elements that needed first to be laid-out as bridges that will enable a trustworthy exploration of the possible added advantage to the teaching practice of intervention-GBTs in their first 2 years since graduation. With these, out of the way, I now reflect and discuss on the findings of my study as contribution to new knowledge to the TSPCK literature in science education.

9.4 The empirical finding that contribute to new knowledge

The formulation of TSPCK as a construct saw the emergence of studies exploring the construct with pre-service teachers in different topics (e.g. Mavhunga 2016; Mavhunga, & Rollnick, 2013; Rollnick. et al., 2017). However, what remained un-answered in the literature is whether the quality of TSPCK acquired in the explicit intervention during the training of science pre-service teachers is retained when they reach the place of work. Also, whether they bring any added advantage in their teaching practice. Furthermore, the complexity of capturing and measuring TSPCK in classroom enactment remained a challenge not explored by these studies, as well as generally in the literature. The findings of my study contribute towards addressing these gaps in three succinct areas. These are: (i) A provision of a **tool** for capturing and portraying TSPCK seen in enactment as reflected in section 9.2 above; (ii) findings about the **retention** of the quality of TSPCK first acquired in a formal course; and (iii) about a possible **added advantage** of an early exposure to TSPCK to the teaching practice. Teaching practice here refers to TSPCK explored in both the

planning for teaching and the actual classroom teaching. The contributions into these areas are new and original.

9.4.1 Retention of TSPCK acquired in a pre-service teacher programme

One of the key purposes of this study was to explore the retention of the acquired quality of TSPCK of GBTs as a direct result of an early exposure to explicit TSPCK based intervention. According to Ausubel (2012), acquisition and retention of knowledge are pervasive lifelong activities, essential for competence performance, efficient management, and the improvement of daily tasks, which the author argues lies in the formal instructional practices of schooling. In the same vein, Halpern & Hakel (2003) contend that the underlying rationale for any kind of formal instruction is the assumption that knowledge, skills, and attitudes learned in a setting will be recalled accurately and used in some other context in future.

Educators are thus introducing active teaching/learning practices in classrooms to ensure learners' understanding and long-term retention of their acquired knowledge. In this way, formal instruction becomes a pre-cursor to life-long learning, instead of short term improvement of learner performance in school.

The TSPCK acquired during the early exposure to explicit TSPCK-based intervention was located at the level of reasoning about teaching a specific topic. I referred to this TSPCK as planned TSCPK, in order to distinguish it from that observed in the act of classroom teaching (Mavhunga et al., 2016). The sample of intervention GBTs explored in this study were confirmed in Chapter 5 to have experienced an improvement of TSPCK in their respective topics of intervention by a jump of two quality categories, to a category denoted according to the planned-TSPCK rubric with a score of three, which is a 'developing' category. Teachers in this category are able to: (i) structure a topic into at least three big ideas, with clear distinction of these ideas from concepts that could be regarded as subordinate concepts; (ii) identify a misconception and provide a corrective response that draws on two other components of TSPCK interactively; (iii) identify areas in a topic that are potentially difficult for learners understanding, by pinpointing the specific gatekeeping concepts

that are problematic; (iv) plan for the simultaneous use of representations at more than one level of explanation including the sub-microscopic level; and (v) their teaching of conceptual strategies reflects TSPCK episodes that draw from the above in a format illustrating interactions among the components. This level of quality of TSPCK in graduate teachers about to enter the world of work was thus deemed admirable. This is the case because firstly, Shulman's (1987) view of developing pedagogical reasoning, where the transformation of content knowledge is the essence of the process was being realised. Secondly, because the cohort represented a breakthrough in the literature where the development of TSPCK in a specific topic appeared to be in place way before they acquire experience in real practice. PCK, and by inference TSPCK, is widely understood to be developed with extended time, full of reflection, in practice (Bishop & Denley 2007). Thus, the question of the retention of such admirable quality of TSPCK by graduate pre-service teachers once in practice was a legitimate question to explore.

Findings in Chapter 6 presented evidence of retention of the same quality of TSPCK ("developing") in the majority of the GBTs with exception of one teacher, the teacher Ntombi. Ntombi was scored an overall score of 1 when in practice, denoting a limited category. Her score was one category level down from her post-score of 2. In her view, her drop in TSPCK was related to the pressure of being a beginning teacher in a new school environment. The other reason for shifting towards algorithmic reasoning, as hinted at by Ntombi in her interview (Figure 6.16), is attributed to the demands of schools, where emphasis is often placed on preparing learners for their final examinations at the expense of teaching for conceptual understanding, thus developing anxiety to teach for the examinations.

Teacher Sharon, one of the participants who retained a good score of 3, ascribed her retention of acquired TSPCK back to the TSPCK intervention that had explicit discussion on the common learner misconceptions found in stoichiometry. Her responses in the post-test and that of two years in-practice suggesting evidence of retention of planned TSPCK were indicative of this link. In her response regarding how she would help learners' who consistently demonstrate difficulties while working on preparation of molar solutions (Figure 6.3), we see Sharon acknowledge the

common learner misconceptions about mass relative to molar concentration. This she does by pointing out in both the post and the in-practice tests that; *"the mass of salts does not mean that the number of particles is the same".* She similarly identifies the specific concepts to be emphasised in the topic (different molar masses), which relates to aspects of the component of curricular saliency in both the post and in-practice tests. She then emphasises the fact that "adding 10 grams of salt to the same volume of solvent does not mean adding the same number of ions/particles for the different salts". The explicit reference to connections/non-connections between macroscopic and sub-microscopic representations, while simultaneously dealing with a misconception, is noticed in both the responses in the post- and in-practice tests. Sharon's reference in both the post and in-practice tests to the meaning of grams as not referring to the same number of ions/particles for different salts, demonstrated retention of understanding of common learner misconception about the topic.

A similar scenario was observed in teacher Jaba's post vs. in-practice TSPCK test responses on how to apply the component of conceptual teaching strategies to teach about different ways of representing organic molecules (Figure 6.11). In the post-test, the teacher explained that, he would approach the lesson with the aim of addressing the question posed by the learner about positional isomerism through an activity with molecular modelling balls. In the activity, learners would be required to build different models, to display various positional isomers in random arrangements during the lesson. In response to the same test item, in the 'in-practice test' two years later (Figure 6.11), teacher Jaba suggested giving each learner the task of drawing a (3D) molecule using molecular structural formula followed by lists of incorrectly drawn molecules, before asking them to identify why each is incorrect. According to Oh and Oh (2011), models play key roles in developing scientific understanding of the natural world and are believed to support science instruction in various ways. Such moments were noted, where the teacher demonstrated repeated use of the component of representations at different levels in explaining the main concept under discussion, as retention of the acquired ability for the interactive use of the components of representations and curricular saliency in both the post- and in-practice tests.

However, notwithstanding the slight differences observed within the finer details of the findings, the overall pattern that emerged from the analysis indicated that the majority of the intervention GBTs noticeably retained the quality of acquired planned TSPCK in their intervention topics, two years in practice. This retention could be linked back to the explicit TSPCK based intervention received, while in training as pre-service teachers. As mentioned above, retention of knowledge is one of the underlying rationale for education. It speaks to the realisation of the assumption that knowledge, skills, and attitudes learned in a formal setting will be recalled accurately, and will be used in some other context at some time in the future. It is to be noted the observed retention happened in the presence and possible ill-influence of constraints exerted by the daily pressures such as the school culture and context, or personal bias and motivational levels, and any other personal traits that could involuntary enter the space. Evidence of their real and possible effect are seen in the reflections of teacher Ntombi, whose retention was slightly weaker. According to Ausubel (2012), retention of knowledge into the future is linked to meaningful learning that in turn involves acquisition of new meanings from both the presented meaningful learner material and a meaningful presentation. Thus, the link of the observed retention back to the explicit TSPCK intervention programmes speaks to the extent of the meaningfulness of the TSPCK based programme, in terms of both the material used and the logic in its presentation. The finding validates the arguments posited by several science education researchers, that an early exposure to PCK (by inference TSPCK) fast-trek's and enhances the teacher's professional knowledge (e.g., Henze & van Driel, 2015; Nilsson 2014). Furthermore, the finding is consistent with the argument forwarded by Mavhunga, and Rollnick, (2013) that an early exposure of pre-service teachers to explicit PCK development in specific topics would spare beginning teachers from many years of frustration before gaining experience to develop their own TSPCK in core topics.

An important contribution to new knowledge made by this finding is that an explicit early exposure to PCK development in a specific topic can influence the retention of the acquired planned TSPCK at least in the first two years of practice.

In the next section, I reflect on the new contributions about the added advantage derived from the early exposure of the GBTs to explicit TSPCK development in the planning to teach familiar and unfamiliar chemistry topics

9.4.2 Added advantage on planning to teach familiar and unfamiliar topics

The search for added advantage as a direct link to the intervention, created a need for the introduction of a control group. These were the comparable-GBTs from a sister university in the same geographical area. Their equivalence to the intervention GBTs was argued and established in Chapter 3. The value of introducing a control group was targeting the need to cancel out all contextual and other factors that could have an impact on the findings. The value derived from such a research design is reflected upon in detail in Sections (i), (ii) & 9.4.3, below. The first evaluation done was to determine the level of TSPCK across the intervention and comparable-GBTs in a context of planning to teach. In this context, two cases were evaluated. The first case was to compare the two groups of GBTs in a topic familiar to one group, and for the second case in topics that are new to both groups.

(i) Advantage seen in planning to teach familiar topics

As alluded to in Chapter 7, I started the analysis of this part with a postulation that the intervention GBTs had an added advantage over their comparable GBTs in the topics of intervention, with which they would be familiar. This was because the intervention GBTs had been exposed to the same test tools earlier, during their pre-service intervention programme. In this context, which I termed the 'familiar context', the intervention GBTs would be expected to be familiar with the topic, while the comparable GBTs would not.

As alluded to in Chapter 7, the same TSPCK test tools used in the parallel topics of intervention attended by the three intervention GBTs as "in-practice tests" were similarly administered to the comparable group of the three GBTs, and analysed. This is the same test where the intervention GBTs showed retention of the score they gained in the post-test discussed in Chapter 6.

The overall pattern that emerged from the analysis of three intervention GBTs versus the comparable control sample of three GBTs in the topics of intervention (familiar context) revealed that the intervention-GBTs displayed a visible advantage of two quality category levels higher, over the comparable GBTs in the quality of planned TSPCK. Similarly, the overall pattern from the collective average scores per component showed that the intervention GBTs demonstrated an advantage in the quality of planned TSPCK over their comparable GBT counterparts across all the TSPCK components in the topics of intervention. The intervention GBTs were assigned a group average score of 3, which denotes the developing TSPCK proficiency in the topics of intervention. On the contrary, the comparable GBTs were assigned an average group score of 1, which denotes the lowest quality category of limited TSPCK in the same topics, see (Table 7.2).

Examples of extracts showing a comparison of written responses between teachers Jaba (intervention GBT) vs. Mpho (comparable GBT) in the topic of Organic Chemistry have been inserted into Figures 7.2 and 7.3. For instance, in responding to the question of how to help students distinguish organic alcohols from other compounds, teacher Jaba suggested beginning his lesson by pointing out that the -OH functional group is not the only requirement for a compound to be an alcohol. He then confirmed accurate understanding, noting that for a compound to be an alcohol, it needs to have the-OH as the only functional group on the carbon atom of an organic molecule. The explicit emphasis for the need of the -OH functional group as the only group attached specifically to the carbon atom and not any other atom shows an understanding of the key pre-concepts that need to be understood prior to teaching the concept of organic alcohols. The understanding of such concepts, as well as identification of key pre-concepts that need to be understood prior to teaching a particular topic, is an element of curricular saliency (Geddis and Wood (1997). The teacher further suggested taking the learners through each example, to point out why each is/isn't an organic molecule. Examples in this case refer to the use of line structural drawings given as options in the test tools, which form part of the knowledge of a range of subject matter representations (Geddis & Wood 1997, p. 612).

On the other hand, the teacher Mpho the comparable GBT partner pair equally acknowledged that *"alcohols have an-OH group"*. However, he did not provide linking explanatory notes, nor did he identify the specific misconception that learners may hold in distinguishing organic alcohols from other compounds. The response provided by teacher Mpho reveals that although the teacher seemed to possess good content knowledge of the topic, he lacked the ability to formulate explanations with reference to the knowledge brought about by the TSPCK components. This understanding points to a gap between content knowledge and the needed knowledge to teach it, it is a realisation that TSPCK does not seem to be at the surface and readily available for use at the right time, but must be developed over time. The above observation is consistent with the argument in the literature that acquiring and possession of strong content knowledge from content courses alone may not necessarily translate into effective teaching of such content to learners (Grossman et al., 1989; Lee et al., 2007). This finding supports other research studies, which argue that teachers develop PCK in the context of planning, teaching, reflecting on and re-teaching a particular topic (Hashweh, 2005; Magnusson et al., 1999).

Another example, where the comparable GBTs displayed a lack of ability to formulate explanations with reference to the knowledge brought about by the TSPCK components was captured between teachers Tzepo (intervention GBT) and Thembu (comparable GBT) in the topic of electrochemistry (Figure 7.4). In his written response, teacher Tzepo correctly identifies the learner errors in the extracts by pointing out that the Cl^- ion moves towards electrode M, (anode) since it is the positive electrode, where oxidation takes place. He then corrects the learner error, by stating that Cl^- ions are oxidised to Cl_2 (g) and not Cl_2^+, hence linking the correct representation to the concept under discussion. He further suggests use of the correct equation ($Cl^- \rightarrow Cl_2 + 2e^-$), an indication of drawing on the component of representations at symbolic level. He finally emphasises that learners often confuse between electrode M, the (anode) and electrode N, the (cathode) terminals, an indication of awareness of content areas that often pose confusion/misconceptions among learners.

In response to the same question item, teacher Thembu similarly identifies the learner errors, by noting that the equations in extracts 2 and 3 in the test tool were both wrong. However, the teacher fails to provide a corresponding confrontation strategy as to how he would assist the learners move towards the correct understanding.

In addition, I had to spend a lot of time, during the stimulated video recall interviews held, using a variety of prompts to make the comparable GBT to concisely point out that alcohols need to have an -OH group attached to a carbon atom and not any other atom, as indicated in Figure 7.2. Moreover, when asked whether, if given a chance to re-formulate his response, he had any additional information to add, the comparable GBT simply repeated known standard textbook definition about -OH as a functional group.

The examples used above suggest that the intervention GBTs displayed added advantage in the quality of planned TSPCK in the topics of intervention over their comparable GBT counterparts. While this finding was reasonably expected, the interesting aspect is the extent of the difference between the TSPCK quality levels between the two groups. A gap of two quality categories was indicative of the added advantage that the intervention GBTs held.

(ii) Advantage seen in planning to teach unfamiliar topics

According to the postulate made at the inception of the analysis in this section, the overall performance in the quality of TSPCK demonstrated by the intervention GBTs over their comparable GBTs in the topics of intervention was expected. In order to single out the likely impact of the TSPCK-based intervention programme on the observed performance, the quality of planned TSPCK displayed between intervention GBTs versus the comparable GBTs in new topics was measured.

In this context, which I termed the unfamiliar context, I expected no advantage in the scores from the two groups in the new topics, as both groups were being treated to the new test tools for the first time. For this analysis, one experienced practicing

physical science teacher was added to this sample as a reference to the likely quality of teacher expertise/experience at the time.

The overall pattern that emerged from the findings of the average person scores in the new topics (unfamiliar context) (Table 7.4) revealed that the intervention GBTs displayed an added advantage in the quality of TSPCK over their comparable GBTs. However, this time the advantage constituted one quality category level up across all the TSPCK components. The intervention GBTs were assigned a group average score of 3 in the unfamiliar context, which denotes the developing quality of TSPCK. On the contrary, the comparable GBTs were assigned a group average score of 2, which denotes the basic quality category in the scoring rubric.

An example of sample written responses showing a comparison of intervention GBTs added advantage over the comparable GBTs in the new topics between teachers Menjo (intervention GBT) and Dido (comparable GBT), is shown in Figure 7.8. In this example, the GBTs were asked to select representations they find most useful in teaching the topic of organic chemistry from a list provided in the test tool. They were then required to explain how they would use the selected representation(s) to explain the boiling points of butane (0.5°C) and pentane (36°C) in Grade 12. In his responses, teacher Menjo described how he would conceptually engage with only three of the listed representations, which were both line and 3D drawings, at both symbolic and sub-microscopic levels, to explain the effect of intermolecular forces on the boiling points of butane and pentane. This rightly demonstrates an explicit link of core aspects of content knowledge with the representation. The teacher explained that he would not use the 4th and 5th representations because they are clustered, and the bonds between the atoms are not explicit. The teacher's reasons not to use both the 4th and 5th representations for teaching at Grade 12 illustrates understanding the value of selecting representations based on the knowledge of learners for the aspect of the concept being explained, which reveals drawing on the component of learner prior knowledge. The teacher's efforts are consistent with Shulman's proposition that choosing suitable representations involves thinking through the main ideas in the lesson and identifying alternative ways of representing them to students (Shulman, 1986, p. 16).

The teacher further suggested the use of line structures to show intermolecular forces, using a drawing that could be interpreted as a 3D projection that was revealed in his explicit labelling in Figure 7.8. According to Gabel (1998), an explanatory tool such as a diagramme or an image can provide learners with a way of visualising the concept, and thus help develop a mental model for the concept. The teacher was assigned a score of 3 for use of representations at different levels of component sophistication, and drawing interactively on the component of curricular saliency to support the understanding of a singular concept.
This finding is consistent with the understanding in the literature that the quality of PCK in a topic is demonstrated by the synergistic interactions of the components of PCK and by inference TSPCK (Aydin, Demirdogen, et al., 2015b).

In response to the same question item, teacher Dido similarly indicated that the 1st and 3rd representations would apply at school level, and not the 2nd and 5th representations. The teacher did not, however, provide supporting explanatory notes to link the selected representations with aspects of the concept to be explained. He simply noted that *"the temperature will increase from the smallest to the largest",* a response considered broad and generic. The teacher was subsequently assigned a score of 1, which corresponds to the limited quality of TSPCK following the criteria used in the scoring rubric, where limited use of a scientific representation without linking explanatory notes to aspects of the concept being explained is assigned a maximum score of 1.

Another case, showing a single quality category level difference in the quality of TSPCK was lifted from written responses between teachers Tzepo (intervention GBT) and Thembu (comparable GBT), under the category of conceptual teaching strategies.
Looking at the responses provided in extracts (Figure 7.11), both teachers correctly observed that it does not matter the position on which a substituent group is attached in representing organic molecules. However, teacher Tzepo went further to suggest going back to the periodic table to help explain bonding in a carbon atom. The teacher's reference to aspects of SMK learnt earlier (periodic table) and link to a new

concept demonstrates awareness and the benefit of drawing on the component of learners' prior knowledge.

In summary, the nature of the quality of planned TSPCK generated from the qualitative analysis and discussions captured from the topics of intervention and the new topics included aspects where generally, the intervention-GBTs demonstrated: (i) knowledge of potential misconceptions and/or confusion by learners; (ii) improved structuring of the topics for teaching; (iii) identification of aspects regarded difficult to teach; (iv) use of representations; and (v) improved teaching strategies, drawing on one or more of the other content components of TSPCK. On the contrary, the comparable-GBTs were largely found to struggle in providing convincing evidence of sophisticated connections between the different components of TSPCK in their responses.

As mentioned earlier, the understanding of the knowledge components of TSPCK and the manner in which they are to be used in order to develop TSPCK constitutes what Mavhunga (2016) refers to as 'pedagogical transformation competence' or PTC. According to the author, once acquired, this ability is to be applied to engage with the required content of each topic to develop TSPCK across related topics.

Therefore, the possible effect of practice on the quality of planned TSPCK in both topics of intervention and the new topics, displayed by the intervention GBTs over their comparable GBT counterparts could be attributed to the advantage derived from the acquired TSPCK in the topic of intervention, and carried forward as PTC in order to develop further TSPCK in the new topic. This observation is further confirmed from the observed advantage in the group average score generated between the intervention-GBTs vs. the comparable-GBTs in the new topics, being unfamiliar to both groups. These are thoughts that were developed with the topics of intervention, during the pre-service intervention studies, and now applied to pedagogically transform content knowledge in the same topics as well as new topics two years since the exposure.

The findings across the two groups of GBTs however showed the highest score of TSPCK being a score 3, denoted as 'developing' and not necessarily exemplary (according to the TSPCK rubric) as would be expected of expert teachers. This was evident from the higher quality score (4) assigned to the expert teacher in the quality of planned TSPCK in the new topic (Table 7.4). A score of four corresponds to the exemplary quality category in the scoring rubric. In his response, the teacher exceptionally demonstrated high quality TSPCK by additionally suggesting engaging his learners in small group discussions regarding why each of the compounds provided in the test tool is/or is not an organic alcohol, before presenting their thoughts to the whole class. This was unlike the beginning teachers, who responded to this test item from a teachers' perspective only.

I acknowledge the random pairing of the GBTs, based on the topics in which they were treated to as a limitation to be noted when making conclusions. With the said limitation in mind, emphasis is placed on the overall pattern rather than the individual pairs. The pattern visibly points to a visible added advantage demonstrated by the intervention GBTs' quality of TSPCK in a context of planning to teach with pedagogical transformation in mind. It is consistent with Van Driel and Henze (2015, p. 121) argument that "specific interventions in teacher education or professional development programmes, can contribute to enhancing teachers' PCK". I consider this finding new and derived from my original research design effort, thus contributing to new knowledge.

In the next section I reflect on the findings generated from the analyses of the added advantage on the nature of the quality of the GBTs' enacted TSPCK. This is the second component of the question that sought to determine the possible existence of added advantage, in the GBTs' enacted TSPCK in real classroom teaching.

9.4.3 Added advantage in the nature of enacted classroom teaching

The main purpose of this section was to reflect on the added advantage seen in the quality of the GBTs' enacted TSPCK in real classroom teaching. The discussions in this section complement the findings of the added advantage on the quality of

planned TSPCK presented in the previous section. According to Rohaan et al. (2009), PCK is not only limited to what teachers know but it is embedded in "what a teacher does, and the reasons for the types of actions they take in relation to teaching a specific topic" (p. 158). As alluded to in the methodology Chapter 3, teachers' classroom practice and activities provided the main platform for witnessing and capturing enacted TSPCK. In the following section, I briefly reflect on the enacted classroom teaching of the same subset of GBTs and the expert teacher described in the previous section.

9.4.3.1. The nature of the GBTs' enacted classroom teaching

In this study, as mentioned in Chapter 4, the quality of enacted TSPCK in real classroom teaching was determined succinctly by focusing on the quantity of the interacting TSPCK components, the depth brought about by their sophistication, and the sequence of use observed in a TSPCK episode. This is congruent with the understanding in the literature that the quality of PCK in a topic is demonstrated by the extent of the synergistic interactions of the specific components of PCK and by extention TSPCK (Aydin, Demirdogen, Akin, et al., 2015; Park & Chen 2012).

The overall findings generated from the analysis with respect to the quality of enacted TSPCK in real classroom teaching in Chapter 8 revealed that the intervention-GBTs advantageously exhibited an array of a higher quantity of TSPCK episodes in their classroom teaching that denoted higher quality TSPCK compared to the comparable GBTs. For instance, the findings with respect to the nature of the quality of TSPCK episodes displayed in (Figure 8.1) revealed that firstly, all the GBTs displayed presence of simple TSPCK episodes in their teaching. Secondly, in contrast to comparable GBTs, where only one teacher (Dido) displayed proficient TSPCK episodes, all intervention GBTs in addition to simple TSPCK episodes further displayed evidence of episodes of TSPCK that could be categorised in the higher category quality of proficient and sophisticated TSPCK.

The second overall finding was that the specific content components of TSPCK in the identified episodes were observed to interact with each other in a variety of clearly

distinguishable combinations that appeared complex and idiosyncratic, similar to both the broader discipline and topic-specific PCK (e.g. Mavhunga, 2018; Aydin et al., 2014; Park & Chen, 2012). This finding provides evience for the argument forwarded by Gess-Newsome (2015) that topic-specific professional knowledge, (TSPK), which has been equated in this study to TSPCK, is canonical knowledge that reflects best practice in teaching a given topic.

The generated component interactions were found to differ by the type of components present, the quantity and the sequence in which the components emerge in a specific TSPCK episode. In some cases, some of the components were found to be repeated more than once, thereby adding more depth to the explanations. The displayed component interactions were seen to interact with each other in either a linear standalone sequence or an interwoven structural format, or would comprise both linear and interwoven sequence structural formations.

For example, out of the eight different TSPCK episodes generated by teacher Menjo (Table 8.2), three of them saw three components of TSPCK interacting. The episodes were however expressed in different formats as: RP/LP/CS; LP/WD-CS, and RP/WD-CS. Thus, while the three TSPCK episodes have the same quantity of components in an interaction, they emerge differently from one another.

This finding is in line with the understanding in the literature that PCK, and by extension TSPCK, is not a linear sum of its constituent components, but is rather constituted by the interaction among the components with each other (Park & Chen, 2012).

The findings further revealed that the more complex component interactions appeared to emerge from specific kinds of teacher tasks. The teacher task that appeared to be associated with sophisticated TSPCK episodes were explanation of important content in the lesson for both the GBTs and the expert teacher. For example, teacher Menjo (intervention GBT) displayed a sophisticated episode, (minute 55-65), as he explained the concept of ferromagnetism and the behaviour of magnetic field lines. In the extract, the teacher calls on two learners to come forward and perform a simple demonstration (RP). He then repeatedly probes for learners'

understanding regarding what was causing the compass needles to deflect (an aspect of (LP), before informing them that the needle is ferromagnetic, emphasising that if it was just a needle of plastic, it wouldn't deflect. The explicit emphasis of the compass needle being ferromagnetic and not just a needle made of plastic is evidence of understanding the need to highlight a gate-keeping concept often found difficult for understanding by learners (WD). He explained this observation from the interference of the magnetic fields (CS), which come about as a consequence of the devices being ferromagnetic. Here we see the teacher making connections between ferromagnetism and the behaviour of the magnetic field lines. Talking over a representation (RP), the teacher explained another important point about the position of the needle of the compass being at a tangent to the magnetic field (CS).

The example above shows evidence of thoughts that were developed with the topic of electrochemistry, to which the GBT was exposed during the pre-service intervention studies. In actual classroom teaching, we see the teacher apply the same thoughts to pedagogically engage with the concepts of the topic of electromagnetism, a topic from a different Physical Science learning area (Physics). This demonstrates a concrete example of transfer of acquired PTC across different subject domains. This finding is consistent with Mavhunga (2016) argument that the ability to learn both the knowledge of the five components of TSPCK and their combined interactive use in formulating explanations and responses to questions on teaching a topic, is transferable across related physical science topics.

The contribution made to new knowledge from the above finding is that, unlike the the study by Mavhunga (2016), which was conducted in the context of pre-service teachers' reasoning and planning about teaching a particular topic, in this study, the successful transfer of the competence in transforming content knowledge (PTC), was observed with beginning teachers in real classroom teaching. I consider this finding original to knowledge on enacted TSPCK. The finding is further strengthened by the observation that none of the intervention GBTs chose to teach a topic of their intervention for observation, they all chose a different topic not covered explicitly in the intervention.

On the other hand, the only comparable GBT (teacher Dido), who displayed proficient TSPCK in his enacted lesson teaching profile, was observed to effect a particular kind of learner engagement to the quality of TSPCK. As shown in his teaching sequence profile (section 8.3.1-ii), teacher Dido uniquely engaged learners in class, through building on their responses to introduce the next complex element of the concept under discussion. This learner engagement was different to the standard question and answer approach, as it uniquely used an element of formative assessment of the learners' effort displayed on the board for calculating the nature of his next move. This approach resulted in the teacher generating TSPCK episodes where the component of learner prior knowledge was largely common in his set of TSPCK episodes (Table 8.2). Here learner prior knowledge was expanded to also mean confirmation of understanding of the concepts presented freshly in the lesson a moment ago. This demonstrated a concrete example, where the component of learner prior knowledge refers to the immediate past within the lesson as it unfolds.

The teacher's engagement with learners in constant formative assessment of concepts that had just been taught, thus drawing on their potential misconceptions, seemed to come in strongly as an approach to teaching, rather than as a teacher task. This aspect appeared to help the teacher score in the higher quality category level of proficient TSPCK. This observation was further reflected in his mind set during the pre-lesson interview held, where the teacher indicated that his learners believed the topic was difficult to understand, hence the reason for engaging them in more learner activities throughout the lesson as his teaching approach.

However, when compared to the TSPCK episode lesson profile of the expert teacher, it was noted that the observed higher quality TSPCK seen in the classroom teaching of the intervention GBTs was a little less than that of the expert teacher. For instance, the expert teacher was observed to successfully use a calculated single sentence assessment as a trigger to build the next complicated teacher move, irrespective of the location of the teacher task in the lesson. For example, at (minute 55-65) the teacher, informed by learner interactivity, was seen to re-visit an important concept that had just been taught to explain new content, therein demonstrating the ability to perform reflection-in-action (Scion, 1987). A similar observation was made

when the expert teacher was explaining the concept of Lewis dot structures (minute 25-30); where the teacher was observed to progressively vary the use of examples in his teaching. In the enacted lesson, he first used simple diatomic molecules of Cl_2, and CO_2, this was followed by the ammonium molecule (NH_3) which is slightly more complex. Thereafter the teacher introduced the most complex molecule-NO_2, where learners were allowed to follow the newly learnt octet rule, while at the same time discovering that the rule can be broken, and does not always hold. Such moments of combining conceptual principles and rules of a topic as tools to confront known areas of learner difficulty or potential misconceptions is evident of expert practice.

This observation is consistent with the common theoretical understanding that expert teachers have a richer repertoire of teaching strategies (Kaiser et al., 2015) that novice teachers such as the GBTs are yet to develop. This is in line with Shulman's amalgam postulate of a strong focus of content and pedagogy as part of one indistinguishable body of knowledge (Shulman, 1986, p.6).

The above finding points to an added advantage accrued by an early exposure of pre-service teachers to explicit TSPCK development. Such an exposure seemed to have provided the intervention GBTs with the tools on which to fall back when reasoning about teaching a topic (familiar or unfamiliar), and also when teaching a topic even from a different but related discipline. However, when compared to an expert teacher within the limitations of the design of this study, insight is hinted that the GBTs are yet to develop their own repertoire of strategies that comes with an extended reflective period in practice. For this reason, the value of a good reflective experience in practice is not replaced by the early exposure to TSPCK; but the added advantage is that intervention-GBTs are at least a step ahead in progressing towards such expertise. This finding is the pinnacle of my new contributions to the literature of TSPCK and PCK in broad. It offers a case for consideration when solutions towards closing the challenge in education of finding ways to minimise the persistent and perennial gap between theory and practice are sought.

9.5 Summary of research questions

The main research question asked in this study pertained to how an early exposure of GBTs to explicit PCK development in a specific topic influences the retention of the acquired TSPCK and their actual classroom practice.

In answering this question, it was necessary to first elaborate on the PCK models adopted for this study and the theoretical framework that underpin their relationships in (Chapter 2). It was equally important to be clear about the research methodology followed in enabling the qualitative comparative method used for data collection and analysis in (Chapter 3). The development and validation of a new tool for scoring enacted TSPCK in real classroom teaching was likewise needed and discussed in (Chapter 4).

Given the tacit nature of PCK, and the crucial role that initial teacher education preparation programs play in enhancing teachers' understanding and skill development, it was important to first confirm the reported improvement in the quality of pre-service teachers' TSPCK in the topics of intervention with this particular sample in Chapter 5. The retention of the GBTs quality of planned TSPCK in actual classroom practice was then determined in Chapter 6. This was followed by establishing the advantage derived from the GBTs early exposure to explicit TSPCK in a planning context in Chapter 7, and the nature of enacted TSPCK displayed in the GBTs real classroom teaching in Chapter 8.

To determine for retention of the quality of planned TSPCK as well as enacted TSPCK in real classroom teaching of the GBTs in the early years of their teaching careers, the main research question was re-structured into three sub-questions. Following below is a summary of the findings, conclusions and recommendations, with responses to each research question asked in this study.

Research Question 1: The first research question was used to measure the extent of retention of the quality of planned TSPCK previously acquired from the pre-service teacher training intervention programme by the GBTs in the topics of intervention. This study was built on trustworthy baseline data that confirmed the intervention-

GBTs gain in the quality of TSPCK as a direct result of the exposure to the explicit intervention during their last year of training as pre-service teachers. In addition, the TSPCK tool used was an established, existing valid tool for scoring the quality of planned TSPCK, which was re-evaluated for reliability in this study. The findings to answer the research question were derived directly from comparison of the post-test scores and the in-practice scores freshly administered two years after the post-test.

The answer to this research question is that with the exception of one, the seven intervention-GBTs were able to successfully retain the quality of planned TSPCK, previously acquired at the time of the pre-service intervention programme in the respective topics of intervention two years later into their actual classroom practice.

Research Question 2: The second research question was used to measure the added advantage, derived from the GBTs early exposure to explicit TSPCK development. The comparison for added advantage as a direct result of the intervention required the introduction of a control group comparable to the intervention GBTs. Research Question 2 explored this advantage from a 'planning to teach' context. Data with respect to this research question were collected from two sets of cases (with familiar and with unfamiliar topics) and analysed in comparison to a control group of comparable-GBTs. The reference of one expert teacher who did not experience the TSPCK intervention was added to this sample to provide additional soft insight into the likely quality of expert teaching at the time.
The answer to this research question is that the intervention-GBTs displayed added advantage in the quality of planned TSPCK evident over their comparable GBTs when planning to teach in both topics of intervention and in new topics.

Research Question 3: The third research question was used to measure the quality of the GBTs enacted classroom teaching in topics of their own choice. The analysis was rested on the evaluation of the quality of TSPCK episodes identified in two consecutive video-recorded lessons lasting 45 minutes each, making a total of 90 minutes. The video lessons were captured from real classroom teaching of the same sub-set sample of three intervention GBTs and three comparable GBTs, plus one expert teacher. The seven participants observed during their real classroom

teaching formed seven separate mini-cases, because they all taught different topics across which I searched for evidence of TSPCK episodes, and were not therefore compared in pairs. Additional data was captured from (i) planning for lessons, collected from pre- (post-) lesson interviews and researcher's classroom 'think notes'. A newly developed and validated classroom TSPCK rubric for scoring TSPCK in action was used in order to score and grade the quality of enacted TSPCK displayed in the classroom teaching of all the participants. The tool served to capture and portray the range of TSPCK episodes evident in a lesson. These were presented as TSPCK episode teaching profiles.

The answer to this research question is that the intervention-GBTs demonstrated the added advantage over the comparable GBTs in respect of two aspects: firstly, the intervention GBTs displayed a slightly higher quantity of simple TSPCK episodes than the comparable GBTs in their teaching. Secondly, in contrast to comparable GBTs, where only one teacher displayed proficient TSPCK episodes, all intervention GBTs, in addition to simple TSPCK episodes, further displayed evidence of episodes of TSPCK that could be categorised as proficient. This is a higher order quality of TSPCK. The observed higher quality TSPCK episode profile seen in the classroom teaching of the intervention GBTs was, as in the planning context, a little less than that of the expert teacher who displayed a higher proportion of proficient and sophisticated TSPCK episodes.

The three research questions summarised above provided the findings to enable me respond to the main research question. For the intervention GBTs in this study, an early exposure to explicit TSPCK development in specific topics was found to positively influence the retention of the acquired TSPCK, and provide them with an added advantage in their planning when teaching both familiar and unfamiliar topics. It also improved the quality of their pedagogical transformation of content in the classroom in their chosen topics.

9.6 Conclusions

This study explored an unanswered question in the literature as to whether there is value in exposing pre-service teachers explicitly to TSPCK development in core topics of a discipline. This view followed the widely reported consensus of the value of PCK as knowledge for teaching in science education, and more explicit values when the construct is explored within specific topics (Ayidin, 2015; Potgieter et al., 2017; Mavhunga and Rollnick (2013). My study was inherently linked to the perennial challenge of the theory-practice gap that has captured the minds of education researchers since the outcry by Dewey (1904) a century ago. At the heart of the problem is the recognition of the dissonance between preparation to teach and the actual teaching experience. This incongruence speaks to the lack of connections between what Aristotle named *episteme* and *phronesis*. Accordingly, the conception of knowledge as episteme refers to a body of knowledge about many different concepts. On the other hand, knowledge as phronesis is used for action in specific situations. The possession of one over another would naturally exasperate the theory-practice gap. In science education, the experience is not different to this widely observed trend. Pedagogical Content Knowledge (PCK), especially when offered within topics, has emerged in this study as the theoretical construct that offers science education practitioners a framework by means of which to potentially bridge the theory-practice divide.

The findings in this study have provided empirical evidence for the widely supported claim, made by Abel (2008), that there is value in teaching PCK within topics. In addition, it shows that PCK is topic specific. This study offers insight into the extent, a measure of what the value postulated by science education researchers such as Abel might look like in real and measurable terms.

The study concludes a visible, recognisable advantage in qualitative terms accrued to pre-service teachers who are exposed to TSPCK much earlier in their training programmes than is currently the case.

9.7 Limitations of the study

Qualitative research design, by nature, suffers from the lack of generalisation in the absence of statistical proven evidence. Thus, one cannot generalise the findings as a small sample of seven teachers out of a class of N=24 in the intervention GBTs and out of three in the class of comparable GBTs. Furthermore, the use of one practicing teacher rather than a sample that represents the province, was also quite limiting. The study was also, limited to two years in practice, which is an insufficient basis on which to claim sustainability into the future.

Bias was also understood to be a limitation in collecting and analysing the research data, where video recording the observed lessons could have affected the natural setting and behaviour of the participants and their learners. To mitigate any bias arising from this limitation as mentioned earlier, I enlisted the help of a team of three independent raters, with many years of experience teaching physical science and strong background knowledge in science education and PCK research to assist in scoring data captured from the TSPCK test tools and watching, coding, and analysing the video recorded lessons. I also undertook to fully describe in thick detail, the procedures and methods followed in this research study. This was to make thorough interpretations of all the participants and processes followed throughout the course of study. Furthermore, to minimise on the effect of my presence on the behaviour of both the teachers and the learners, I always stressed the fact that I was there to observe how the teachers were teaching, to try and understand their way of thinking before, during, and after instruction. This was in order to benefit from their experience in practice, and not to judge or critique them.

It is further argued in the literature that generalisations in comparative case study design emphasises the transferability of the causal propositions to other contexts, rather than generalising from one case to a wider set of cases (Goodrick, 2014)**.** This proposition implies that, despite the limitations of the very small sample size, the emerging patterns in this study are convincing enough for exploration of the value in TSPCK with larger samples. The study has shown that it is possible to transfer the

learnt PTC for development of TSPCK across new topics in the context of planning to teach as shown by Mavhunga (2016), but more excitingly, in new topics enacted in real classroom teaching, using the TSPCK theoretical framework as shown in this study.

While limited, the study provides an assurance to a proposed path pre-service teacher programmes are to take in order to influence policy on initial teacher training and on-going professional teacher developments. At the minimal level, the results suggest a kind of an induction programme for beginning teachers.

9.8 Implications within the limitations of the study in the context of South Africa and Africa as a whole

In the following section, I provide the implications and recommendations of this study, within the South African context and share a personal view. This is followed by a reflection on the theoretical framework with respect to the qualitative research design method used and the establishment of ensuring trustworthiness and the limits of the study.

9.8.1 Implication for the science education research community

- Through this study, I have proposed a theoretical framework that links planned Topic Specific PCK to actual classroom practice in Chapter 2. Such an explicit link has enabled the understanding of the translation of planned TSPCK, developed with specific topics during the planning and reasoning context, for development of PCK across related Physical Science topics in real classroom teaching.
- The findings in Chapter 4 have put forward empirical evidence of a valid TSPCK classroom rubric that has the sensitivity of evaluating and grading the quality of enacted TSPCK in real classroom teaching. The new rubric is recommended for use in evaluating and scoring shifts in the quality of enacted TSPCK in both pre-service and in-service teacher professional training programmes.

- The findings in Chapter 8 revealed that, the more complex TSPCK component interactions seemed to emerge from specific kinds of teacher tasks. I therefore recommend further research to be conducted, to identify and develop teacher tasks that appear to promote emergence of complex TSPCK component interactions in teacher education programmes. As pointed out by Mavhunga (2018), identification of such tasks informs science educators of the tasks that promote emergence of TSPCK, which provides evidence of the desired pedagogical transformation of content knowledge.

9.8.2 Implication for science teacher education programmes

- The discussions from the findings in Chapter 5 showed that PCK within a topic can be improved considerably when SMK is presented through learning to reason about teaching a specific topic. Equally, the findings in Chapter 6 revealed that the quality of planned TSPCK, acquired through explicit discussions of the knowledge that effects transformation of content knowledge in core Science topics among prospective science teachers can be retained in actual classroom practice. It is therefore recommended that teacher preparation methods courses could model their teaching programmes alongside the TSPCK theoretical construct, where the content of each specific concept in a science topic is separately thought about and reasoned through the five content specific components of TSPCK. This finding has immediate potential benefits for teacher preparation in South Africa, with an acute shortage of skilled educators in the areas of Mathematics and Science education (DEB, 2014) and an inadequately prepared Science teaching force.
- The findings generated from Chapters 7 and 8 showed that beginning physical science teachers, who have been exposed to explicit PCK development in core science topics, displayed an added advantage in the quality of both planned and enacted TSPCK across different physical science topics in their actual classroom teaching. These findings suggest that the intervention GBTs were able to export the ability to learn both the knowledge of the five components of TSPCK, as well as their combined interactive use in

formulating explanations and responses to questions on teaching a topic in the same perspective with new topics in actual classroom practice. This ability is known to be a desirable attribute of expert teachers, and is acquired over extended periods of practice, reflection and trial and error. The findings however appear to suggest that an early exposure to explicit TSPCK development in specific topics may lead to retention and importantly transference of the acquired competence to other topics. It is therefore recommended that rather than trying to touch on almost every aspect of educational theory and practice, teacher preparation methods courses should give priority to development of PCK in specific research-based core science topics that are known to nurture important student engagement and learning. This recommendation is in line with the core practices movement, which calls for conceptualisation of a teacher preparation framework that is organised around those core practices and pedagogies that are most essential to efficient teaching (McDonald et al., 2013; Windschitl et al., 2012).

- This study further recommends structured context-specific TSPCK based induction programmes to catch those cohorts of beginning teachers without the TSPCK exposure. Such programmes would have the immediate benefit of sealing the transition theory/practice gap between beginning teachers initial years of teaching and teacher expertise. The programmes will also have an immediate benefit for developing counties like South Africa, which have no nationally coordinated teacher induction programmes.
- For developing countries like Kenya, and other African countries that are in the process of reforming their current high stakes examination-oriented education systems to a competency based education learning, the study offers a glimpse into the kind of competencies to be considered for adaption in teacher preparation programmes.

9.9 Critical reflections of the research process

Each chapter of this study opened with a short reflection on the purpose and progress of the research process. This assisted in creating a connection and flow from one session to another, even though different aspects were discussed. Following below is a reflection on the formulation of a conceptual framework, in which investigations were conducted on the transfer of the acquired pedagogical transformation competence (PTC) developed with specific topics during the planning and reasoning context and across new topics in real classroom teaching.

9.9.1 Conceptual Framework: Planned TSPCK translated into classroom practice

This study was grounded in the broader pedagogical content knowledge theoretical framework, by acknowledging Shulman's statement that: "comprehended ideas must be transformed in some manner if they are to be taught" (Shulman, 1987, p.16). The framework, however, shows a particular focus on the level of teacher knowledge located at a topic level of the TSPCK, as suggested in the taxonomies of PCK (Nezvalová, 2011; Veal & Makinster, 1999). The framework thus draws on selective aspects from both the Mavhunga (2012), the TSPCK model, and the consensus Teacher Professional Knowledge and Skill (TPK & S) model in Gess-Newsome (2015).

The Mavhunga (2012) TSPCK model, which is drawn from a teacher's ability to transform content knowledge of specific topics into teachable forms, considers afterGeddis and Wood (1997) that content knowledge is transformed through the five content-specific components of TSPCK. The model thus separates the teacher knowledge needed for teaching specific topics from the broader teacher professional knowledge bases.

The topic-specific nature of the Mavhunga model (2012) allowed me to explore and link the transfer of the acquired ability to transform content knowledge, developed at the time of the pre-service teacher training programmes, with a single topic as planned TSPCK across other Physical Science topics in real classroom teaching.

On the other hand, the consensus Teacher Professional Knowledge and Skill (TPK & S) model in Gess-Newsome (2015), also separates the teacher knowledge needed for teaching specific topics from the broader teacher professional knowledge bases. The model however goes further to reveal how the topic specific professional knowledge of PCK, which has been equated to TSPCK in this study, translates into real classroom teaching. According to the framework, planned TSPCK is linked to actual classroom practice through a series of teachers' and students' filters and amplifiers. The TPK & S model allowed for exploration of the factors that enhance and/or filter the translation of GBTs' acquired pedagogical transformation competence (PTC) across new topics in real classroom teaching. The resulting integrated theoretical model (Figure 2.6) shows the interrelationships between the two models depicting the transfer of acquired PTC with specific topics, across new topics in real classroom teaching.

The framework further acknowledges that generally, classroom practice can directly inform and be informed by the broader generic knowledge bases. I have called this frame 'Planned TSPCK translated into classroom practice'. I view this frame as original.

Although the new refined consensus model (RCM) was published towards the end of this study, I can however see some connections with my proposed framework that I would like to point them out here in order to influence future studies from your work. The proposed integrated frame is linked to the three realms in the consensus model, in that it reveals the sequence where the developed collective knowledge of pre-service teachers (cPCK) in specific topics, is first acquired by individual beginning teachers as personal PCK (pPCK). The acquired personal PCK or planned PCK is then enacted in real classroom teaching as enacted PCK (ePCK) (Figure 2.6).

9.9.2 The research methodology used

The interest of this study was centred on understanding the extent to which the quality of planned TSPCK previously acquired by beginning teachers of Physical Science (GBTs) from pre-service teacher intervention training programmes is retained in actual classroom practice. The other interest was to establish the

advantage, derived from an early exposure to explicit PCK development in a specific topic. I thus employed the qualitative research of a multiple comparative case study design (Merriam, 2009). The advantage of comparative case studies, especially in understanding the success of an intervention were explored through qualitative and to a lesser extent quantitative methods, with the intention of gaining in-depth understanding of the cases (Goodrick, 2014, p. 5). These aspects have been demonstrated in this study through in-depth analysis of the participants' video recorded lessons and comparisons of completed TSPCK test tools.

I maintained the purpose of the study throughout the research process and thus reflect on the benefits of a qualitative multiple comparative case study design.

9.9.3 Understanding how context influences the success of an intervention

The qualitative multiple comparative case study design helped me to first measure retention of the quality of the GBTs' planned TSPCK, acquired at the time of the pre-service teacher training intervention programme. To realise this, freshly analysed qualitative pre- versus post-intervention, TSPCK tests were quantitatively processed and compared to show evidence of improved TSPCK in the topics of intervention. The findings from these data sets served as a credible and trustworthy baseline from which the comparison with measurements for retention of the acquired quality of TSPCK in actual practice was measured.

The retention of acquired quality of TSPCK was then measured by comparing qualitative data sets that were quantitatively processed in a similar way, to show evidence of retention of planned TSPCK in the same topics used during the intervention studies; both at the end of the intervention, as well as two years into professional practice, in 2016. Some of the post-versus in-practice qualitative responses showing evidence of retention of the acquired quality of TSPCK have been included in Chapter 6.

To establish for any added advantage with respect to planned TSPCK in the teaching practice derived from the GBTs early exposure to explicit PCK development in

specific topics on planned TSPCK at the time of the pre-service training programme, comparisons of qualitative data sets were also quantitatively processed in the respective topics of intervention and new topics. The findings showing evidence of added advantage in the quality of planned TSPCK between three intervention GBTs who formed a sub-set from the total seven, controlled by a sample of three comparable GBTs, as well as one expert teacher, have been included in Chapter 7.

The completed TSPCK test tools were analysed and scored using the criterion-based TSPCK rubric forwarded by Mavhunga & Rollnick (2013), for scoring the quality of planned TSPCK.

As mentioned in Chapter 3, the scoring rubric was developed and validated in a separate study (Mavhunga and Rollnick, 2011) and used in several other studies (Rollnick. et al., 2017; Rollnick. & Mavhunga, 2016).

Lastly, the added advantage derived from an early exposure to explicit PCK development in specific topics on the nature of the GBTs' enacted classroom teaching, was measured. The process followed involved evaluating and grading video-recorded lessons of enacted classroom teaching of the same sample of three intervention GBTs and three comparable GBTs, plus that of one expert teacher in topics of their choice. A newly developed and validated TSPCK classroom rubric, reflected on in section 9.3 above, was used to evaluate and grade shifts in the quality of enacted TSPCK displayed in the observed video lessons.

The qualitative data collected from the observed video lessons were further processed and used to portray enacted TSPCK more explicitly through quantification and visual displays in form of TSPCK maps. Therefore, the visible evidence of the TSPCK component interactions revealed the quality of enacted TSPCK in this study.

In addition, pre- and post-lesson interviews and researcher field notes were also evaluated for emerging patterns from the video recorded lessons. Some of the video recorded lessons have been included in Chapter 8 in the form of transcripts that provide supporting evidence of improved enacted classroom teaching.

Two major findings identified in this chapter were that; the intervention-GBTs advantageously exhibited a higher quantity of TSPCK episodes in their classroom

teaching that denoted higher quality TSPCK compared to the comparable GBTs. The second finding is that all the intervention GBTs in addition to simple TSPCK episodes further displayed evidence of episodes of TSPCK that could be categorized in the higher order quality of proficient TSPCK. Both these findings were well evidenced using the teaching profiles, which indicated the quality, timinig and number of TSPCK episodes for each participant. Furthermore, the visual representation of the episodes in form of TSPCK maps made it easy to compare and contrast the teachers in addition to identification of the specific teacher tasks, where sophisticated TSPCK was likely to emerge.

The comparative case study design therefore enabled me and the team of the three enlisted independent raters, who helped in the peer validation of the generated test scores, to carry out in-depth explorations of interactions of TSPCK episodes, even with the small sample size of this study.

Generally, the environment in the classrooms observed was welcoming. However, some of the participants felt uneasy, especially with regards to being video recorded. This anxiety was promptly addressed by re-assuring the participants of the anonymity of their identities. In addition, the participants talked about the probable challenges they experienced in enacting specific topics with their learners during the pre- (post-) interview sessions. The responses provided from these sessions were however brief, with little elaboration.

9.9.4 Answering questions about causal attribution and contribution

The use of comparative case study design allowed me to compare shifts between the quality of planned TSPCK and its retention in practice, both retrospectively and prospectively. The comparisons of responses generated from TSPCK test scores and the recorded video lessons between the intervention-GBTs, and the comparable GBTs helped me to establish the causal relationships, resulting from the GBTs' early exposure to explicit TSPCK development, and their actual classroom practice.

There were however a few cases where I borrowed some component from the mixed methods design, such as proving for validity of the TSPCK classroom rubric for scoring TSPCK in action in Chapter 4. This is where I provided both arguments for interpretive argument and the calculated argument, as well as use of the kappa reliability calculations instead of statistical calculations. The mixed methods component was, however, so minimal as to warrant calling this study mixed methods. The use of a control group was also found to be best, although within reason, as it would have been unethical to have a control group in the same class as that where the investigations were conducted. This would have meant half the class was not exposed to TSPCK.

I therefore made sure the study did not suffer from the "Hawthorne effect", where participants subconsciously modify their behaviour to fit the expected results of an experiment, when they are aware that they are part of an experiment, by introducing the control group. This effect could have made it very difficult to determine whether the observed improvement in the quality of TSPCK was a direct result of the TSPCK based intervention programme or not.

The study however, took place in the presence of other factors, which made it difficult to account for the causal effect of a single factor, the impact of the TSPCK intervention on the classroom practice of the intervention GBTs over time. I thus acknowledge, as pointed out by Wunsch et al. (2010), that there are a number of factors that operate over time, due to changes in behaviour, and modifications of the environment or context.

9.9.5 Validity and trustworthiness

Some of the practices widely reported to contribute to the quality of data collected have been mentioned at various points in the discussions above. This included the use of variety of sources of data called triangulation. The use of video recorded lessons, interviews and lesson plans etc. to collaborate written responses, helped to reduce my own bias and establish credibility of the research findings. Trustworthiness was also ascertained through involvement of a team of experienced

independent raters, who assisted in analysing the responses captured from completed TSPCK test tools, as well as watching the video recorded lessons, and scoring the identified episodes in the prescribed quality categories in the newly-developed and validated TSPCK classroom rubric.

9.10 Future research

This study has shown that firstly, improvement in the quality of planned PCK, as a direct result of an explicit discussion of transformation of content knowledge as a teaching strategy in a pre-service programme, could be retained in actual classroom practice. Secondly, the pedagogical transformation competence (PTC) learnt, through the explicit discussion of the knowledge components that effects transformation of content knowledge in core science topics in a planning and reasoning context is transferrable for development of PCK in new topics in real classroom teaching. As mentioned above, the findings of this research study are exploratory at this scale. There is therefore a need for further research to establish the influence of an early exposure to explicit PCK development in specific topics on the retention of the aquired PTC for planning and enactment (or not as the case may be) across different science topics and other topics of closely related disciplines on a bigger sample of beginning teachers.

Secondly, this study investigated the impact of the TSPCK-based intervention program on retention of the quality of GBTs' acquired TSPCK and their current classroom practice. The study however omitted an important aspect, namely that the intervention could contribute to learners' performance outcomes. I therefore recommend future research on the impact of the TSPCK-based intervention programme on learners' classroom performance outcomes. There is little doubt that a study on teacher preparation-teacher practice-student outcomes relationship would be beneficial in understanding the impact of the TSPCK construct, and its effect on student learning outcomes. Such evidence regarding what teachers learn in their training programmes, what they subsequently do in their classrooms as new professionals, and what their learners learn as a result, may provide the information

required to work towards creating better teachers, better teaching, and better classroom outcomes.

9.11 Final remarks

I started this study with a simple question as to whether an early exposure to explicit PCK development in a specific topic translates to coherent and effective classroom practice by graduate beginning teachers of physical science (GBTs). Little did I know my own conceptual understanding of PCK, and by extension TSPCK as a valid theoretical construct for implementation within topics in initial teacher preparation programmes, and its transfer in real classroom teaching.

A reflection of the findings generated in this study suggests that the idea of TSPCK as a valid theoretical construct has the potential of making a difference in preparing science teachers, who can successfully manifest good conceptual understanding of science topics/concepts on entry into their new profession. I have come to understand the potential hidden in understanding the set of the five content specific knowledge components of TSPCK, and their interactive use in developing TSPCK across Physical Science topics in real classroom teaching.

I end this study with a quote by Darling-Hammond (2012), who aptly sums up the challenge for teacher professional standards as follows: *the critical question for the teacher standards movement is as to how the standards will be used, how universally they will be applied, and how they may leverage stronger learning opportunities and a more common set of knowledge, skills and commitments across the profession.* She adds that robust standards weakly applied can be expected to have much less effect than those that are used as in other professions as an inviolable expectation for candidates and institutions to meet (quoted in OECD, 2013a: 42).

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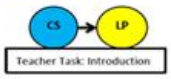
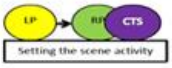
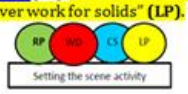
APPENDICES

APPENDIX A: THE MAVHUNGA & ROLLNICK (2013) RUBRIC FOR SCORING PLANNED TSPCK

	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • No attempt to address the misconception.	• Identifies misconception or prior knowledge • Provides standardized definition as a means to counteract the misconception • No evidence of drawing on other TSPCK components.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using one other component of TSPCK interactively.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on two or more other component of TSPCK interactively.
Curriculum Saliency	• Identified concepts are a mix of Big Ideas and subordinate ideas • Identified pre-concepts are far from topic • Sequencing no value due to mixed concepts • Reasons given are generic - benefit of education.	• Identifies at least 3 Big Ideas • Not all 3 Big ideas subordinate concepts identified • Suggested sequencing has one or two illogical placing of Big Ideas. • Identified pre-concepts are far from the current topic • Reasons given for importance of topic exclude conceptual considerations and show no evidence of drawing on other TSPCK components.	• Identifies at least 3 Big Ideas • Subordinate concepts correctly identified for all Big Ideas • Provides logical sequence • Identifies pre-concepts relevant to the topic • Reasons given for importance of topic include reference to conceptual scaffolding/sequential development draw on one other TSPCK components e.g. what makes topic difficult.	• Identifies at least 3 Big Ideas • Subordinate concepts correctly identified for all Big Ideas with explanatory notes • Provides logical sequence of all three Big Ideas and with logical reasons • Identifies pre-concepts relevant to the current topic and explanatory notes given • Reasons given for importance of topic include conceptual scaffolding with reference to other TSPCK components e.g. Learner Prior Knowledge and what makes topic difficult.
What makes topic difficult	• Identifies broad topics without reasons and specifying the actual sub-concepts that are problematic.	• Identifies specific concepts but provides broad generic reasons such as 'abstract'.	• Identifies specific concepts leading to learner difficulty • Reasons given relate to one other TSPCK components.	• Identifies specific concepts with reasons linking to specific gate keeping concepts and to TSPCK components such as prior knowledge and aspects of curricular saliency.
Representations	• Limited to use of only macroscopic analogies, demos, etc.) representation with no explanation of specific links to the concepts represented	• Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.	• Use of macroscopic representation and use of scientific symbolic representation with explanatory notes linking the two representation to the aspect(s) of the concept being explained • Use of above representations combination with reference to one other TSPCK components e.g. learner prior knowledge	• Use of macroscopic representation or symbolic representation with sub-microscopic representation to enforce a specific aspect • Explicit link to other components of TSPCK e.g./emphasis of core aspect of CK demonstrated in the representations and learner prior knowledge
Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions • Lacks aspects of curriculum saliency • Use of representations limited to macroscopic or symbolic scientific symbolic representation	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy • Lacks aspects of curriculum saliency • Use of macroscopic and symbolic representations with no linking explanatory notes	• Considers confirmation/confrontation of student prior knowledge and/or misconceptions • Considers at least one aspect related to curriculum saliency e.g. sequencing or what not to discuss yet or emphasis of important concepts • Uses at least two different levels of representations to enforce understanding.	• Considers student prior knowledge and evidence of confrontation of misconceptions. • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding and may show awareness of learner difficulty.

APPENDIX B: TSPCK CLASSROOM RUBRIC FOR SCORING TSPCK IN ACTION WITH SAMPLE ANCHORS

Type 1: Simple TSPCK Episode	Type 2: Proficient TSPCK Episode	Type 3: Sophisticated TSPCK Episode
• Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teacher task segment • The TSPCK component interactions maybe interwoven or have a linear sequence structural formation. • Both components work together to support an explanation of a single or a pair of concepts that are related	• Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teacher task segment Or one of 3 components is addressed implicitly based on the choice of representation or explanation Or Evidence of three different TSPCK components interacting, evidently and distinguishably in a specific teacher task segment, but one component repeating and bringing a different level of explanation that complements the initial emergence. • The TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both • The three components work together to support an explanation of a single or a pair of concepts that are related	• Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment or • Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment, with one of the components repeated more than once or one of the components bringing different levels of sophistication (e.g. representations used at macro, symbolic and sub-microscopic levels. • TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both. • All the TSPCK components work together to support an explanation of a single or a pair of concepts that are related
Teacher: "We are going to learn about a new physical quantity, referred to as the mole" **(CS)** **Teacher:** "what do you understand by the term mole? What comes into your mind when you hear the word amount? A pair of shoes, a dozen eggs **(LP)**. **TSPCK Map** 	**Teacher;** "Before we can start this lesson, who can tell me what an atom is? What is atomic number" **(LP)**. The teacher draws the structure of the lithium atom on the chalk board, indicating the sub-atomic particles **(RP)**. He then develops a table matrix, over which he introduces the octet rule, by explaining variations in the number of electrons across elements **(CTS)**. **TSPCK Map** 	The teacher displays a visual slide of the Hoffman's apparatus showing electrolysis of water. **Teacher:** "What do you notice about the volumes? How do you know which flask contains H_2 & which one contain O_2? He then explains the observed differences over the visual slide, linking the reacting mole ratios, with the resulting gaseous volumes **(WD)**. **Teacher;** "An important property about gases is that the same quantity (mole) of any gas at STP occupies the same volume (22.4 dm^3 " **(CS)**. He then cautions that; this does not however work for solids" **(LP)**. **TSPCK Map** 

APPENDIX C: PRE-LESSON INTERVIEW QUESTIONS

1. What do you intend the students to learn from this lesson?
.....
.....
.....
2. Why is it important for students to know about this topic/concept?
.....
.....
.....
3. What teaching strategies/procedures would you take to engage your students?
.....
.....
.....
4. Why would you implement such teaching procedures?
.....
.....
.....
5. What difficulties about students' thinking do you think could influence your teaching of this lesson?
.....
.....

APPENDIX D: POST-LESSON INTERVIEW QUESTIONS

1. How do you think the intended lessons objectives were achieved?

……

……

2. Could you recall what assisted you to explain the concepts?

……

……

3. What challenges did you experience?

……

……

4. What would you do differently next time if any?

……

……

APPENDIX E: CHEMICAL EQUILIBRIUM RESEARCH PROJECT-QUESTIONNAIRE

This information is for research purposes only: your responses will be treated confidentially. Pseudonyms will be used if a need to refer arises. This page will be detached and stored separately.

SECTION A: BACKGROUND INFORMATION

Female	Male

NAME AND SURNAME: Gender (tick):

HOME province and town:

Code: ……

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. What comment would you write on a learner's script who writes:

A reaction reaches equilibrium when the concentrations of the products and reactants are equal.

Response A: No; when a reaction reaches equilibrium it does not mean the concentrations of the reactants and products are equal. The concentration of reactants and those of products are not equal at equilibrium. Sometimes the concentration of reactants is more than that of products and vice-versa. It depends on the type of reaction.

Response B: No*;* when a reaction reaches equilibrium the concentration of the products and the reactants are not equal. Equilibrium is reached when both reactions proceed at the same rate.

Response C: No; the concentration of reactants and products at equilibrium are not necessarily equal. Each reagent may have its own concentration which is different to the other. What ensures a reaction to be at equilibrium is the rate at which the forward and the reverse reaction occur. For equilibrium to occur this rate must be equal for both reactions.

Response D: None of the above

Choose your response, and use the space below to expand on your choice.

2. In a classroom setting, which of the following responses will you choose to answer a learner who seems to be in doubt and asks you:

''Do both the forward and the backward reaction actually take place if a closed system is at equilibrium?''

Response A: Yes; the rate at which the forward reaction occurs is the same as the rate at which the backward reaction occurs.

Response B: Yes; for a reaction to be considered as at equilibrium, the rate of the forward reaction is the same as the rate of the reverse reaction. As products are formed, they decompose or react with each other and form reactants. In this way the reaction is kept at equilibrium.

Response C: Yes; a reaction that is at equilibrium has a forward and a reverse reaction. The forward reaction produces products and the reverse reaction produces reactants.

Sometimes the concentration of products is higher than reactants, sometimes vice versa.

Response D: None of the above.

Choose your response, and use the space below to expand on your choice.

CATEGORY B: CURRICULUM AWARENESS

3. Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the **three main ideas** (main concepts) to be taught about equilibrium at Grade 12? Choose from the list provided.

Dynamic equilibrium	Equilibrium constant
Chemical reactions	Rate of reaction
Lê Chatelier's principle	Equilibrium shift
Factors that affect equilibrium	Calculation of equilibrium concentrations
Open and closed systems	Homogeneous and Heterogeneous equilibrium
Physical equilibrium	Forward reaction and reverse reaction
Extent of reaction	Other

1.
2.
3.

3.1 Make a map or a diagram of these three ideas showing how they link to subordinate ideas.

3.2 What topics must have been covered in chemistry before you can teach chemical equilibrium?

3.3 Make a map or a diagram of these three ideas showing how they link to subordinate ideas.

3.4 What topics must have been covered in chemistry before you can teach chemical equilibrium?

List of Topics to be taught before Chemical Equilibrium	**Place them in a sequence** (the one to be taught first , place it as No. 1)	**Provide reasons for the proposed sequence**

		.

3.5 Why is it important for learners to learn about equilibrium? Identify reasons related to:

Conceptual progression
Application
Motivation or Interest

CATEGORY C: WHAT MAKES THE TOPIC DIFFICULT TO UNDERSTAND?

4. Tick (✓) from the list below, concepts of chemical equilibrium you consider difficult to teach? You may also add your own. Explain why you consider the chosen topics difficult to teach

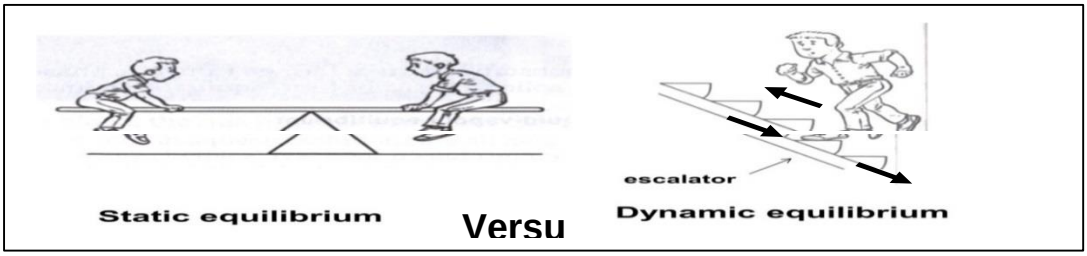
Concept	✓	**Why considered difficult?**

CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

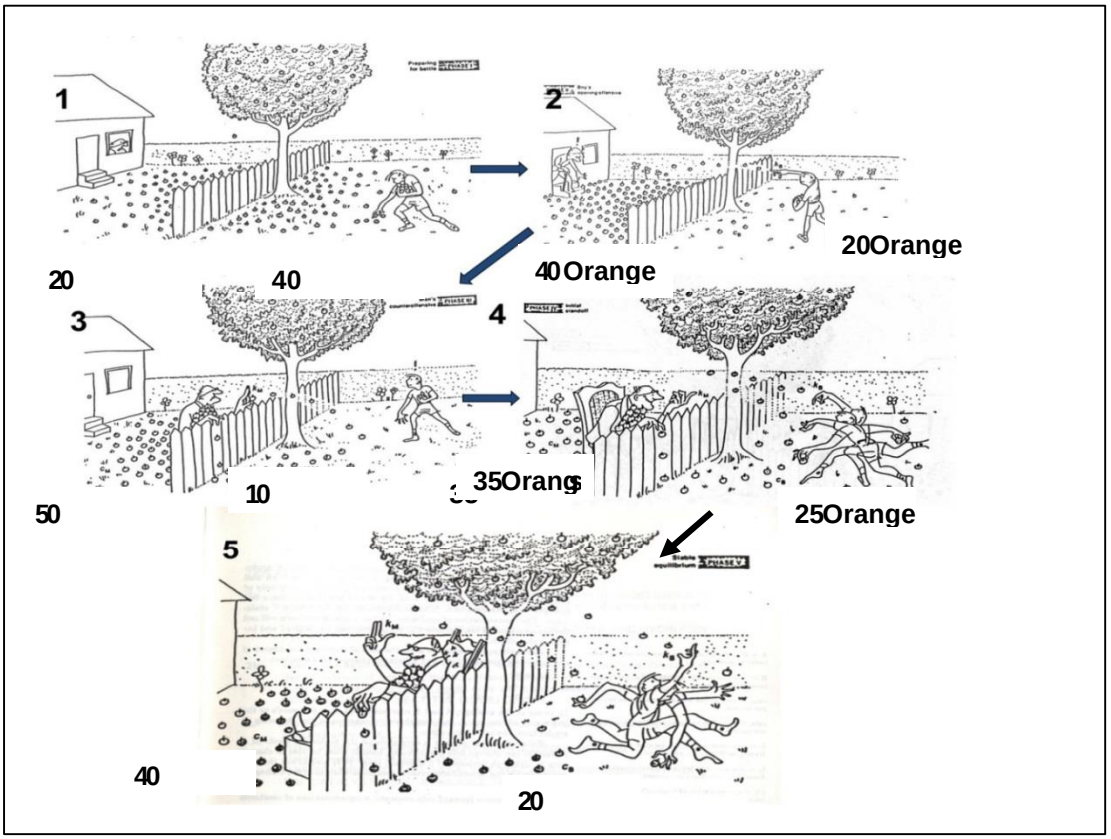
Dynamic and Static equilibrium

5. Below are possible representations/analogies/models for teaching the concept of static versus dynamic equilibrium.

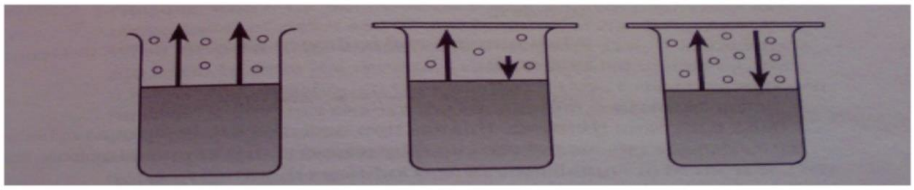
Representation 1



Representation 2



Representation 3



5.1 Complete the table below by providing as many details as possible.

Representation No.	What I Like	What I do not like
1		
2		
3	.	

5.2 Which representation do you like most?

5.3 How would you use the representation that you like most?

CATEGORY E: TEACHING STRATEGIES

Le Châtelier's' Principle

6. Following below is a student's written response in a class test designed to assess prior knowledge of students about Le Châtelier's' Principle.

Question:

What is the effect of adding more water to reaction given below at equilibrium?

$CH_3CO_2H\ (aq) + H_2O\ (l) \rightleftharpoons CH_3CO_2^-\ (aq) + H_3O^+(aq)$

A student responded:

'More $CH_3CO_2^-$ (aq) and H_3O^+ (aq) will be formed, to counter act the effect of adding more water to the reactants. This will happen until a new equilibrium is reached'.

6.1 Following the student's response, how will you teach a lesson on predicting the effect of factors disturbing the equilibrium*?*

APPENDIX F: ORGANIC CHEMISTRY RESEARCH PROJECT-QUESTIONNAIRE

This information is for research purposes only: your responses will be treated confidentially. Pseudonyms will be used if a need to refer arises. This page will be detached and stored separately.

BACKGROUND INFORMATION

SURNAME: _____

NAME _____ Gender (tick✓):

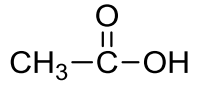
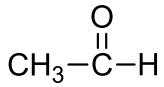
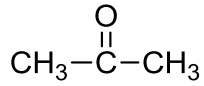
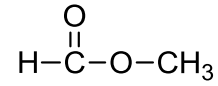
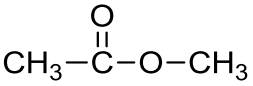
Female	Male

HOME province and town: _____

Personal Code:

SECTION A: STUDENT'S PRIOR KNOWLEDGE

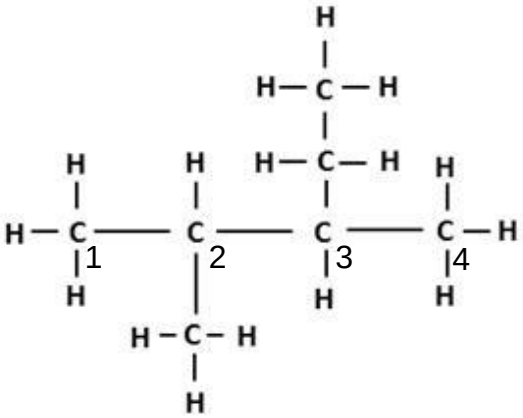
1. You hand out a worksheet to be used in a classroom activity and ask students to select compounds that are alcohols from the table below:

1 CH_3-OH	2 	3 	4 CH_3-CH_2-OH
5 	6 	7 NaOH	8 

Sipho selects compounds 1, 2, 4 and 7. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds?

2. You have asked the students in your class to name the compound below according to the IUPAC rules. You encourage students to work in pairs to complete this task.

Mary is confused about naming the compound and asks Charlie for help. Charlie starts by identifying the longest chain from left to right and ends up with four carbon atoms numbered as shown on the diagram below. He names this compound butane, he then states that there is a methyl group at C2 and an ethyl group at C3.



Both Mary and Charlie agree that this compound is 2-methyl-3-ethyl-butane. How would respond to these two students?

SECTION B: CURRICULUM AWARENESS

1. Which of the following would you consider the **four** most important chemical concepts that must have been covered in Chemistry before you can teach organic Chemistry? Indicate your choice with a tick [✓] next to each concept that you choose, and give a reason for your choice. You can also add any other concepts.

Concepts	✓	Reason
The atom		
Periodic Table		
Chemical bonding		
Mole and stoichiometry		
Electronegativity		
Intermolecular forces		
Gas laws		
Acids and bases		
Electrochemistry		
Chemical equilibrium		

2. Which of the following would you consider to be the **three main concepts (big ideas)** to be taught in organic Chemistry at Grade 12? Indicate your choice with a tick [✓] next to each concept that you choose.

Concept	
Carbon has a unique nature	
Organic compounds are named according to the IUPAC system.	
Alkanes have unique properties.	
There is a relationship between physical and chemical properties	
Some acids belong to the homologous series known as carboxylic acids.	
There are different ways of representing organic substances.	
There are several major types of reactions for organic materials.	
Structural isomers have the same molecular formulae.	
Alkenes undergo combustion.	
Functional groups in organic Chemistry tell us about the different types of compounds.	
Empirical formulae tell us how many atoms of each kind are present in compounds.	

3. In the table below list these main concepts you have chosen in the order in which they should be taught.

4. Explain briefly your reasons for the order you chose.

_____

_____

5. Make a map or a diagram of the three concepts which you chose in 2 above showing how they link to subordinate concepts.

6. Why is it important for students to learn about Organic Chemistry? Identify reasons related to:

SECTION C: WHAT MAKES THE TOPIC DIFFICULT TO TEACH?

Which of the following organic Chemistry sections (topics) do you consider difficult to teach? Explain why these topics are difficult to teach.

Concept	**Why is it difficult to teach the concept?**
Molecular formulae	
Structural formulae	
Functional groups	
IUPAC names	

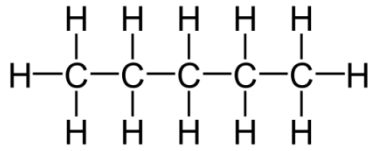
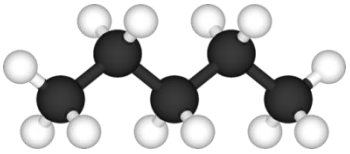
Isomers	
Homologous series	
Types of organic reactions e.g. substitution, addition and elimination	
Combustion	
Esterification	

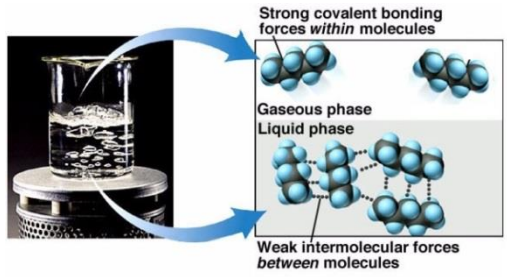
SECTION D: REPRESENTATIONS/ANALOGIES/MODELS

1. There are many ways of representing a molecule with molecular formulae C_5H_{12}, (pentane). Representations for C_5H_{12} are shown below.

a) Which representations do you find the most useful?

b) Complete the table and describe when you would use each of these representations in your teaching.

Representation	Use in teaching
1 	
2 	
3 CH_3-CH_2-CH_2-CH_2-CH_3	
4 	

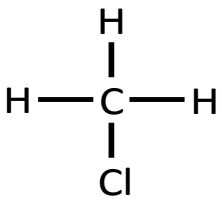
5		

Section 5 continued

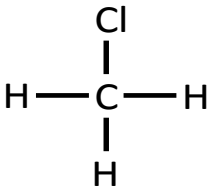
c) How would you use the representation(s) that you chose in (a) on the previous page to explain the differences in the boiling points of butane (-0.5°C) and pentane (36°C)?

SECTION E: TEACHING STRATEGIES

1. You draw the structure of chloromethane as shown below on the chalk board.



Teacher's Drawing

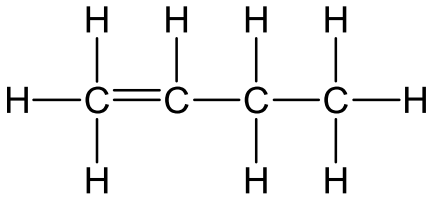


Student's Drawing

A student asks: "Is it okay if you swop around the chlorine and a hydrogen atom like this (the student draws a second structure as shown above)".

How would you teach a lesson about the different ways of representing organic molecules to this class?

2. In a diagnostic test a student drew the incorrect structure below.



Given that you have taught your students how to draw structural formulae, how would you conduct a revision lesson, to correct this student's response?

APPENDIX G: ELECTROCHEMISTRY CHEMISTRY RESEARCH PROJECT- QUESTIONNAIRE

The purpose of this research is to find the difficulties associated with teaching of electrochemistry. The Information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity
Code…

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. How do you respond verbally to a learner who writes on a script?

''The electrons flow through the salt bridge to keep the galvanic cell neutral''

Response A: No, this is not the case; the electrons do not flow through the salt bridge to keep the galvanic cell neutral but through the external circuit. Only ions flow through the salt bridge.
Response B: No, this is not the case; electrons need a medium like a wire (solid) which is a good conductor for them to flow. The salt bridge contains a solution and only ions can flow within the salt bridge.
Response C: No, this is not the case; electrons flow through the external wire whereas the ions flow through the salt bridge. The flow of the ions through the salt bridge will maintain the Galvanic cell electrically neutral.
Response D: None of the above. I have another response, which is…

Choose your response and indicate the reason(s) for choice in the space below:

My choice is **Response _____.**

2. What will your answer be to a learner who asks?

"Is it true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction always occurs at the cathode?"

Response A: Yes, it is true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction always occurs at the cathode. The electrons may be lost by the anode material or by the ions near the anode and gained by ions near the cathode.
Response B: Yes, it is true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction at the cathode. The difference is that, in the electrolytic cell the anode is positive while the cathode is negative and vice versa for the galvanic cell.
Note that electrons flow from the anode to the cathode.
Response C: Yes, it is true, in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction at the cathode. However, in the electrolytic cell the cathode has a negative charge and the anode has a positive by virtue of being connected to the positive terminal of the cell.
Response D: None of the above. I have another response, which is…

Choose your response and indicate the reason(s) for choice in the space below:

My choice is **Response _____.**

3. Reflecting on your experience of teaching electrochemistry, what misconceptions have you observed common in this topic?
Write your answers in the spaces given below:

CATEGORY B: CURRICULAR SALIENCY

4. The following questions relate to planning and sequencing of concepts.
4.1 What concepts in electrochemistry at Grade 12 do you believe are the main ideas1 for understanding by students at the end of the instruction of this topic?
Choose at least three from the provided list and place them in a sequence that depicts the best order of teaching. Provide reasons for both your choice and suggested sequence

Oxidation and reduction occur simultaneously.	Equations must be balanced
Energy from chemical reactions can produce electricity	Electrochemistry has important applications in everyday life
Electrical neutrality is preserved in a cell	Electroplating processes use redox reactions
Electrode potentials are linked to the energy of the half reaction	Calculation of cell potentials
Half- cell reactions are linked to electrode potential	Galvanic cells produce electricity
Ions carry charge in solution Other	Other
Electricity can be used to produce a chemical reaction.	

1 Main ideas are statements describing key understanding that must be learnt in a topic.

Suggested concepts and sequence	**Reasons**
1	
2	
3	

4.2 Make a map or a diagram showing how these three ideas link to subordinate concepts

4.3 What topics must have been covered in chemistry before you can teach electrochemistry?

List of Topics to be taught before electrochemistry

4.4 Why is it important for learners to learn about electrochemistry? Identify reasons:

CATEGORY C: UNDERSTANDING OF WHAT MAKES TOPIC EASY OR DIFFICULT TO UNDERSTAND

5. What concepts do you find difficult to teach in electrochemistry? Select your choice and provide reason(s) in the table below.

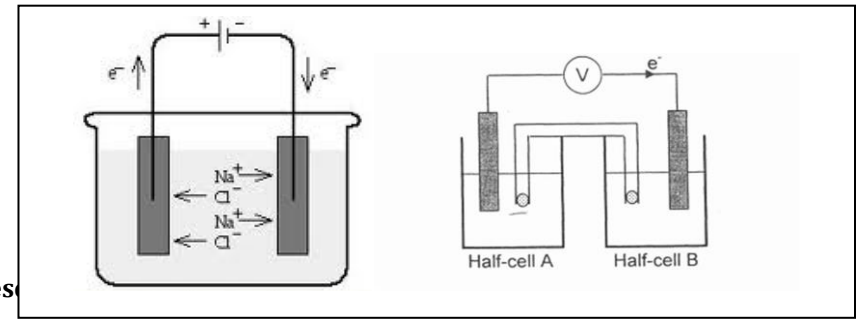
Concept	√	Why is it difficult to teach?
Cell construction Galvanic vs. electrolytic cells		
The calculation of cell potentials		
Identification of anode and cathode using EΘ values/ Using half- cell reactions to identify the electrodes		
Conduction in the electrolyte		
Electrical neutrality		
Working with the electrode potential values		
Deciding positive and negative electrodes in galvanic and electrolytic cells		

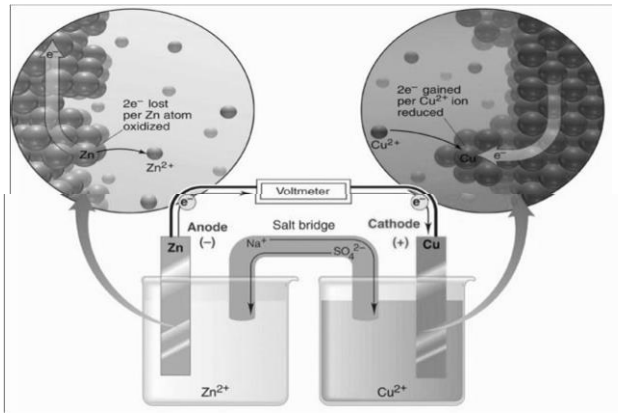
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

7. Below are possible representations for teaching the concept of electrochemical cells (galvanic and electrolytic cells).

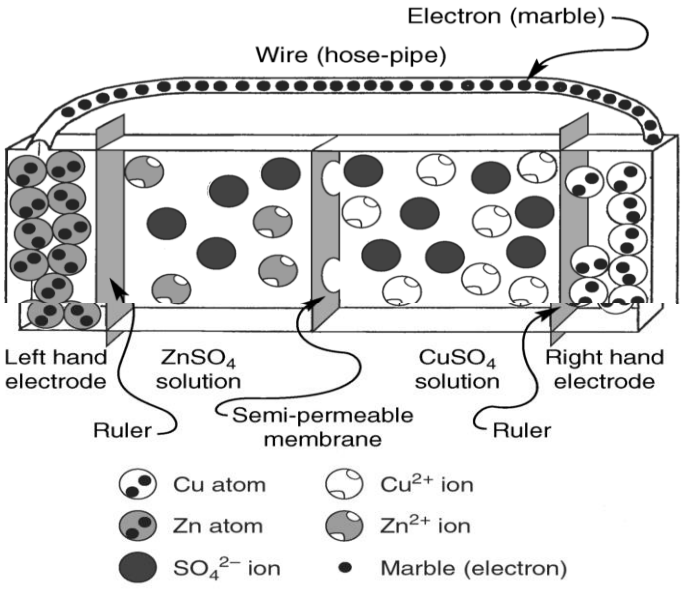
Representation 1

Repres





Representation 3



6.1 Complete the table below by providing as many details as possible about each representation.

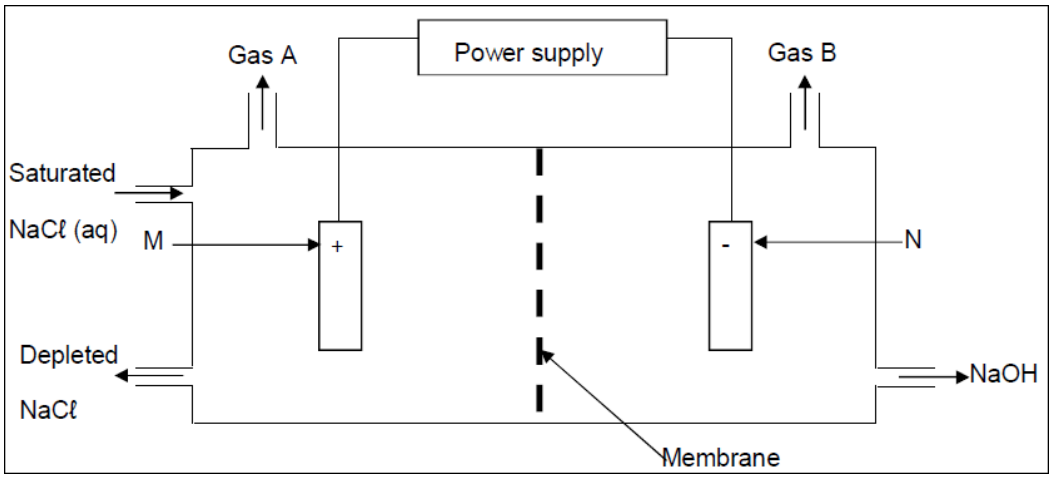
Representation	What I like What	What I like What I do not like
1		
2		
3		

6.2 Which representation do you like most?

6.3 How would you use the representation that you like most in a lesson?

7. **Learners are given the following task:**

You ask learners to study the membrane cell shown in the diagram below and determine which products will form during the electrolysis of a saturated salt solution.
Let's assume you ask the learners to write down the equation for the half reaction taking place at the electrode M.



The learners provided the answers below:

Extract1	**Extract 2**
(i) $2Cl^- \rightarrow Cl_2 + 2e^-$	i. $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Extract 3	**Extract4**
(i) $Cl_2 + 2e^- = 2Cl^-$	i. $Cl^- + 2e^- \rightarrow Cl_{2(g)}$

Explain how you would assist these learners to move towards the correct answer explaining what their errors are.

APPENDIX H: TEACHER SHARON'S STOICHIOMETRY RESEARCH PROJECT-QUESTIONNAIRE

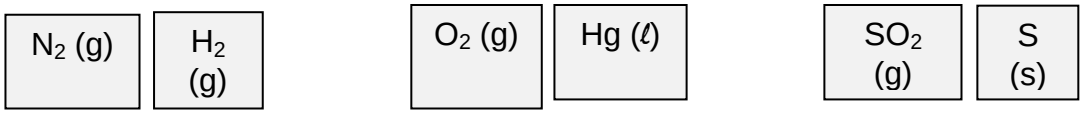
The purpose of this research is to find the difficulties associated with the teaching of Stoichiometry. The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

Please write your responses directly into the response boxes; E-mail: mihesojosephat@gmail.com

NAME:	**Sandra**	
GENDER	Female ✓	Male
CURRENT SUBJECTS TAUGHT	Physical Sciences	Geography
NUMBER OF YEARS TEACHING	2 years	
QUALIFICATIONS B.ED Sc.	Where Obtained	Main Subjects
		Physical Sciences

CATEGORY A: LEARNER'S PRIOR KNOWLEDGE

1. Before starting the section on reaction stoichiometry you give the learners a diagnostic test. One of the questions in the diagnostic test is reproduced below.
Each cube represents a volume of 22.4 dm^3 at STP. In which of the three pairs of cubes, Set A, Set B or Set C, is there 1 mole in each cube and in which of the three pairs cannot contain 1 mole in each cube?



Set A Cubes Set B Cubes Set C cubes

How would you respond verbally to learners who state that all the cubes contain one mole?

Response A	At standard temperature, or 0°C and standard pressure, or 101, 3 kPa one mole of any gas at STP occupies a volume of 22.4dm^3. This is called the molar volume but it only applies to gases at STP. Hence cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain 1 mole. The pair of cubes in Set B contains a liquid in one cube and the pair of cubes in Set C contains a solid in one cube. So, one of the Set C pair of cubes and the Set B pair of cubes contain other substances that are not gases. So Set B and Set C pairs do not contain one mole in each cube.
Response B	That is incorrect. All three pairs of cubes cannot contain one mole of substance. One mole of a gaseous substance occupies a volume of 22.4dm^3 at STP. So only the cubes of Set A contain one mole. The pairs of cubes in Set B and Set C do not have cubes that all contain one mole of substance since only one of the substances in the cubes of Set B and Set C are gaseous substances at STP
Response C	It is important to check the phases of the substance. Molar gas volume only applies to substances in the gaseous phase. One mole of any gas at STP occupies 22.4dm^3. So the cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas

	will contain one mole. There are exactly the same number of gas molecules, approximately 6,02 x 10^{23} particles in these cubes. The other substances in the pairs of cubes, Hg and S, are not in the gaseous phase. You would need to know the masses of mercury and sulphur in order to calculate if the cubes with these substances in Set B and Set C contain one mole of these substances. So, only in Set A is there one mole of substance in each cube in the set
Response D	None of the above. I have another response which is

Response A is the most explicit explanation in addressing the learner's misconceptions. This is seen where this response says that at STP, gases occupies a volume of 22,4dm^3 and this is called molar volume which applies to gases only. Meaning that learners will then check again the cubes looking first for gas phases of substances. It further explain that Nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas are the only substances to contain 1 mole at STP, simply because of molar volume which applies to gases only. From this it also gave a reason why set B & C are not considered to have 1 mole in each cube, saying that one the cubes of set B and one from set C do not contain a gaseous substance hence molar volume does not apply to those pairs and therefore those two pairs (set B & C) do not contain 1 mole in each cube. This explanation develops conceptual understanding while taking learners step-by-step on arriving at 1 mole of a substance; it provides all the conditions for a substance to have 1 mole at STP.

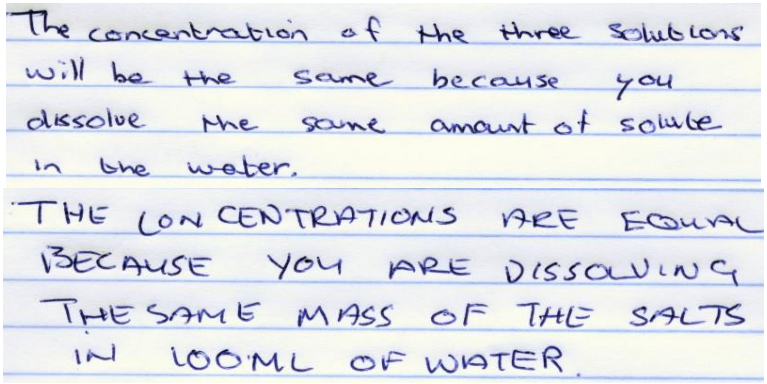
2. After teaching the learners about concentration you give them an exercise to do for homework.

In one question you ask learners the following question.

-During a practical lesson you have to make up molar solutions. You are provided with 10 g of sodium chloride, sodium bromide and sodium iodide. You dissolve each of these salts in a 100 ml volumetric flask.

Do these solutions have the same or different molar concentrations? Explain your answer.

How would you respond in writing when giving feedback to the homework exercise to learners who provide the following answers?


The concentration of the three solutions will be the same because you dissolve the same amount of solute in the water.

THE CONCENTRATIONS ARE EQUAL BECAUSE YOU ARE DISSOLVING THE SAME MASS OF THE SALTS IN 100ML OF WATER.

Response A	The mass of the salts does not mean that the number of particles is the same. The ions of the different salts have different relative atomic masses and therefore the molar mass of each salt is different and so the concentration of solutions will be different. Referring to the periodic table you can, by inspection, see that sodium chloride has a smaller molar mass than sodium iodide, and would therefore have a greater number of ions. Therefore the amount of salt, measured in moles, will also be different. Remember that just because the mass of each salt is the same the amount of salt, measured in moles will be different. Since concentration is the amount of substance per unit volume, the concentration of the

	sodium chloride solution will be greater than that of the sodium bromide, which would be greater than that of the sodium iodide. If you add ten grams of the salt to the same volume of solvent you are not adding the same number of ions for the different salts
Response B	Concentration mathematically is the number of moles per unit volume. You need to calculate the number of moles for each of the three salts. This is done by dividing the mass of the sample by the molar mass of each salt or using the formula n = m /M. You need to refer to the periodic table to calculate the molar mass of each salt by adding the atomic mass of each element in the salt. So, firstly calculate the number of moles of each salt in 10 grams of the salt. Once you have calculated the number of moles of each substance then use the formula c = n /V to find the concentration of each solution. The concentration of the solutions will be different
Response C	You need to understand what concentration is before you answer a question like this. So you were asked to dissolve three different salts in a given volume of water. Then you were asked if the concentration of these three solutions was the same or different. You must remember that concentration mathematically is the number of moles divided by the volume. So you need to work out how many moles of each salt and divide this by the volume of water you dissolved the salts in. The concentration of the three solutions cannot be same even if the mass of these salts is the same and the salts are dissolved in the same volume of water
Response D	None of the above. I have another response

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response ___A___
Response A is a good response that can be given to a learner with a misconception of mass relative to concentration. The other responses are also correct but they do not give the explanation behind the mass concept instead approaching this misconception mathematically. Firstly, response A explained that the equal mass of the salts does not mean the number of particles is the same. Since these salts have different molecular weight (molar mass), resulting to different concentration of solutions. From this equation C = m/V x 1/MW (where C is the molar concentration, m is the mass in grams, V is the volume, and MW is the molecular weight or molar mass). Response A explained that all solutions have the same mass, same volume where they are dissolved, but they have different molar mass which leads to different molar concentrations. It then explained that sodium chloride has the smaller molar mass than sodium iodide and therefore it would have a bigger number of molar concentration. Adding 10 grams of the salt to the same volume of solvent does not mean adding the same number of ions / particles for the different salts. This approach is a good conceptual teaching strategy in responding to learner misconceptions about mass relative to molar concentration. This response provides both a respond and a teaching or explanation of why we do not consider same concentration to have come from the same masses of solutions but there are also other factors to be looked upon, such as the molar mass of solutions

CATEGORY B: CURRICULAR SALIENCY

3. The following questions relate to planning and sequencing of concepts.

3.1. What concepts in stoichiometry at Grade 11 do you believe are the main ideas[1] for understanding by students at the end of the instruction of this topic?

Choose at least three concepts from the provided list and place them in a sequence that depicts the best order of teaching. Provide reasons for both your choice and suggested sequence.

Theoretical yield is the amount of product that is formed when a reaction goes to completion based	**Molar ratios** can be used to determine the amount of reactants used or the yield of product

on the stoichiometry of the reaction.	formed.
Molar Mass of an element or compound expresses the equivalent relationship between one mole of a substance and its mass in grams.	**Balanced chemical equations** provide the combining ratios of reacting substances and their products in a chemical reaction.
Stoichiometric calculations combine balanced chemical equations and the concept of the mole to calculate the masses of all reactants required and products formed in a chemical reaction.	**Molar Volume** of a gaseous substance expresses the equivalent relationship between one mole of a gas and its volume of 22,4dm^3 and standard temperature and pressure.
Conservation of mass is a chemical law that allows quantitative relationships to be established in chemical reactions.	**Dilution** is the process of decreasing the concentration of a solution by addition of solvent to a solution.
Concentration is a property of a solution and relates to the number of solute particles per unit volume.	The amount of substance in a given mass or volume can be expressed as a **constant amount of elementary particles.**
Limiting reagent is the reactant that used up in a chemical reaction and determines the amount of product formed.	**The mole** is the SI unit for amount of substance and allows us to connect the macroscopic scale of matter with the microscopic scale of matter and can used to help count elementary particles that make up substances.
Concentrated solutions have more particles per unit volume than **dilute solutions**.	
The **actual yield** of product formed depends on the reagent that limits the amount of the other reactant that reacts.	Gravimetric and volumetric analysis are **quantitative analysis methods** to determine the amount of substance.
Reaction stoichiometry involves the determination of molar ratios of the amount of reactants and products in a chemical reaction through balanced chemical equations.	**Avogadro's number** expresses the equivalent relationship between one mole of a substance and the number of entities it contains. Avogadro's number has been experimentally determined to be 6,02 x10^{23} particles
Volume is the amount of space occupied by a sample and from the volume of a gaseous substance the amount of substance can be determined.	**Mass** is the amount of matter contained in a sample and from the mass of a chemical substance the amount of substance can be determined.

Suggested concepts and sequence	**Reasons**

1. The Mole **2. Concentration** 3. **Limiting reagent**	Based on the Grade 11, CAPS document, the concepts of mole, concentration and limiting reagent are the main ideas in transforming stoichiometry topic in this grade. When transforming the concept of 'stoichiometry' concept, I will start teaching the concept of mole, concentration and then end with the limiting reagent concept. These three chosen concepts are crucial in understanding stoichiometry hence they are regarded as the big ideas of stoichiometry. The topic of stoichiometry is conceptually divided into four conceptual parts: mole, concentrations, mass analysis and limiting reagent. The other concepts will be included as the subordinate concepts. This proposed sequence is strategically organised to develop the conceptual understanding of stoichiometry. The 'mole' concept is the fundamental concept in understanding stoichiometry and it draws more on learner's prior knowledge from Grade 10. Hence starting with this idea to link it with learner's prior knowledge in introducing them to stoichiometry develops conceptual understanding which is systematically organised. Secondly, concentration is the second concept which applies the concept of mole in working with molar concentrations. In this concept, learners will be expected to apply more of the concepts taught under mole: molar volume, volume, mass, moles, etc. Lastly, the concept of limiting reagent is of the higher order analysis, hence this concept will be taught later in the topic. It requires learner understands of mole, concentration so that they can apply it in solving limiting reagent (stoichiometric calculations) problems.

3.2. Make a map or a diagram showing how these three ideas link to subordinate concepts.

STOICHIOMETRY			
Mole	Amount of substance Avogadro's number Avogadro's law Mass and molar mass Volume and molar volume		
	Concentration	Dilution Concentrated solutions Standard solution Mass volume	
		Limiting reagent	Theoretical yield Actual yield Percentage yield Molar ratio Conservation of mass Balanced chemical equation Reaction stoichiometry

3.3. What topics/concepts must have been covered in chemistry before you can teach stoichiometry?

List of Topics/Concepts to be taught before teaching Stoichiometry
BELOW ARE THE PROPOSED TOPICS/CONCEPTS TO BE TAUGHT BEFORE STOICHIOMETRY: • Atoms (atomic mass unit, atomic weight, atomic number) • Molecules (diatomic molecules) • Density • Law of conservation of mass • Ideal gas law (pressure, volume) • Balancing chemical equations (chemical formula) Ratios (mathematical knowledge

3.4. Why is it important for learners to learn about stoichiometry? Identify reasons

- Stoichiometry provides an essential set of tools widely used in chemistry, including such diverse applications as measuring ozone concentrations in the atmosphere and assessing different process of converting coal into gaseous fuel. Knowing this will help students understand certain process and how/why things happens as they do.

- Knowing stoichiometry will help the students find out the composition of molecules and general proportions of how to combine things to get them to react completely. Thus, having the right proportions of things gets pretty important when you don't have a whole lot of reactants to waste (cost reduction), or when you're in the field of pharmacy (preventing overdose and death).

- Studying stoichiometry will help learners to make useful predictions of how things react or should react

CATEGORY C: UNDERSTANDING OF WHAT MAKES TOPIC EASY OR DIFFICULT TO UNDERSTAND

4. What concepts do you find difficult to teach in stoichiometry? Select your choice and provide reason(s) in the table below.

Concept	✓	Why is it difficult for learners to understand?
Amount of substance/mole	✓	Firstly, there is no clear and unambiguous definition for the basic concept amount of substance, the physical quantity for which the mole is the unit although it is often difficult to provide formal definitions for base quantities. Secondly, different authors have argued that by a definition, a unit for a physical quantity should elucidate how objective quantitative information on the physical quantity can be obtained by means of measurement but the mole differs in this respect since there is no method or instrument for measuring the mole. Thirdly, most of the science teachers teach mole in a traditional way as the "number of moles" represented by 'n', this confuses learners when they have to change from 'number of moles' to 'amount of substance'. Therefore, learners do not see mole as SI unit but as a 'main concept' Fourthly, most teachers conceptualises mole as a quantity EQUAL to Avogadro's number, this makes it hard for learners to understand this concept as it seems not be in an existence of its own but associated with Avogadro's number. They fail to get the logic or relationship between mole and Avogadro's number. Fifthly, an effective conceptual understanding of this concept is hindered by the use of

		language when teaching it (semantic problems). Lastly, Furio et al (2000) argues that mole concept's introduction deprives it of a chemical meaning and makes 'mole' difficult to understand by learners since they have no previous ideas about this concept
Stoichiometric calculations	✓	This concept challenges learners' mathematically. Firstly, learners do not comprehend the principles of measurement, the nature of a physical quantity and its unit and the relationships between measurement and physical quantities. Secondly, algebraic formulations are not standard practice when solving problems on this concept.
Limiting reagent	✓	This is because some learners cannot determine the 'limiting reagent' in a given problem, when one substance is added in excess. Learners find it hard to apply the law of conservation of mass and moles in determining the limiting reagent in a solution
Theoretical yield and actual yield	✓	The first challenge is that most learners have learning difficulty in understanding limiting reagent hence it would be hard for them to apply limiting reagent understanding in working with theoretical yield. Secondly, some learners confuse the theoretical yield with actual yield, this happens mostly when they have to apply values to the equation (percent yield). Lastly, theoretical yield is abstract for learners to easily understand.

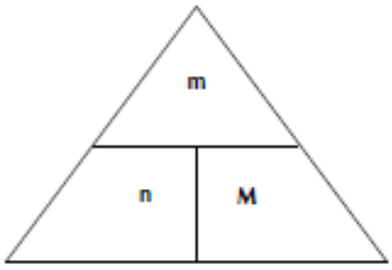
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

5. Below are possible representations for teaching the relationship between mass, mole and number of elementary particles.

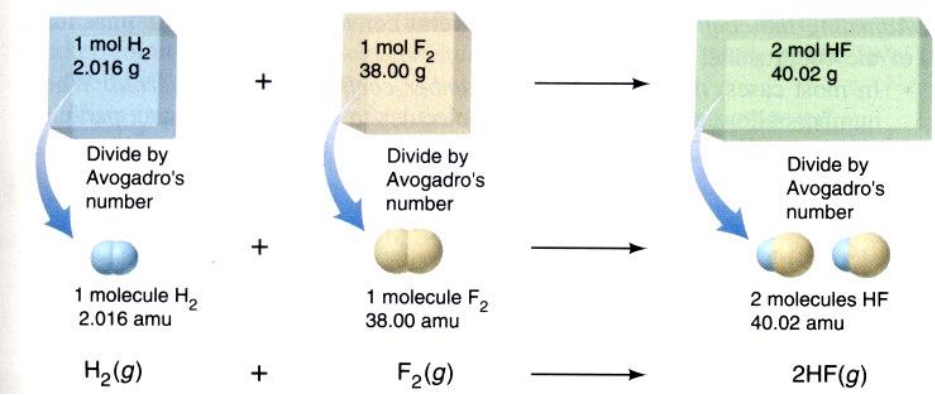
Representation 1

Items	Kind of Set	Number in Set
Socks, dice	Pair	2
Eggs, oranges	Dozen	12
Bottles, cans	Case	24
Brushes, pencils	Gross	144
Sheets of paper	Ream	500
Atoms, molecules	Mole	$6{,}02 \times 10^{23}$

Representation 2



Representation 3



5.1. Complete the table below by providing as many details as possible about each representation

Representation	**What I like**	**What I do not like**
1	I like that it draws from learner's prior knowledge by using 'items' which most if not all learners are familiar with. Secondly, I like the use of symbolic representation ($6{,}02 \times 10^{23}$	I do not like that it does not clearly show the development of the understanding of mass in relation to moles and number of particles. On the use of Avogadro's number, I think this will create misconceptions where learners will think that mole is equal to Avogadro's number. Hence I do not like the use of Avogadro's number in this context
2	I like the fact that the relationship between mole, mass & number of elementary particles is clearly shown symbolically on this representation	I do not like the Fact that this representation gives a superficial understanding, where learners will only memorize the equation (from triangle). Secondly, this representation shows only one level of representation (symbolic) which might not effectively be used in differentiating/comparing the concept of mole, mass and number of elementary particles. This representation does not seem to be developing a conceptual understanding but memorization
3	I like that it shows a link between macroscopic and sub-microscopic view of matter using the mole concept and the relationship between amount of substance and number of particles. I also like that the representation highlights how the symbolic representation (balanced chemical equation) can represent both the macroscopic and sub-microscopic explanations for chemical change.	I do not like that the representation does not clarify what is it that learners have to divide with Avogadro's number, whether it is mole (amount of substance) or mass

5.2. Which representation do you like most?

Chosen representation 3

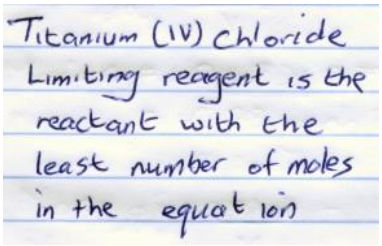
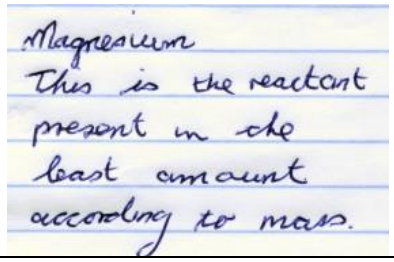
This representation shows a relationship between the mass, mole and number of particles in a substance. Therefore, I would use this representation when teaching the concept of mole (molar mass). In this regard, I would project it for learners when showing them that mass of the substances (combined) is equal to the mass of the product. Simply because of the amount of substance reacting which then results to the same amount of substance being formed (conservation of mass). From the mass of each substance, I will tell learners that they can calculate the amount of substance present in each substance by dividing with Avogadro's number. I will then emphasize the mole ratio reacting on a certain mass ratio to form different but related number of elementary particles' ratio

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES

5. Learners are given the following question in the mid-year examination.

> About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:
>
> $$TiCl_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgCl_2(\ell)$$
>
> In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.

The learners are asked to determine the limiting reagent of the reaction, giving reasons for their answers. The learners provide the following answers.

Extract 1	Extract 2
	

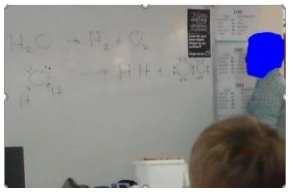
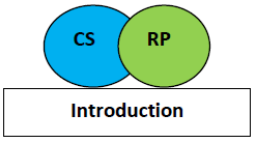
Explain how you would assist these learners to move towards the correct answer, explaining what their errors are and highlighting the strategy you will use.
In your response:

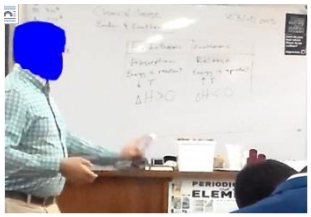
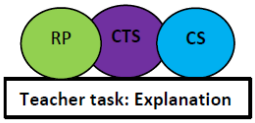
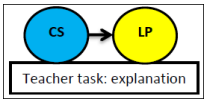
1. Explain why you think your strategy will work.
2. Indicate what you consider as important in your strategy

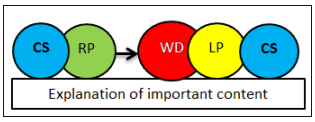
In overcoming the learning difficulties of understanding limiting reagent concept, I will use conceptual teaching strategies to develop clear conceptual understanding. Firstly, the coefficients in the balanced equation indicate that the reaction requires 1 mole of $TiCl_{4(g)}$ for every 2 mole of $Mg_{(l)}$. Therefore, for all $TiCl_{4(g)}$ to react completely, we would need 2 X 18,643.35 mole of $Mg_{(l)}$ (from mole calculation). However, there is only 4,708.33 mol of $Mg_{(l)}$ meaning that Magnesium is the limiting reagent. This is what learners were supposed to do.

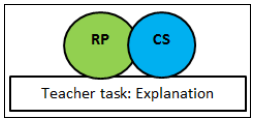
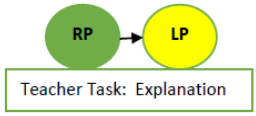
I will start by doing a verbal explanation of the reaction, highlighting that limiting reagent is the reagent that is used up in a reaction limiting the product formed (simplified version). I will then weigh out about 3,5g of $TiCl_{4(g)}$ and about 1,1g of $Mg_{(l)}$ (these masses are the approximate mass reaction ratio since we are given big masses to measure). These measurements would be deliberate in order to give a conception on the misconception that the substance with the least mass is the limiting reagent, this can only be confirmed after looking at the mole ratio reacting. From this demonstration, I would ask learners which substance is completely used up and which one is in excess. After this, I would then move to the calculations (representing symbolic of what they observed). In these calculations we would calculate the moles of each reactant (considering its atomic weight), from here I would together with learners get the moles of $TiCl_{4(g)}$ that reacted with the moles of $Mg_{(l)}$. I would then ask the learners, what mole ratio is needed for $TiCl_{4(g)}$ to completely react with $Mg_{(l)}$? From the learners' response I would then allow them to explain their reasoning to get their understanding / misconceptions on mole ratio. Finally I would work with them to find the perfect mole ratio that is needed for a complete reaction to take place. Therefore, I think this strategy will work because it will take learners from what they see (macroscopic) during the demonstration, before they do the calculation (symbolic) they will already know which substance is limiting the reaction. This will help them not to just look at the equation or mass of substances when solving limiting reagent problems.

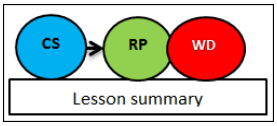
APPENDIX I: OVERVIEW OF TEACHER JABA'S 1ST LESSON

Time sequence	Class Action in sequence	Comments	Analysis
0:5-10	**Teacher**; '*We are starting a new topic today in the chemistry section* **Teacher**: "What do you understand by the term energy **Learner:** the power to do work **Teacher:** "*Very good*, the different forms of energy we have sound energy, Heat energy etc.	The teacher introduced the lesson by a recap on what was taught in Grade 10, before moving on to probe for learners' understanding about the meaning of the two terms exothermic and endothermic reactions, in the new topic. He then explained the different forms of energy (e.g. Heat, sound etc.,) clarifying a common misconception, where learners often refer to heat energy as the only form of energy and not one of the many other forms of energies	In this segment, the teacher introduces the topic, by a recap on what was taught in Grade 10, an aspect of (LP) He then explains the difference between energy and the different forms of energy e.g. Heat, sound etc., Here we see the teacher emphasises the most important concepts to be understood in the topic which is an element of curricular saliency, but the statement by itself is not a TSPCK episode, but simply laying the ground for the lesson.
10:20	**Teacher:** "*Chemical reactions are about the making and breaking of bonds. If I want to break bonds, do the molecules release energy or absorb energy?".* **Learners***: release ……. absorb* **Teacher: "***energy must be put in to separate the electrostatic forces holding the molecules together. Bond formation involves release of energy, this is critical to understand. If we know exactly how much energy is absorbed to break bonds of various molecules, which can be looked up in researched tables, it becomes very easy to understand, whether the reaction is exothermic or endothermic, by simply checking how much* energy is being absorbed and how *much energy is being released….If more energy is released than absorbed, then it is endothermic because the net energy change, my overall energy is absorption and if my net energy change is release of energy, i.e. releasing more than I am absorbing, then I have an exothermic reaction.*	He went on to place a graphical visual representation as he carried on establish the meaning of the absorption and release of energy, over the representation The teacher moved on to introduce the concept of bond breaking and bond formation, stating that; He then posed a question; 	At face value the discussion on the meaning of endothermic and exothermic reactions seemed like the teacher recalling student prior knowledge. However, the teacher defined the two terms, (CS)and moved on to place a symbolic representation (RP)as he carried on to establish the meaning of the two terms, while relating to the representation. **Simple interwoven TSPCK Map: CS/RP** 

Time sequence	Class Action in sequence	Comments	Analysis
20-30	**Teacher:** *"In all chemical reactions, there is energy being released and energy being absorbed but basically it's about which is the biggest. If it is an exothermic reaction, it does not just mean the release of energy, but what is my net overall energy change and not just the release or absorption of energy"* **Teacher;** *"let us look at the differences between exothermic and endothermic reactions.* *The teacher summarizes the differences on the chalkboard with the learners"*	The teacher developed a table with two columns, for making comparisons between endothermic and exothermic reactions  He then applied question and answer technique to summarize the differences between the two forms of energy changes.	In this extract, the teacher develops a table, as a representation (RP), over which he applies the variation theory to pull together the similarities and differences of the two forms of energy reactions, an aspect of (CTS). He finally summarises the key points with the learners, an elemenet of (CS). **Proficient interwoven TSPCK Map: RP/CTS/CS** 
30-40	**Teacher**: "*Later on we will see when we deal with Le Chatelia's principle and K_c values that; we shall refer to energy as a reactant and a product. An endothermic reaction means energy is the reactant, while an exothermic reaction, is where there is release of energy (temperature), energy is product*". **Teacher;** "*you need to be very careful with the concept of endo, which denotes decrease in temperature because of it absorbing energy, we tend to think its keeping more energy in the substance, but the point is that energy is coming from the environment, something else is becoming colder, while exothermic reactions is release of energy from the syste*; which learners often find difficult to comprehend".	He then informed learners that later, when they will be dealing with Le Chatelia's principle and K_c values, they will refer to energy as a reactant and a product He then cautioned learners about the use of the two terms; endothermic and exothermic, a common misconception that learners hold about the topic (LP). He then introduces the symbols H and (ΔH).	In this teacher task segment, The teacher links the content under discussion to key concepts to be taught latter in the topic, identification of concepts to be taught in a topic is an aspect of (CS). He then re-visits the two main concepts that have (endothermic and exothermic reactions) just taught, cautioning learners about their use by emphasising a common misconception about the topic which indicated (LP). **Simple linear TSPCK Map: CS-LP** 

Time sequence	Class Action in sequence	Comments	Analysis
40-50	**Teacher:** "*Letter H- represents enthalpy, while delta (ΔH) denotes change in energy. If (H) is bigger than zero, it's a positive number and if it is less than zero it is a negative number. Endothermic reactions will always have positive ΔH values, while ΔH values for exothermic reactions are always negative".* **Teacher;** *"You will see that when energy is given out ΔH will be a negative value indicating energy is given out, and a positive value for endothermic reactions.* ***Teacher**: "The X- axis on the diagram does not refer to time but chemical energy, energy of actual substances and not energy in the environment"(LP). The difference is all about which way the energy value is going in a system, strengths of bonds between reactants and products". (CS). "Endo means energy has been absorbed. You've got to know this".*	The teacher Introduces two symbols (H) and (Δ H) used in representing energy. He then projects a visual slide showing energy level diagrams to explain the concept of change in enthalpies for exothermic and endothermic reactions (RP).  Talking over the visual slide projection, the teacher re-emphasizes the aspect of absorption and release of energy asking for reasons, and repeatedly referring to the visual slides. Endo means energy has been absorbed.	In this segment, the teacher introduces the two symbols (H) and (Δ H), for energy and change in energy respectively (CS). He then projects a graphical visual slide show of energy level diagrams, an element of representations, (RP), to explain change in energy (Δ H), thus gets re-phrased to highlight a key gate keeping concepts that when not fully understood leads to difficulty of the topic (WD). He points out that the X-axis does not however refer to time but chemical change. The explicit emphasis of the X-axis not refer to time, but chemical energy, energy of actual substances and not energy in the environment is evidence of understanding of common misconception about the topic which falls under the component of Learner Prior Knowledge (LP). The teacher re-emphasizes the main concept under discussion; stating that; *"Endo means energy has been absorbed. You've got to know this".* Knowing where to place emphasis or not is an aspect that falls under TSPCK component of curricular saliency (**CS**). TSPCK episode; Four different components interacting evidently; **Sophisticated linear/interwoven TSPCK Map: CS/RP-WD/LP/CS** 
	Lesson 2: Topic Formation of Ionic compounds		
50-60	**Teacher:** *"metals are things that have positive ions, so my positive ions are metals, and they donate electron. Metals have very low electron affinity, and electro negativity. They include polyatomic ions as well* **Teacher: "***Is an ammonium ion*	The teacher wrote the symbols of the metals on the white board. He then used a carbonate ion as an example, and asked learners for the formula of the ammonium ion before writing both ions on the white board.	In this teacher segment, we see many aspects linked. The teacher uses different examples (RP), to explain the most important concepts in the topic i.e. formation of ionic

Time sequence	Class Action in sequence	Comments	Analysis
	negative or positive? " **Learners:** respond in a chorus Positive/negative **Teacher**: *"In most times, always your salt is made from a metal and a non-metal. Your negative ion is got to be a non-metal and your positive ion a metal, either single or poly atomic ion. Although we have exceptions like ammonium ion".* **Teacher: "***when representing the salt in symbolic form you must write the positive ion first but there is an exception to that rule as well".* **Learner:** a learner correctly identified as acetate ion as negative **Teacher:** *"when bonding with acetate, always write the acetate ion first in the formula, but when saying in words, begin with the metal ion*".	He posed a question Teacher moved on to explain how to state and represent formulae He then asks whether the acetate ion is negative or positive He draws a table and begins inserting names of various acids as he explains how to write the formulae by identifying the reactants and using crisscrossing method between acid radicles and metal/metal oxides to write the formulae of various salts, using symbolic representations. The teacher emphasized the need for learners not to remember (recall) or memorize the formulae, for their examinations but to always work out the formulae.	compounds (CS). **Simple interwoven TSPCK Map: RP/CS** 
60-70	Teacher: *"Today we are going to look at the ionization of silver nitrate and solid potassium iodide" (KI)* **Teacher:"** *which of the four ions when put together will form a precipitate, based on the solubility rules, you learnt earlier.* **Learners:** identify ions **Teacher; "***K^+ & NO_3^- ions are called spectator ions as they do not take part in the reaction (watch what is happening) as they do not change. They are found on both the reactant and products sides and are crossed out".* **Teacher:"** *the whole colour change was just silver ions and iodine ions forming silver iodide".* **(LP**).	The teacher begins by explaining the basics of identifying the ions present in ionic compounds. He then derives the ionic equation for the reaction between aqueous silver nitrate and potassium iodide. He posed a question and commented the learners before using equations to indicate the separation of ions in solution. The teacher indicated the overall ionic equation and asked leaners to identify any ions that do not change The teacher then used an analogy of the spectators who only watch and cheer from the sides as a game is played by the players in the field.	The teacher introduces the main concept of the lesson, by applying equations (symbolic representations-RP), to help learners go deeper into the understanding of ionisation. The last sentence indicates what causes colour change being only the ions that react. He emphasises this by repeating the same statement over and over. This to me is evidence of understanding of common misconception about the topic which indicates the presence of the component of Learner Prior Knowledge (LP). **Simple linear TSPCK Map: RP-LP** 

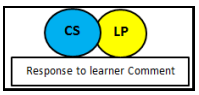
Time sequence	Class Action in sequence	Comments	Analysis
70-80	**Teacher:** *"I want you to write the net ionic equation and identify the spectator ions for the reaction between NaOH and AgN0$_3$, on your own quickly"*. The teacher moves around the classroom guiding learners, as they worked individually**.** **Teacher;** *"All these reactions we have done are known as ion exchange reactions".* He repeats the statement for emphasis. **Teacher:** *"compounds are neutral but in reality they contain positive and negative ions. For example, pure (Na) has no charge but it is charged when in NaOH solution"* He then illustrated swapping of ions in an ion exchange reaction using the pieces of paper. **Teacher: "***I did not make any changes but I just swapped them around. In redox reactions, there is swapping of electrons instead of ions".*	Teacher then used more examples including reaction between lead acetate and sodium chloride solution and gave out an exercise. He then repeated all the steps for writing ionic equation of the reaction between NaOH and AgN0$_3$, together with the whole class, guiding the learners on a shorter way of writing the net ionic equations without necessarily having to write full stoichiometric equations of all reactions, by identifying the precipitate and being able to write the ionic equation directly, thus skipping the long process. The teacher then used pieces of paper on which was written NaOH and $AgNO_3$ (silver nitrate), pinned on the chalkboard to represent bonding in ionic substances	In this teacher segment, we see the teacher give out an exercise, and went on to summarise the main idea about ion exchange reactions (CS). He uses of pieces of paper, (implied representation-R**P**) to illustrate what actually happens during ion exchange, as aspect learners often find difficult to understand(WD) **Proficient linear/interwoven TSPCK Map: CS-RP/WD** 

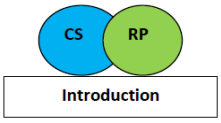
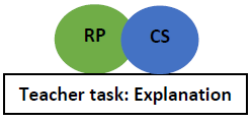
APPENDIX J: OVERVIEW OF TEACHER TZEPO'S ENACTED LESSON

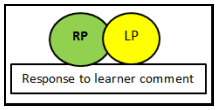
A reflection on the responses captured from teacher Tzepo's pre-lesson interview revealed that, the teacher was able to concisely articulate his teaching intentions. For instance, in the first lesson, the teacher stated that; by the end of the lesson, learners should be able to; learn about the different forms of energy particularly mechanical energy, stating that the topic would help them to differentiate between Potential and Kinetic energy. For the 2nd lesson, the teacher indicated that he intended learners to learn about; the fundamental concepts of solubility and precipitation reactions, observing that understanding solubility and precipitation reactions was important in helping learners to predict insoluble and soluble salts. He further pointed out that the fundamental concepts of solubility and precipitation reactions would be important when teaching the topic of stoichiometry and concentrations. The teacher seemed to be projecting on how learnt concepts would apply to specific topics to be learnt later in the course, which indicates drawing on the component of curricular saliency. As argued in the literature, familiarity with topics and issues that have been and will be taught in the same subject area during the preceding and later years in school and the materials that embody them, reflects knowledge of vertical curriculum (Shulman, 1986 p.10). The teacher went on to specify that he would engage learners in class demonstrations, class discussions and question and answer methods, in both lessons as his teaching strategies.

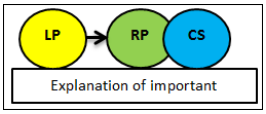
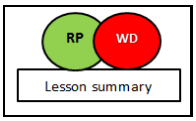
Following below is an overview of teacher Tzepo's 1st video enacted lesson

Topic: Mechanical Energy

Time sequence	Class Action in sequence	Comments	Analysis
5-10	**Teacher**; "*our new topic today is on energy* can *I hear from you, is there any familiar word in that topic? Energy…who can remind us what energy is? Who can remember the meaning of energy?* **Learner:** it is the capacity to do work. **Teacher:** "*Very good, the different forms of energy we have sound energy, Heat energy etc. Explaining over the slides, the teacher pointed out that; there are all sorts of energies that include mechanical energy, radiation energy, where there is no medium involved.*	The teacher introduced the lesson by probing for leaners' understanding about 'energy, the big idea of the topic. He went on to explain the different forms of energy, and posed a question. Responding to the learner's answer, the teacher informed the class that the definition provided by the learner was very general. He then moved on to place a visual slide projection, showing different forms of energies.	In this teacher segment, the teacher introduces a new topic, by probing for learners' understanding/familiarity about the topic (LP). He then explains the difference between energy and the different forms of energy e.g. Heat, sound etc., Here we see the teacher emphasise the most important understanding in the topic which is an element of curricular saliency, (CS)**:** **Simple interwoven TSPCK Map :CS/RP** 

Time sequence	Class Action in sequence	Comments	Analysis
10:15	**Teacher: Teacher:** *"Who has read or heard about Potential energy?"……* **Learner;** energy of objects in relation to its position. **Teacher:** *very good (PE) is the energy of an object in relation to its position with other objects that it interacts with for instance, gravitational energy is energy of an object in relation to gravitation, while chemical potential energy involves molecules. For electrical (PE), it's about moving electrons or moving charges in relation to the position of two objects".*	He then introduced the concept of potential energy (PE), one of the subordinate concepts of the topic, by asking learners what they understood by the term from their previous grades He then posed a question; He went on to differentiate (PE) from other forms of energies The teacher emphasized this concept by repeating the meaning of potential energy generally, before moving on to explain what is involved when referring to, electrical potential energy, as another form of energy.	In this teacher segment, the teacher introduces a new concept; potential energy (CS). He then uses examples to explain the differences between PE and other forms of energy. He explains this, over the visual slide projection (RP). **Simple interwoven TSPCK Map:CS/RP** 
15;20 20-30	**Teacher:** *"today's topic is on gravitational PE. what do you understand by the term gravity"* **Learner:** It's what pulls objects downwards **Teacher***: "nice one that is gravity. When we talk about gravitational force, it is the force that pulls everything towards the centre of the earth. Do we have other planets besides the earth with gravitational force?* **Learners**: Pluto **Teacher**: '*Yes on the moon or in space the book would come down very slowly because the gravitational force is very low. Things always fall towards the centre of earth'.*	He then introduced the topic of the day, by posing a question, on what the learners understand by the term gravity. The teacher commented the learner, but quickly pointed out that, the other planets have gravity although the gravitational force varies, with the Earth having much more than the other planets. He then demonstrated the effect of gravitational force by letting a book fall from his hand) 	In this extract, the teacher introduces the concept of *gravitational* potential energy (CS) by physically demonstrating the effect of gravitational force using real objects (RP)**.** **Simple interwoven sequence TSPCK Map: CS/RP** 
30-40	**Teacher:** *I have an example here for you to discuss for 2-3 minutes. Look at that elephant on that slide. What do you think of the motion of the elephant, when it is on top of that tower and when allowed to fall off the tower?* **Learners were hesitant** **Teacher:** "*If you remove the step the elephant is held on, it will start falling*	The teacher projected a visual representation of an elephant on top of a tall tower. He then posed a question and gave the learners time to discuss the change in velocity before asking any learner who was willing to summarize how the velocity would change as the elephant falls from the	Here the teacher explains why the different masses of falling objects do not affect their velocities. In this segment the teacher allows learners to perform a demonstration (RP) before explaining why velocity of falling objects is not affected by their masses, a common

Time sequence	Class Action in sequence	Comments	Analysis
	slowly and increase the velocity…you should note that the speed of falling objects are not affected by their respective masses **Teacher**; *"For example, between this chalkboard duster and elephant, how many of you think the duster would be the first to hit the ground"?*  **Teacher:** *if it is not for the effect of air resistance on the paper, the gravitational force is equal to all objects used, according to the laws of physics.* The teacher did not however mention Galileo's experiment.	tower to the ground. On realising the learners might not have quite understood the question, the teacher provided a clue. The learners began discussing amongst themselves about the velocities of falling objects with different masses The teacher called on one of the learners to come forward and perform a simple demonstration to confirm that the mass of falling objects does not affect their velocity. He gave him two objects with different masses; a chalkboard duster and a piece of paper and asked him to drop them from the same height and observe if the two objects would hit the ground at the same time. He then asked posed another question… There was a prolonged argument in the classroom, with most leaners being of the view that the elephant would hit the ground first.  He then explained why the mass does not affect the velocity of falling object	misconception about the topic (LP). **TSPCK episode:** **Simple interwoven TSPCK Map: RP/LP**  ,
	Lesson 2: Topic Solubility		
40-50	**Teacher:** '*There are two things that learners must know about salts 'I assume you know already that some chemicals are soluble while others are not soluble'. There is something we know about potassium; we know that it is very reactive. Which group does it belong to?* **Learners;** group 1	The teacher began the lesson by asking learners what they understand by solubility of substances, specifically in HCl $_{(aq)}$ He referred the learners back to the table of solubility rules. He re-visited the solubility rules, reading them over again;	In this segment, the teacher introduces the concept of solubility by referring learners to what they learnt in previous lesson about solubility rules (LP|). He then explains the concept of solubility of salts in acids (CS) using equations as symbolic representations(RP)

Time sequence	Class Action in sequence	Comments	Analysis
	Teacher: '*look at where chlorides are HCl is also a chloride. You'll see that chloride solutions are all soluble except those of silver, lead and mercury'.* Do sulphate salts dissolve in $HCl_{(aq)}$. *Sulphate salts are all soluble except sulphates of Lead, Barium and Calcium*. **Teacher:** '*Look at carbonates; it should indicate that all are soluble except those of potassium, sodium and ammonium. This means that carbonates can dissolve in $HCl_{(aq)}$ acid because there is no exception'.* **Teacher:** *"To respond to such questions, you must be familiar with solubility of compounds"*	The teacher then uses an equation to represent the reaction between solutions of potassium and barium chloride. $KY + BaCl_2 \rightarrow BaY + KCl$ and concludes by saying (KCl) is soluble therefore (BaY) is the precipitate formed.	TSPCK episode: Three different components interacting in both linear and interwoven sequence: **Proficient linear/interwoven TSPCK Map: LP-RP/CS** 
60-70	**Teacher** *"who can re-call how to represent the formula of Iron (II) Sulphide and the charge on an iron ion"?* **Learners** did not respond **Teacher**: "*you should first know the charge on the sulphide and iron ions. You then need to work through the equation and cancel out the identical charges before you can establish the formulae of this compound"*	The teacher moved on to explain how to represent formula and charge of compounds by posing a question on the formula of Iron (II) Sulphide and the charge on an iron ion, With no response from learners, the teacher referred learners back to the periodic table to help explain how the knowledge about valence electrons helps in determining the charge of an ion. This helped the teacher to explain formation of neutral compounds through cancellation of identical charges in an equation	In this segment, the teacher uses the periodic table as a representation, (RP), to highlight a key gate keeping concept that causes difficulty in learners understanding (WD), i.e. deriving the formulae of a compound. TSPCK episode: Two components interacting in an interwoven sequence **Simple interwoven TSPCK Map: RP/WD** 

APPENDIX K: OVERVIEW OF TEACHER MPHO'S ENACTED LESSON

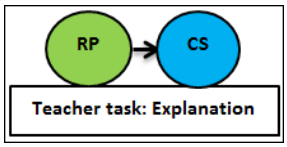
Teacher Mpho's video lessons were both captured in the topic of particle model of matter, in a Grade 9 natural science class. The teacher's first lesson was on the three states of matter. The lesson second lesson was a sequel to the first lesson, focusing on diffusion of matter.

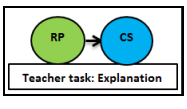
In the pre-lesson interview prompts, on what the teacher intended his students to learn about in the first lesson, teacher Mpho said that he projected his learners to *understand* the particle model of matter and be able to differentiate between the three states of matter. In the 2nd lesson, the teacher said that he intended his learners *to know* the meaning of diffusion and how particles move from areas of high concentration to areas of low concentration.

He then explained that the topic would help learners understand changes of state of matter for the 1st lesson. For the 2nd lesson the teacher held that learning about diffusion would help learners understand the movement of particles in each of the three states of matter, and be able to explain scientific processes like boiling and melting points. He added that he would apply discussions, assessments and generally reading of related information by the learners as his teaching strategies. For the second lesson, the teacher indicated that he would use a perfume and vanilla essence to demonstrate diffusion of matter. In response on how he would implement the proposed teaching procedures, the teacher explained that, it was important to read and carry out discussions to elicit new ideas and possible misconceptions from the learners. As regards to the difficulties about student's thinking that could influence his teaching, the teacher indicated that the level of understanding of the particle model is abstract, and some learners find it difficult to comprehend movement of particles in space.

Topic: Diffusion

Time Sequence	Class Action in sequence	Comments	Analysis
0-10	**Teacher:** *"How do we notice if someone is smoking outside or the location of the dust-bin without seeing, what is happening to the particles of the smoke, rotten food to reach me so as to inhale and smell it"?* **Learner**; particles are spreading	Teacher Mpho introduced the lesson by a re-cap on the previous lesson on states of matter and identifying the processes of melting, freezing, and evaporation. The teacher then moved to the day's topic by posing a variety of probing questions related to the processes that results to diffusion.	In this teacher segment, the teacher introduces the topic, by a recap on what was taught in Grade 10. Acknowledging that teacher sought for learner prior knowledge, however this by its own is not a TSPCK episode
10-20	**Teacher:** raise your hand up when you smell my perfume. **Learners** …continuously raised up their hands beginning with those seated in front backwards. **Teacher**: *Particles particles move from areas of high concentration to areas of low concentration that is the reason why the perfume reached different learners differently, but spontaneously. From where I was, there was high concentration and at the back we had lower levels of concentration. This represents diffusion in a gas*.	The teacher then picked a perfume and sprayed around the front, of the class and asked learners to rise up their hands when they smelled the perfume…  He moved on to explain the	In this teacher segment the teacher uses macroscopic representation (perfume) as well as illustrations of particles drawn on the chalk board to explain a potential learner difficulty, about movement of particles. He makes explicit the key gate keeping concept by re-phrasing what actually makes concept difficult by making explicit the actual difficulty ; i.e. "the empty space between particles. TSPCK episode: Two different

Time Sequence	Class Action in sequence	Comments	Analysis
	Teacher: Teacher: *look at the next page of your text book, look at the particles, what can you say about them? How are they arranged? Particles at a higher concentration are packet together. What type of energy was in the particles immediately I sprayed the perfume?* **Learners**.....Kinetic Energy (KE) Teacher: *Why are you saying Kinetic Energy, we have two types of energy Potential Energy and Kinetic Energy. Particles experience Kinetic Energy when they are in motion.* **Learners**.....between the particles we have air particles **Teacher:** "*there is absolutely nothing; no air no oxygen, there is absolutely nothing that is why it is important to learn the particle theory, so that we can understand how the particles in gas, liquid and solid behave".*	energy involved when particles are in motion using illustrations showing particles closely packed together and a second one with particles sparsely packed and asks leaners; what is in between the spaces of the particles. the teacher comments the learners and wrote on the chalk board as he emphasised that there is absolutely nothing; no air no oxygen, there is absolutely nothing as 	components interacting evidently **Simple interwoven TSPCK Map: RP/WD** 
20-30	**Teacher:** "*today we shall be looking at the topic of particle model of matter we all know the three states of matter, can we name them"? And can we think of the fourth state of matter? (LP)* **Learners**: states of matter are only three **Teacher;** *A very interesting question, when people started building cars, nobody thought of aero planes, ships etc. I am not saying there is another state, but there may be another one in the future. The particle model therefore focuses on particles. Can we see particles, like particles in this piece of chalk, or in water* **Learner** ....no **Teacher**; *In the notes that I gave you, I differentiated between; solids, liquids and gases. I want one of you to read the key questions I gave you, it's very important you read the questions.* **Teacher:** *in solids, particles are closely packed in a lattice what about liquid?* **Learners**..... particles are separated **Teacher:** "*So the particles are separated, we are done with arrangement of particles. Let us now look at the solid, do you think the particles that are closely parked are*	Then teacher then introduced the topic of the day, asking about the states of matter, and if there is a fourth one The teacher commented the learner He drew a table on the black board with three columns, on which he wrote; gas liquid and solid in each column. The teacher wrote properties of the three states of matter as; arrangement of particles, under solid state.	In this teacher segment, the teacher probes for learners understanding about the pre-concepts needed prior for the topic. He then uses illustrations (RP) to introduce the three states of the matter, the main concept under discussion (CS). Two different components interacting evidently in a linear sequence **Simple linear TSPCK Map: RP-CS** 

Time Sequence	Class Action in sequence	Comments	Analysis
	moving?" **Learners**…..no		
30-40	**Teacher**: They move but in fixed positions, so the particles vibrate in one place and there is some force keeping them together. Now let us look at water, are the particles vibrating in water? Learners ….no **Teacher:** "*they are vibrating in terms of particles how can you explain this, what would you say can you see the jack "* **Learner……**read from the text book **Teacher;** "*what about gases, we said the particles are separated, particles in air are all over"* **Teacher;** *"What can you say about the movement of particles of a solid as well as a gas"?* **Learners:** They move around **Teacher:** "*Think about many people parked in the stadia on an important day like freedom day.The particles move and slide past each other, what of gases*"? **Learners**……	The teacher repeats the same procedure for the liquid state, asking whether the particles are vibrating. There are mixed responses from the learners. The teacher picks a bottle half filled with water, lifts up the bottle and asks whether the particles vibrating in water. The teacher refers learners to the course book, before asking one learner to read the extract from the text book The teacher picks up the bottle again pours off water, to explain the continuous movement of water, because particles slide over each other	
40-60	**Teacher:** "*what is the next property on the table"?* **Learners** ….forces of attraction **Teacher**; "*what can you say about the forces of attraction in a gas?"* **Learners**……. Very weak **Teacher;** *"The forces holding air particles together are very weak for the liquid the forces are weak and for solid the forces are strong"*	The teacher moved to the next property on forces that hold particles together.	In this extract, the teacher segment, the teacher uses a table as a representation to explain the properties of the three states of matter. He further uses the analogy of people packed in a stadium to explain vibration of particles in fixed positions. We see the component representations and curricular saliency interacting evidently in a linear sequence **Simple TSPCK episode:** Two different components interacting in a linear sequence. **Simple linear TSPCK Map: RP-CS** 

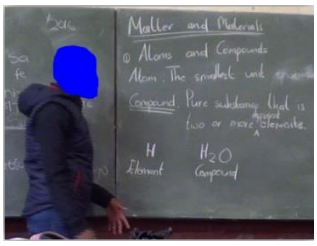
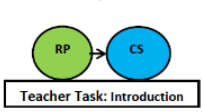
Time Sequence	Class Action in sequence	Comments	Analysis
60-70	**Teacher:** "*what was our last property, check in your text books"* **Learners**: …spaces **Teacher;** "*that is explained by the diagram in the book".* **Teacher**: "*for a gas we have very big spaces, for a liquid we have small spaces and very small spaces for the solids. Solids are closely packed; therefore the spaces are very small"* **Teacher:** any question?		In this teacher segment, we see the teacher repeat the same aspects across the three states of matter. There is no episode.

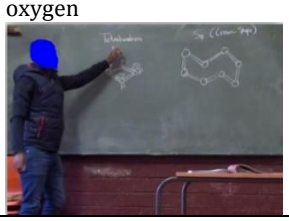
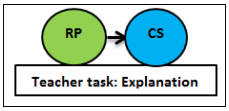
APPENDIX L: OVERVIEW OF TEACHER THEMBU'S ENACTED LESSON

Teacher Thembu's first lesson was on matter and materials. The second lesson was in a different area of physical science, (Physics) about the Doppler Effect.

In response to what the teacher intended his students to achieve by the end of the two lessons taught, during the pre-lesson interview, teacher Thembu said he wanted his students to learn about matter and materials, and how elements combine to form compounds in the 1st lesson. He went on to explain that the topic was important for preparing learners for their final examinations. For the second lesson the teacher explained that he intended to teach about the concept of the Doppler Effect, stating that he would employ classroom discussions and activities as his teaching strategy. As regards the difficulties about students' thinking that could influence teaching the lesson, the teacher pointed out that his learners have a very short concentration span, which makes it difficult to maintain their attention throughout the entire lesson. From the responses captured above, we see the teacher suggest effective teaching strategies, which can help achieve the intended learning purposes. However, the reason provided for teaching the topic tends to lean more towards performance in examination, instead of conceptual understanding by learners.

Topic: matter and materials

Time Sequence	Class Action in sequence	Comments	Analysis
5-10	**Teacher;** *"We are going to learn about matter and materials, and I am going to show you the difference between elements and compounds. ….."What is the difference between an atom and a compound"?* **Learners:** Responded in a chorus **Teacher**: …"which one is an element and which one is a compound"? Do you understand this?	The teacher informed learners about the new topic and posed the first question. He wrote the chemical symbols of the Hydrogen atom and the water molecule, on the chalk board and posed the next question…"  	At phase value, the teacher seemed to introduce the lesson by probing for learners' prior understanding about atoms and compounds. However he moved on to place equations and illustrations (RP) to explain how atoms of elements combine to form molecules, which indicate drawing on aspects of curricular saliency (CS). In the teacher segment we see evidence of two distinct standalone TSPCK components interacting in a linear sequence**.** **Simple linear TSPCK Map: RP/CS** 
11-20	**Teacher**: '*I think I gave you the different structures last time,* sulphur (S_8) *he then drew the structure of phosphorous ….this is a tetrahedron, anyone who can draw for us the structure of oxygen'*	The teacher referred to the text book, and drew the structure of phosphorous and the symbol; P_4. He then the depicted the structure of sulphur (S_8) and moves and depicted the symbol of an oxygen molecule and asks a volunteer to come	

Time Sequence	Class Action in sequence	Comments	Analysis
		and draw the structure of oxygen 	
20-30	**Teacher:** "*we are going to look at the first structure look at the equations, are they balanced'?* **Learners**……..No **Teacher;** '*The focus of today's lesson is not on balancing the equations but to represent the structure*' 	He then used letter symbols to illustrate how atoms of elements combine to form molecules i.e. ($A + A \rightarrow A_2$), before writing the equation between the Hydrogen and Chlorine atoms: $H + Cl \rightarrow HCl$ on the chalk board. 12:15. The teacher wrote two other equations $Cl + Cl \rightarrow Cl_2$ and between $N_2 + H_2 \rightarrow NH_3$ and asks whether the equation is balanced He then asks them how they would balance it, which they easily do.	In this teacher segment, the teacher uses illustrations (RP), to probe for learners understanding about the pre-concepts needed prior to teaching the topic, which indicates presence of the component of Curricular saliency (CS). Two components interacting in an interwoven sequence; **Simple linear TSPCK Map:RP-CS** 
30-40	**Teacher**: "*okay the last one, let us say you have methane, okay the chemical formula for methane is CH_4 so how many Hydrogens to we have"* **Leaners**……..4 Learner easily draws the structure of CF_4 **Teacher;** is the structure correct? **Learners**…….no He then came up with other examples, calling on a different learner to come and draw the structure of I_4	Teacher represents structure of methane and asks anyone who can draw for us the one for CF_4 He then asked learners whether the structure is correct, before calling on a second learner to depict the structure of I_4 on the chalkboard. The teacher however said all the structures given can be correct, but failed to explain or give any reason.	The teacher appeared to be applying both the ball and stick as well as tangential representations to depict the bonds in the structures but failed to visibly bring out what he was trying to teach. When asked during the post lesson interview what he was trying to explain, the teacher repeated what he had told the learners, stating that" 'The structures are just the same, they all represent the molecule"

Time Sequence	Class Action in sequence	Comments	Analysis
40-50		The teacher then asked learners to do the exercise that had been written on the chalkboard, which required them to use circles to represent the molecules of CO, H_2S, SO_4, I_2, CCl_4. He gave the leaners a few minutes to do the exercise Teacher summarised the lesson by going through the structures drawn by the learner	No TSPCK episode observed as the teacher seemed muddled in his teaching.
50-80	**Lesson two; Grade 12** **Topic: Doppler Effect** Teacher; "*I want one of you to come and use the formula on the chalkboard to work out the frequency towards and away from the source of ambulance".*	The teacher depicted an illustration of the ambulance and the pedestrian on the chalkboard, and copied some data from the text book on the chalkboard. He then called on a learner to come forward and apply the Doppler effect formula to find the Doppler Effect on between the pedestrian and the Ambulance. The students worked through the examples and the teacher summarized their workings on the chalkboard. The lesson involved learners working out the solutions while the teacher came in to help where they were finding problems	In this teacher segment, we see many aspects linked together. The teacher gives out some arbitrary values and calls on one learner to come forward and work out the frequency towards and away from the source, using the Doppler effect formula. There was no episode observed in this teacher segment. Most of the working was done by the learners with minimum teacher involvement

APPENDIX M: UNIVERSITY ETHICS CLEARENCE

Wits School of Education

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

19 August 2015

Student Number: 1107853

Protocol Number: 2015ECE015D

Dear Josephat Miheso

Application for Ethics Clearance: Doctor of Philosophy

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

Examining and Enacted Topic Specific Pedagogical Content Knowledge of Physical Science Beginning Teachers: A case with science teacher graduates from a PCK based undergraduate chemistry programme.

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

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

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

All the best with your research project.

Yours sincerely,

M Mabetha

Wits School of Education

011 717-3416

cc Supervisor – Dr Elizabeth Mavhunga

APPENDIX **N:** GDE ETHICS CLEARENCE

For administrative use only:
Reference no: D2016 / 379
enquiries: Diane Buntting 011 843 6503

GAUTENG PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

GDE RESEARCH APPROVAL LETTER

Date:	**30 March 2016**
Validity of Research Approval:	**30 March 2016 to 30 September 2016**
Name of Researcher:	**Miheso J.M.**
Address of Researcher:	**Unit D336 Empire Gardens; 36 Empire Road; Park Town; 2193**
Telephone / Fax Number/s:	**063 227 1471**
Email address:	**1107853@students.wits.ac.za**
Research Topic:	**Examining Topic Specific Pedagogical Content Knowledge (TSPCK) of beginning Physical Science Graduate Techers from a TSPCK based undergraduate intervention programme**
Number and type of schools:	**EIGHT Secondary Schools**
District/s/HO	**Ekurhuleni North; Ekurhuleni South; Gauteng East; Johannesburg Central; Johannesburg East and Johannesburg North.**

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved. A separate copy of this letter must be presented to the Principal, SGB and the relevant District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted. However participation is VOLUNTARY.

The following conditions apply to GDE research. The researcher has agreed to and may proceed with the above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

CONDITIONS FOR CONDUCTING RESEARCH IN GDE

1. *The District/Head Office Senior Manager/s concerned, the Principal/s and the chairperson/s of the School Governing Body (SGB.) must be presented with a copy of this letter.*

2016/03/31

Office of the Director: Education Research and Knowledge Management ER&KM)
9th Floor, 111 Commissioner Street, Johannesburg, 2001

APPENDIX O: COPY OF TEACHERS ETHICS CONSENT FORMS

University of Witwatersrand. Education Campus, Science and Technology Division; 27 St Andrew Road; Park town.

Email: mihesojosephat@gmail.com Cell: 066 227 1471

The Principal,

DATE: 5/08/2015

Dear Sir/Madam,

My name is Josephat Miheso I am a student in the School of Education at the University of the Witwatersrand.

I am doing research on – the advantage brought about by the early exposure graduate beginning teachers of physical science, to explicit TSPCK development in the quality of their actual classroom teaching. My research involves understanding the knowledge that enables the teacher to transfer his/her learned knowledge for understanding by students. The reason why I have chosen your school is because one of my respondents is a member of your schools' teaching staff, from whom I intent to observe two consecutive 45 minutes chemistry lessons for my data collection phase.

I will use the following tools to collect data for this study: a teacher's pre-lesson interview guide, and a video recorder to capture teacher/learner classroom interactions. The video camera will be focused on the teacher and not the students. I will therefore be joining the chemistry teacher during his normal classroom lessons. I will strictly adhere to the school timetable. After the lesson, I will conduct a brief video-recorded post lesson interview session with the teacher to reflect on the observed lesson. The study will take place in mid of third term, before students sit for their examinations.

I kindly request your permission to conduct my research in your school as outlined above. I am aware that learners are involved and I have prepared information and consent forms for them and their parents. The research participants will not be advantaged or disadvantaged in any way. They will be re-assured that they can withdraw participation in the research at any time during this project, without any penalty. There are no foreseeable risks in participating in this study. The participants will not be paid any allowances for this study.

The names of the research participants and identity of the school will be kept confidential at all times and in all academic writings about the study. Your individual privacy and that of the school will be maintained in all published and written information resulting from the study.

All research data will be destroyed between 3-5 years after completion of the project.

Please let me know if you require any further information. I look forward to your response as soon as is convenient.

Yours sincerely,



Josephat Miheso

Email address 1107853@students.wits.ac.za

School Principal Consent Form

Please fill in the reply slip below if you agree to participate in my study called:
Examining Planned and Enacted Topic Specific Pedagogical Content Knowledge of Physical Science Beginning Teachers: A case with teacher graduates from a PCK based undergraduate
B. Ed programme

My name is: L.P. [redacted]

	Circle one
Permission to review/collect documents/artifacts	
I agree that my school will participate in this study	YES/NO
Permission to observe you in class	
I agree to observations of lessons in class.	YES/NO
Permission to be audio taped	
I agree to the audio recording of the lessons pertaining to this study only	YES/NO
I know that the recorded lessons will be used for this project only	YES/NO
Permission to be a video taped	
I agree to the video recording of the lessons pertaining to this study only	YES/NO
I know that the recorded lessons will be used for this project only	YES/NO

Informed Consent
I understand that:

- My name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I can ask, and my teacher and learners can ask, for the lessons not to be videotaped.
- The teacher and students will not be compelled to participate but voluntarily agree
- All the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign [signature] Date 24. 09. 2015

Teacher's Consent Form

Please fill in and return the reply slip below indicating your willingness to be a participant in my voluntary research project called:
Examining Planned and Enacted Topic Specific Pedagogical Content Knowledge of Physical Science Beginning Teachers: A case with teacher graduates from a PCK based undergraduate B. Ed programme.

I, [redacted] give my consent for the following:

Permission to review/collect documents/artifacts **Circle one**
I agree that the following documents;, interview guides, classroom checklist and an audio-video camera recorder can be used for this study only. YES/NO

Permission to observe you in class
I agree to be observed in class teaching. YES/NO

Permission to be interviewed
I would like to be interviewed for this study. YES/NO
I know that I can stop the interview at any time and don't have to answer all the questions asked.

Permission to be a audio taped
I agree to be audio recorded for the lessons pertaining to this study only YES/NO
I know that the recorded lessons will be used for this project only YES/NO

Permission to be videotaped
I agree to be videotaped in class. YES/NO
I know that the videotapes will be used for this project only. YES/NO

Informed Consent
I understand that:

- My name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audio taped and/or videotape
- All the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign _____ Date 23/09/2015

APPENDIX P: KAPPA STATISTICS AGREEMENT MEASURES FOR CATEGORICAL DATA

Observer A	Rater_1
Observer B	Rater_2

	Observer A		
Observer B	3	4	
3	1	2	3 (60.0%)
4	0	2	2 (40.0%)
	1 (20.0%)	4 (80.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.822

Observer A	Rater_1
Observer B	Rater_3

	Observer A		
Observer B	3	4	
3	2	0	2 (50.0%)
4	1	1	2 (50.0%)
	3 (75.0%)	1 (25.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.235 to 1.000

Observer A	Rater_1
Observer B	Rater_4

	Observer A		
Observer B	3	4	
3	1	2	3 (60.0%)
4	0	2	2 (40.0%)
	1 (20.0%)	4 (80.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.822

APPENDIX Q: PHYSICAL SCIENCE METHODOLOGY COURSE OUTLINE AT MY UNIVERSITY

The underlying principles

The key purpose of the physical science methodology course is to develop the ability to reason through subject matter knowledge in ways that transforms it into forms that are accessible for understanding by learners. This kind of ability is characteristic of what makes teachers unique from other professions of science in that the ultimate aim is to assist another person to understand scientific concepts. We call this ability Topic Specific Pedagogical Content Knowledge (TSPCK). Unique to the course is the development of TSPCK using examples of topics that are core to the FET physical science curriculum.

Philosophy

The philosophy underpinning the course is rooted in the understanding that teaching is about the transformation of own understanding to the understanding by others. While this view has been expressed since memorial time (Schwab, 1964: Fenstetmacher, 1978) it has remained attractive because it enables rigour and pedagogical depth in understanding content knowledge for the purpose of teaching. The view promoted is that, the teacher's understanding of content knowledge should be beyond concepts and facts but include more importantly the scholarly understanding of the structures of subject matter, the principles of conceptual organization and enquiry in the subject. The second aspect promoted by this view about teaching is that, teaching is also about reasoning. Sound reasoning is understood as requiring both the process of thinking through ones' actions but more importantly the knowledge of the facts and principles onto which the actions and reasons about teaching are grounded.

Pedagogical Research

The structure of the methodology courses across the academic years has a component of research in education. This component exposes prospective teachers to research work in education with the aim to develop both interest and the realization of the value of reflections and investigations in one's teaching practice.

Aim

The aim of this course is to develop your identity as a science teacher, by deepening your understanding of the difficulties of learning science and broadening your classroom repertoire, so that you are able to make informed choices in the teaching of Physical
Science

Learning Outcomes

In Physical science, you should; demonstrate competence in planning, designing, and reflecting on learning programs appropriate for your learners and learning context.
This means that you should be able to;

- Be aware of and understand **national and regional curriculum requirements**.
- Engage in **macro planning,** in order to complete a national science curriculum in the course of year.
- Select, adapt or design coherent **learning programs and lessons** appropriate for the learners' context, taking into account national and regional curriculum policies, learner contexts, and learner differences.
- Select and design appropriate strategies for ascertaining **learner preconceptions** in science.
- Select appropriate **teaching and learning strategies** in planning lessons and other learning experiences, which address learner misconceptions and seek to bring about conceptual change in learners

- Select and design **materials and resources** appropriate to learning programs, taking cognizance of issues such as teaching approach, and the conceptual adequacy and accuracy of the content of the programme.
- Select appropriate **textbooks** for use in the science classroom,
- Include planning for learning about **science in society**, including economic and environmental issues
-

In physical science you should;
Demonstrate competence in selecting, using and adjusting **teaching strategies** in ways which meet the needs of the learners and the context. This means that you should be able to;

- Adjust teaching and learning strategies to cater for **cultural, gender, ethnic, language and other difference**s among learners in a range of contexts, both familiar and unfamiliar.
- Use **investigative science projects** effectively to promote learner development.
- Use **textbooks** effectively during lessons.
- Make judgments about the effect that **language** has on learning in science, and, in that light, make the necessary adjustments to teaching and learning strategies.
- Design **practical work** that take cognizance of safety issues, and ensure that your learners work safely and competently in performing science experiments.
- Manage a **science laboratory** effectively.

Demonstrate competence in monitoring and **assessing learner progress** and achievement in physical science. This means that you should be able to;

- Select, adapt and design **assessment tasks and strategies** which ascertain learner conceptual development.
- Use a range of assessment strategies to accommodate **differences in learning style, pace and context**.
- Evaluate your own assessment strategies in terms of their fairness, reliability and sensitivity to gender, culture, language and barriers to learning and development.
- Assess open-ended learner **science projects** using appropriate rubrics.

Demonstrate respect for and commitment to the educator profession. This means that you should;

- Practice and promote a sense of **respect and responsibility** towards others by cultivating a critical, committed and participatory attitude.
- Behave in ways that enhance the status of professional educators and ensure an accountable culture of teaching and learning
- Promote the values and principles of the **Constitution**, particularly those related to human rights and the environment.
- Envision yourself as a learner-centered science educator

Assessment

The marks for the year will count as follows:

- Coursework 50 %
- November Exam 50 %

The coursework mark will be based on:

- Reading tasks: for most lectures there are reading tasks which must be completed before the start of the lesson in order to receive credit.
- Assignments:

Content

First semester	**Second semester**
• Constructivism**:** assimilation, accommodation and cognitive dissonance • Teaching one core topic (as an example of how to go about teaching any science topic) ➢ Learner misconceptions	• Inquiry oriented science: ➢ Management and assessment of school science projects ➢ Judging at Expo • FET Physical Sciences Curriculum: CAPS**:** Orientation and critique • Classroom talk and argumentation

➢ Curriculum saliency ➢ Content representation ➢ Teaching Strategies ➢ Stages of pedagogical reasoning ➢ Planning a learning programme • Introduction to Research in Science Education • Practical work • Science and Culture ➢ Gender issues in science education ➢ Nature of Science ➢ Indigenous knowledge systems ➢ science and religion (Barbour's typology) ➢ Border crossing and collateral learning;	• Resources ➢ Evaluating and using textbooks ➢ Useful websites and virtual laboratories • Laboratory management • Assessment in science ➢ Physical Science Portfolio requirements ➢ NSC Exams ➢ Setting good quality multiple choice and other questions.

APPENDIX R: PHYSICAL SCIENCE METHODOLOGY COURSE OUTLINE AT THE SISTER UNIVERSITY

Conceptual Framework:
We are committed to the preparation of caring, accountable and critical-reflective educational practitioners who are able to support and nurture learning and development in diverse educational contexts.

After studying this module you should be able to:	**This will be evident when you can:**
1. Demonstrate competence with regard to the knowledge base underpinning the Physical Sciences, and will be able to discuss curriculum terminology and principles.	Explain related terminology and concepts, and plan learning opportunities according to these principles.
2. Demonstrate competence in selecting, using and adjusting teaching and learning strategies that meet the needs of your learners	Select appropriate teaching materials and teaching strategies when planning a lesson and justify the selection in class/group discussions.
3. Explain the concepts associated with school science learner performance assessment processes and procedures	Define concepts related to assessment and effectively use it in your teaching
4. List the important features associated with assessing learner performance in school science and use them to design an effective ongoing assessment approach	Show evidence of being able to design effective assessment opportunities
5. Show creativity in making apparatus/media, and follow a science-on-a-shoestring approach.	Show evidence of competency in overcoming problems in under-resourced schools
6. Incorporate indigenous knowledge in your lessons.	Show evidence of sensitivity and skill in using indigenous knowledge in class.
7. Plan and execute action-research in your classroom.	Doing independent action research
LEARNING UNIT 1:Curriculum development and the fundamentals of the NCS and CAPS	
Outcomes: At the end of this unit you should be able to: • Critically discuss the aims and principles of the National Curriculum Statement (NCS) and Curriculum and Assessment Policy (CAPS) for Physical Sciences • Critically engage with CAPS concepts and link them to practice	
LEARNING UNIT 2: Lesson Planning and CAPS	
Outcomes: At the end of this unit you should be able to: • Formulate lesson outcomes • Plan a lesson in Physical Sciences • Explain the various phases in the lesson	
LEARNING UNIT 3:PEDAGOGICAL CONTENT KNOWLEDGE (PCK) AND REPRESENTATIONS	
Outcomes: At the end of this unit you should be able to: • List the areas of knowledge that effective science teachers need to have and reasons for each. • Explain what is meant by PCK and why it is an important concept for teachers to understand	
LEARNING UNIT 4:Technological pedagogical content knowledge (TPACK)	

Outcomes:
At the end of this unit you should be able to:

- Explain what is meant by TPACK
- Understand the challenges of teaching with technology
- Apply the affordances of TPACK in your teaching

LEARNING UNIT 5: Assessment

Outcomes:
At the end of this unit you should be able to:

- Explain and apply the various assessment concepts
- Show the relationship between assessment and outcomes

LEARNING UNIT 6 : Inquiry-based science education

Outcomes:
At the end of this unit you should be able to:

- Describe the stages in an investigation
- State the importance of learners doing investigations
- Describe the types of investigations
- Plan an investigation
- Describe how teachers can support learners doing investigations

LEARNING UNIT 7: Science-on-a-shoestring. Being resourceful when you do not have equipment

Outcomes:
At the end of this unit you should be able to:

- Explain how you can overcome the problem of a lack of resources in your classroom
- Recognize local resources that you can use in your lessons
- Improvise and develop own material for science lessons
- Design hands-on learning activities using cheap recyclable materials