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EXPLORING THE DEVELOPMENT OF PRE-SERVICE TEACHERS' TOPIC SPECIFIC PCK AND ITS INFLUENCE ON LEARNER OUTCOMES



A thesis submitted to the Faculty of Humanities,

University of the Witwatersrand, Johannesburg, in fulfilment of

the requirements for the degree of

Doctor of Philosophy

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Abstract

The construct of Pedagogical Content Knowledge (PCK) conceptualized by Lee Shulman is widely agreed upon among science education researchers as one important domain of teachers' knowledge for improving classroom instructions. The purpose of this study was to explore the development of Topic Specific PCK (TSPCK) of a group of physical sciences pre-service teachers in the topic of organic chemistry, the quality of enacted TSPCK demonstrated in the actual classroom teaching and its influence on learner outcomes in the same topic. The study was located in a physical sciences (chemistry) methodology class of 17 pre-service teachers who were in their 3rd year studying for a Bachelor of Education degree in a South African University. The study employed a mixed methods research design and a case study as the research strategy. The case comprised two mini-cases which included: the entire class of pre-service teachers for describing quality of planned TSPCK; a subset of 4 pre-service teachers with 4 classes of high school learners for describing the quality of enacted TSPCK and learner outcomes. The entire class of 17 pre-service teachers was exposed to an explicit TSPCK intervention over 6 weeks, focusing on the knowledge components for the pedagogical transformation of content knowledge of organic chemistry. Then, a subset of 4 pre-service teachers from the entire class was followed into the classroom where each of them delivered two lessons each on organic chemistry to 4 classes comprising a total of 88 physical sciences high school learners. The sources of data were: the pre-and post-TSPCK tests prior to and following the intervention; content representations (CoRes) completed during the intervention; video-recording of pre-service teachers' lessons; pre-lesson interview and stimulated recall interview conducted with the pre-service teachers after the lessons; and pre-and post-learner achievement tests and learners' views about the lessons. The TSPCK tests, CoRes and classroom lessons were analyzed using an in-depth qualitative method by identifying moments of interactive use of TSPCK components. The learners' tests were scored using a memorandum of correct answers and analyzed for significant difference via the Rasch Model Analysis. Using both the Statistical Package for the Social Sciences and Rasch Analysis softwares, the Pearson product-moment correlation coefficient was estimated to determine the relationship between pre-service teachers' enacted TSPCK and learner achievement. There were three major findings emerging from the entire analysis. First, following the intervention, the pre-service teachers' TSPCK improved significantly. Second, the pre-service teachers demonstrated enacted TSPCK at the simple, proficient and sophisticated quality categories of TSPCK episodes, one category built onto another in describing the quality of lessons delivered. Third, following the pre-service teachers' teachings, the learner achievement in the topic positively correlated with the PSTs' enacted TSPCK and the correlation increased in positive strength with higher categories of TSPCK episodes emerging from the pre-service teachers' lessons. The study provides novel understanding of the link across collective-TSPCK to personal-TSPCK to learner outcomes.

Keywords: Organic chemistry, Topic Specific Pedagogical Content Knowledge, Pre-service teachers**,** Pedagogical transformation competence, learner achievement.

Declaration

I declare that this research report is my own unaided work and no part has been copied from another source (unless indicated as a quote or referenced accordingly). I also declare that this report has not been submitted before for any degree in any university.

_____

Signature of candidate

13th day of January, 2020

Dedication

To the glory of God

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Abbreviations

DBE	Department of Basic Education
DHET	Department of Higher Education and Training
PSTs	Pre-service teachers
PCK	Pedagogical Content Knowledge
cTSPCK	Topic Specific Pedagogical Content Knowledge
pTSPCK	Personal Pedagogical Content Knowledge
eTSPCK	Enacted Topic Specific Pedagogical Content Knowledge
CK	Content Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge

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CHAPTER 1

1. GENERAL INTRODUCTION TO THE STUDY

This chapter presents the introduction of the study in the context of South African science classroom teaching and learning. It explains the benefits of improving science pre-service teachers' knowledge with the ultimate goal of enhancing the quality of classroom instructions and learner outcomes. Discussions are provided on the purpose of the study, rationale for the study, and research questions formulated to guide the study. The chapter closes by providing the overview of all the chapters in this thesis.

1.1 Introduction

Globally, it is expected of science teacher education programmes to produce knowledgeable science teachers who can deliver high-quality lessons with evidence of learning among learners in the science classrooms. On a general note, some researchers have highlighted that, high-quality teaching and learning is characterised by active engagement with learners which promotes learners' interest in and conceptual understanding of the lessons (Yip, Wong, Yick, Chan & Wong, 2019; Lam & Muldner, 2017). Schleicher (2011) warns that the quality of an education system, as reflected by the level of learner performances, cannot exceed the quality of its teachers. In other words, teachers' quality of classroom instructions and teachers' pedagogical competence are intricately interwoven as one depends on the other. Then, this calls for exploring how science teachers develop the specialized knowledge for quality instruction, the translation of such knowledge into classroom teaching and its influence on learner outcomes. Such an exploration is particularly important in the educational system of a developing country like South Africa with a poor track record of learners' conceptual performances in sciences and mathematics against international benchmarks (Taylor, Fleisch, & Shindler, 2019). The study conducted by Wilkinson (2016) in South Africa showed that, for every 100 learners that began school in 2005, only 56 made it to matric (exit grade) in 2016, 37 passed (at 40% pass mark) and 14 qualified to go university. Likewise, the results of the Trends in International Mathematics and Science Study (TIMSS) assessment across the senior primary grades 8 and 9 from the period of 2003 and 2015 placed South African learners in the rank of "five lowest performing countries including Saudi Arabia (396), Morocco (393), Botswana (392), Egypt (371) and South Africa

(358)" (Reddy, Visser, Winnaar, Arends, Juan, Prinsloo & Isdale, 2016). This is subsequently compounded by the observed quality of matriculation results as highlighted in the National Senior Certificate 2018 Diagnostic report which revealed that only 48.7% of the physical learners achieved 40% and above between the year 2014 and 2018 (Department of Basic Education, 2019, p. 153) later discussed under Rationale below. This is a serious issue which if left unaddressed may hinder South Africa and other African countries in similar situations from creating competent mass of scientifically erudite labour force who could catapult the nation to fulfilling the proposed vision focusing on scientific innovations.

Meanwhile, the reasons for the observed poor performances have been reported to be traceable to various factors, viz: the shortage of qualified science teachers in South Africa; inadequate teachers' content knowledge (Spaull, 2013); and teachers' poor quality of pedagogical content knowledge (Rollnick, 2017). The National Policy Framework for Teacher Education and Development (Department of Higher Education and Training, 2015) acknowledges poor conceptual knowledge and instructional strategies found among high school teachers. The policy then indicates the categories of learning that should be given serious attention in Teacher Education Qualifications programs to promote acquisition, integration and application of knowledge in the prospective teachers who have been referred to as the pre-service teachers (PSTs) in this study. The highlighted categories of learning include: disciplinary learning with emphasis on subject matter knowledge; pedagogical learning which comprises general pedagogical knowledge and specialized pedagogical content knowledge; practical learning; use of information and communication technology learning; and situational learning (Department of Higher Education and Training, 2015). As stated in the policy, the basic target of the programs particularly at the Bachelor of Education degree level is to ensure that PSTs are equipped with adequate pedagogical competence in subject matter knowledge and conceptual teaching strategies to facilitate learning. This necessitates researching and understanding how teachers' professional knowledge may be developed much early in the trajectory of learning to teach, the demonstration of such knowledge in the actual teaching context and its influence on learner outcomes.

Most importantly, Shulman (1986) conceptualized the construct of Pedagogical Content Knowledge (PCK) which has since then emerged as one effective domain of teacher knowledge

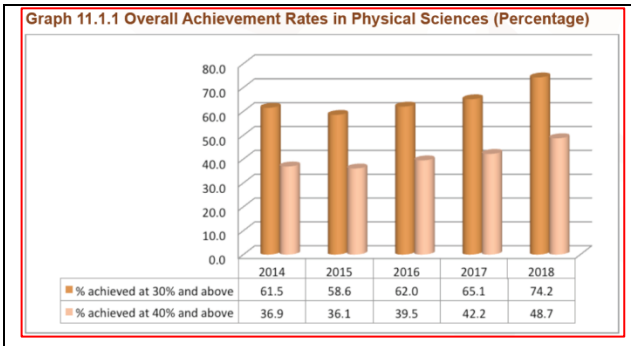
that helps PSTs to learn about the complexity of teaching and learning process. The mutual professional understanding about PCK has been referred to as the collective PCK (cPCK). When a teacher personalizes such an understanding and then, demonstrates it while thinking about teaching, it is regarded as personal PCK (pPCK) which manifests in a planning context as planned PCK (Park & Oliver, 2008). When such an understanding is demonstrated by the teacher in the actual classroom teaching, it is referred to as the enacted PCK (ePCK). Hence, cPCK, pPCK and ePCK are considered the three realms of PCK that should be investigated in order to comprehensively describe a teacher's PCK. PCK is not merely the amount of knowledge in a number of component categories, it is also about the quality of that knowledge and how it is put into action (Abell, 2008). To understand the quality of PCK, in addition to studying individual components, there must be an attempt to understanding the interactions among the knowledge component (Akın & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012). In other words, the quality of PCK describes extent of interactions among the knowledge components which constitute PCK in a given context. This is considered the operational definition use in this study to describe 'quality of PCK' which in turns influences the quality of lessons delivered. The explicit discussions on teachers' quality of PCK and methods of categorizing it into different levels are provided in Chapter 2. Several studies have revealed that, exposing PSTs to teacher education courses along with timely scaffolding, develops their understanding of the components of PCK (Adadan & Oner, 2014; Hume & Berry, 2013; Nilsson & Loughran, 2012). In this line of thought, Mavhunga and Rollnick (2013) developed the construct of Topic Specific PCK (TSPCK) which places the broad PCK at the topic specific level. Similar to the broad PCK, there exists collective TSPCK (cTSPCK), personal TSPCK (pTSPCK) and enacted TSPCK (eTSPCK), all focusing at a specific topic for which a teacher is expected to develop and enact the specialized knowledge for teaching. The construct of TSPCK has been effective in developing PSTs' specialized knowledge in core science topics such as chemical equilibrium (Mavhunga & Rollnick, 2013), electric circuits (Mavhunga, Ibrahim, Qhobela, & Rollnick, 2016), particulate nature of matter (Mavhunga, 2018; Pitjeng-Mosabala & Rollnick, 2018) and so on. Nevertheless, little is known about how such specialized knowledge developed during teacher education programmes, its translation into actual classroom teaching and its ultimately influence on learner outcomes measured as the learners' conceptual performances in this study. This remains a gap in the PCK and TSPCK literature that calls for

serious and urgent attention. It is highly encouraged in the PCK science education community to link the shared professional understanding about PCK (cTSPCK), taught to PSTs in teacher education programmes, to their individual personalized understanding (pTSPCK) demonstrated in planning and enacted in the actual classroom teaching (eTSPCK) in relation to learner outcomes (Carlson & Daehler, 2019). As much as establishing such a link with empirical evidence is a shared desire in the PCK science education community, the subject represents a gap in the PCK literature and thus, it is of high interest in this study. In an attempt to contribute towards addressing this gap, this study explored the TSPCK-learner outcomes link in the physical science topic of organic chemistry by following the development of PSTs' TSPCK through planning, actual classroom teaching and its influence on learner outcomes in the same topic. Further discussions on the rationale for the study are provided in the next section below.

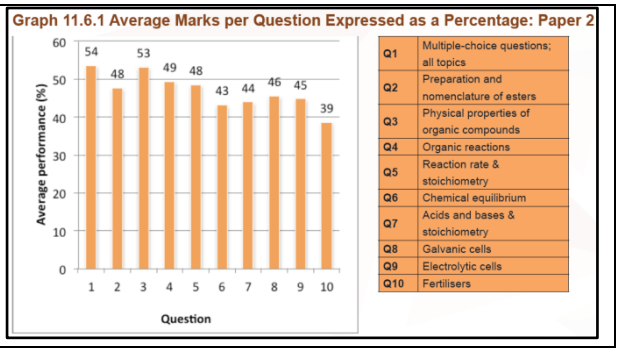
1.2 Rationale

Why focusing on a physical science topic (organic chemistry)?

Physical sciences comprises physics and chemistry taught together as one subject in South African high schools (Department of Basic Education, 2019). Chemistry is traditionally known as a difficult subject to teach and learn at both high school and higher institution levels (Upahi & Ramnarain, 2019; Treagust, Nieswandt, & Duit, 2000). Particularly, organic chemistry concepts are known to be highly demanding cognitively making its learning over-whelming for learners who only operates at the concrete stage of cognitive ability (O'Dwyer & Childs, 2017). In the South African context, the Figure 1.1 below gives the overall Grade 12 physical science learners' performances in physical sciences and specifically, on chemistry topics including organic chemistry.



Overall performance in physical sciences



Overall performance in chemistry topics

Figure 1.1: 2018 Grade 12 learner performances on chemistry topics (Department of Basic Education, 2019, p. 153 & 163)

As shown in the Figure 1.1 above, between 2014 and 2018, the percentage of Grade 12 physical science learners who achieved at 40% and above has only increased to 48.7%. The careful examination of the performances of learners in chemistry topics also revealed the highest performance of 54% on multiple choice questions and 53% on physical properties of organic compounds. Both the performances in physical sciences as a subject and on individual chemistry topics are below the achieving mark of 60% regarded as the minimum qualifying mark for entry into several Higher Education institutions in South Africa to study Bachelor of Science degree in physical science disciplines line Chemistry. One reason for the difficulty in learning chemistry is associated with the abstract nature of the concepts involved (Sirhan, 2007) and the understanding that there are some scientific views used in explaining chemistry which are in most cases contradictory to the learners' everyday experiences (Ortiz, 2019). Consequently, learners develop misunderstandings when they place correct instructional explanations of the chemistry concepts within the framework of contradictory prior conceptions (Duit & Treagust, 2003). Such difficulties in learning concepts of chemistry then call for learners to be equipped with a high-level skill so they could apply the knowledge appropriately when necessary (Zoller, 1990). While significant efforts should be made by teachers to improve their pedagogical strategies, Duit, Schecker, Höttecke and Niedderer (2014) emphasize giving the contents of instruction adequate attention by transforming them into teachable and understandable form. This supports Shulman's conceptualization of teachers' PCK regarded as the product of transformation of content knowledge in other to make content accessible to learners (Shulman, 1987). For science teacher education programmes, Mavhunga (2016) advocates the need to place emphasis on a given core science topic per time in order to fast-track the development of

specialized knowledge for teaching science topics considering the limited time available in such programmes. This supports the argument in the literature revolving around focusing on a topic specific nature of PCK in order to assist teachers' learning about the complexity of classroom teaching and learning process (Gess-Newsome, 2015). Hence, this study focused on developing the PSTs' specialized knowledge in the context of learning to reason and planning the topic of organic chemistry with ultimate goal of linking the knowledge demonstrated in the actual classroom teaching to learners' conceptual performances in the topic.

Why focusing on developing pedagogical transformation competence?

In investigating and addressing learning difficulties associated with teachers' specialized knowledge for teaching, most studies have been focusing more on the experienced teachers. This is based on the argument that, PCK is mostly developed through an integrative process rooted in the classroom teaching over a long period coupled of time (Chan & Yung, 2015; Jang, Guan, & Hsieh, 2009). There is the general understanding that, PSTs have little or no PCK at their disposal due to lack of teaching experiences and so, they hardly display the level of pedagogical competence observed in the experienced teachers (Evens, Elen, & Depaepe, 2015). However, Nilsson and Loughran (2012) argue there could be a positive change of situation if PSTs were provided meaningful ways of describing, recognizing, assessing and explicitly developing PCK. More so, a well-established PCK repertoire progresses from teacher education programmes and continues with experiences of classroom teaching and other professional development programmes (Adadan & Oner, 2014). As highlighted in the paragraph above, the transformation of content knowledge is central in the teachers' possession and demonstration of PCK (Shulman, 1987). While PCK has been described as both a knowledge base used in planning for and the delivery of topic-specific instruction (Gess-Newsome, 2015), Mavhunga and Rollnick (2013) identified content-specific knowledge components from which the pedagogical transformation of a given topic (e.g. organic chemistry) emerges. The knowledge components are: learners' prior knowledge; curricular saliency; what is difficult to teach; representations; and conceptual teaching strategies (Mavhunga & Rollnick, 2013). The argument is that, the responses generated from reasoning through the concepts of a topic using the listed knowledge components interactively reflect the extent of understanding knowledge for teaching the topic referred to as TSPCK (Rollnick & Mavhunga, 2014). More so, in the various

previous studies, the teachers' PCK and its quality has been described not only on which knowledge components comprise the teachers' PCK but also on how and to what degree those components were integrated into PCK (Akın & Uzuntiryaki-Kondakci, 2018; Aydin, Demirdogen, Akin, Uzuntiryaki-Kondakci, & Tarkin, 2015; Park & Chen, 2012). In other words, the quality of a teacher's TSPCK for teaching a specific topic is determined by the extent of his/her understanding of the interactive use of content-specific knowledge components in order to make the content understandable to the learners. This understanding of interactive use of content-specific knowledge components in generating PCK specifically for a giving topic has been referred to as the '*pedagogical transformation competence*' (Mavhunga, 2016). It is important to highlight that, by nature, PCK is not transferable from one person (e.g. a teacher educator) to another (e.g. a pre-service teacher) or from one topic to another topic. However, the pedagogical transformation competence learned to generate PCK in a particular context (e.g. planning) for a given topic (e.g. organic chemistry) could be applied in some other contexts (Mavhunga, 2016). Several studies have empirically proven the effectiveness of specific interventions focusing on specific topics to developing such competence in the PSTs (e.g. Mavhunga, 2016; Mavhunga & Rollnick, 2013) and beginning teachers (Pitjeng-Mosabala & Rollnick, 2018) mostly in the context of learning to teach. By building on these previous studies as a credible baseline in studying TSPCK-learner outcomes, efforts were further made in this study to examine the pedagogical transformation competence in both the context of learning to teach and actual classroom teaching of organic chemistry. Hence, this study examined how the pedagogical transformation competence that the PSTs learned in the context of learning to reason and planning organic chemistry informed the pedagogical transformation competence they eventually demonstrated in the actual classroom teaching and its influence on learners' conceptual performances.

Why focusing on cTSPCK-pTSPCK-eTSPCK learner outcomes link in organic chemistry?

In teaching, teachers carry the major responsibility of supporting learning through lesson planning, lesson enactment and reflection on the enacted lessons (Schneider, 2015). According to Shulman (1987), the thoughts that influence the actual delivery of lessons begins at the transformation stage, an important stage of planning and organizing the content to teach. This implies that, planning for lessons is as important as the actual delivery of lessons itself and

whatever is observed in the actual delivery of lesson could be linked to the efforts put in during planning. While previous studies (e.g. Mavhunga, 2016; Mavhunga & Rollnick, 2013) have shown the possibility of fast tracking the development of PSTs' planned TSPCK for teaching science topics in the context of planning, a gap still remains whether teachers are able to transfer such planned TSPCK captured in the context of planning a lesson to the actual classroom teaching of the lesson (Rollnick & Mavhunga, 2015). While shifting researchers' attention towards going beyond the planning context in investigating teachers' specialized knowledge, Aydeniz and Kirbulut (2014) raise a concern that, the fact that teachers demonstrated developing planned PCK does not automatically guarantee the application of such specialized knowledge in the actual classroom teaching. There may also be circumstances where a teacher can either intentionally or unintentionally desist from applying the knowledge demonstrated in planning when he or she is involved in the actual classroom teaching (van Driel, Berry, & Meirink, 2014). Thus, this study explored how the specialized knowledge introduced to the PSTs (cTSPCK) in the topic of organic chemistry informed their individual personal specialized knowledge (pTSPCK) demonstrated while learning to reason and planning (planned TSPCK) and that which they manifested in the actual classroom teaching (eTSPCK). This was done with the purpose of examining and establishing the cTSPCK-pTSPCK-eTSPCK learner outcomes link. For each of these three forms of TSPCK, the focus in this study was on the extent of PSTs' understanding of interactive use of content-specific knowledge components of TSPCK in pedagogically transforming the content knowledge of organic chemistry. Such an examination was envisaged to provide a comprehensive understanding of the nature of teachers' PCK in a specific topic (Aydin, Friedrichsen, Boz, & Hanuscin, 2014). Hence, an understanding of how PSTs' TSPCK dramatically develops from teacher education programmes through classroom teaching would be important in providing useful information for the design of quality learning opportunities available for teachers-in-training. Furthermore, teachers' characteristics which play a significant role on learner outcomes include teachers' educational background, experience, beliefs about teaching, content knowledge, general pedagogical knowledge, pedagogical content knowledge (Blömeke, Olsen, & Suhl, 2016) to mention a few. Most significantly, PCK has been known to be quite successful in providing a framework for developing and investigating teacher knowledge in science education research however, "very little, if anything at all, is known about the link between PCK and student learning" (Cross & Lepareur, 2015, p. 47) and "unfortunately,

there are few studies that examine the impact of professional development on teacher learning, classroom practice, or student outcomes" (Gess-Newsome, Taylor, Carlson, Gardner, Wilson & Stuhlsatz, 2019, p. 944 - 945). Where knowledge is available, the link between teachers' PCK and learner outcomes has been reported in the literature with contradictory findings (e.g. Gess-Newsome *et al*., 2019; Alonzo, Kobarg, & Seidel, 2012) thereby leaving the issue highly unresolved in the community of PCK researchers. This study also acknowledges the complexity of classroom instruction and learning due to myriad of influences and hence, the difficulty in accurately establishing the link between teachers' PCK and learner outcomes (Gess-Newsome *et al*., 2019; Cross & Lepareur, 2015). Hence, attempts were made in this study to describe the relationship between PSTs' eTSPCK and learners' conceptual performances. In this line of thought, Broadhead (1996) highlighted that a way of improving science teaching and learning is to encourage learners to indicate what makes science difficult for them to learn and how teaching such scientific concepts can be improved. In this way, collecting learners' views would enable teachers to appreciate the perceived instructional influences on learners' learning and conceptual understanding (Halim, Abdullah, & Meerah, 2014). As a result, the participant learners' views about the PSTs' teachings in this study were collected in order to gain insights into the aspects of PSTs' knowledge and instructional practices which promoted or hindered learners' conceptual understanding of organic chemistry. The evidence of the significance of PCK-learner outcomes link is further seen in the argument that, "student outcomes are one way of determining the effectiveness of a teachers' instruction; therefore one way to assess the usefulness of a construct, such as PCK, is to determine if that construct predicts student learning outcomes" (Carlson & Daehler, 2019, p. 83). In this line of thought, Carlson, Gess-Newsome, Gardner and Taylor (2013) argue that, "if a teacher's PCK is strengthened, we should see a positive change in student achievement" (p. 3). Then, it could be reasonably argued that, the ultimate goal for investing in the PSTs by developing their TSPCK is to improve the quality of classroom instructions and eventually contribute towards enhancing learner outcomes. Therefore, in exploring the TSPCK-learner outcomes link, this study followed the development of PSTs' TSPCK through the cTSPCK-pTSPCK-eTSPCK trajectory while learning to teach organic chemistry and its influence on learner outcomes.

1.3 Research questions

Based on the arguments provided in the sections above, the overarching research question guiding this study was formulated as follows: How does the competence to pedagogically transform content knowledge of organic chemistry learned by pre-service teachers influence their quality of TSPCK seen in planning for teaching and actual classroom teaching of organic chemistry in relation to learner achievement? This research question was divided into three sub-research questions stated as follows:

(1) How does an intervention, which focuses on developing competence to pedagogically transform content knowledge of organic chemistry, influence the quality of pre-service teachers' TSPCK in the context of learning to reason and planning?
(2) How does the competence to pedagogically transform content knowledge of organic chemistry that pre-service teachers learned during the intervention influence the quality of TSPCK seen in their actual classroom teachings of organic chemistry?
(3) How does the quality of pre-service teachers' TSPCK seen in the actual classroom teaching of organic chemistry influence learner achievement in organic chemistry?

1.4 Conceptual Framework

This study was grounded in the PCK theoretical framework informed by the Shulman's (1987) argument that, "comprehended ideas must be transformed in some manner if they are to be taught" (p. 16) and the value of 'pedagogically transformed content understanding' lies in its desired effect of enhancing learner outcomes (Rollnick & Mavhunga, 2015). These ideas were guided by the Refined Consensus Model of PCK highlighting the three realms of PCK in relation to learner outcomes (Carlson & Daehler, 2019) and TSPCK construct placing PCK at a topic specific level (Mavhunga & Rollnick, 2013). The detailed discussions on these two conceptual models used in describing PCK theoretical framework are provided in Chapter 2.

1.5 Overview of the thesis chapters

This thesis consists of ten chapters. Chapter 1 introduces the study by identifying the research problem associated with the gap in the literature, providing discussions on the rationale for

conducting the study, research questions formulated to guide the study and overview of the theoretical framework on which the study was grounded. Chapter 2 provides the literature review on the moral work of teacher, specialized knowledge for teaching, detailed discussions on the Refined Consensus Model of PCK and TSPCK construct, previous studies on the interactive use of knowledge components of PCK, capturing and measuring PCK, cPCK-pPCK-ePCK learner outcomes link and the summary of identified gap in the literature. Chapter 3 presents discussions on the research design for this study, rationale for choosing the research design, intervention conducted with the PSTs, instruments for data collection, methods of collecting and analyzing data, validity and reliability of the measures and ethical procedures. Chapter 4 explicitly discusses the intervention conducted in this study focusing on cTSPCK and its content-specific knowledge components from which the pedagogical transformation of organic chemistry emerges. Chapter 5 presents the analysis of PSTs' planned TSPCK visible as personal TSPCK (pTSPCK) in the context of learning to reason and planning to teach organic chemistry. Chapter 6 presents the analysis of PSTs' eTSPCK as teachers' knowledge visible in the context of classroom teaching of organic chemistry. Chapter 7 presents the analysis of learners' performances in the achievement tests focusing on the concepts of organic chemistry taught by the PSTs. Chapter 8 presents the analysis of the relationship between the PSTs' eTSPCK and learner achievement in an attempt to establish the TSPCK-learner outcomes link. Chapter 9 presents the examination of learners' views concerning the factors that have promoted or hindered their conceptual understanding of organic chemistry. Chapter 10 pulls together all the findings emerging from the previous chapters and then presents discussions and implications of the study.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter presents the review of literature relating to the development of PCK, enactment of PCK and learner outcomes. It begins with discussions on learning to teach as a moral endeavour in the context of pre-service teacher education programmes followed by the conceptualizations of PCK for science teaching and the two conceptual models describing the PCK theoretical framework. A specific focus is paid to the pedagogical transformation competence of content knowledge of a given topic and interactive use of content-specific knowledge components in describing the quality of PCK in the topic. Further discussions are provided on the cPCK-pPCK-ePCK learner outcomes link by reviewing the related previous studies. The chapter closes by summarizing the identified gap in the PCK literature which this study intended to address.

2.0 Introduction

This study is grounded in the Shulman's (1987) theoretical proposition that the process which results in effective teaching of content commences before the actual classroom teaching itself, beginning with thorough pedagogical reasoning about the content. The study is also based on the understanding that, the value of 'pedagogically transformed content knowledge' lies in its desired effect of enhancing learner outcomes (Rollnick & Mavhunga, 2015). PCK, as observed in experienced teachers, represents the amalgamation of the knowledge components which promotes such pedagogical transformation (Geddis & Wood, 1997; Shulman, 1987). The PSTs who are being prepared to embark on teaching career are generally required to first develop the ability to pedagogically think soundly about the content, engage in the actual classroom teaching and reflect on their experiences of acquisition of knowledge. Nonetheless, little is known about the translation of pedagogical transformation competence acquired through the teacher education programmes into actual classroom teaching and how such ultimately influences learner outcomes. This chapter presents the review of literature on developing the specialized knowledge for teaching towards improving the quality of classroom instruction and learner outcomes.

2.1 Learning to teach as a moral endeavour in pre-service teacher education

There is an understanding that, education targets the support of entire being of individual learners including the aspects of cognitive domain (Rissanen, Kuusisto, Hanhimäki, & Tirri, 2018). That means education is advantageous to learners in terms of academic development when support is provided to them in an environment that is conducive for enhancing learning. Teacher education programs under the auspices of the universities are concerned with engaging PSTs in the process of learning to teach**,** making them understand the core practices of teaching and how they contribute to learner academic development. In this regard, teaching and learning are considered moral endeavours as they both portray moral work. With regards to the varying degrees of engagement and different levels of success involved in teaching, Sanger, Osguthorpe and Fenstermacher (2015) encourage differentiating between "teaching morally and teaching morality" (p. 2) as one strategy for understanding the different spheres involved in the moral work of teaching. While teaching morally entails exhibiting moral behaviors valuable for learners to learn from (Gholami & Husu, 2010), teaching morality comprises of efforts that provide learners with the means for developing ethical competency (Rissanen *et al*., 2018). Sanger (2008) describes teaching morally as the teachers' knowledge of "what is good, right, caring, and virtuous and be able to enact those things in their practice" (p. 176). In other words, good understanding of teaching should be rooted in what is important for learners to know and such understanding should be put into practice in the actual classroom practice. From the experience of teacher-educators who teach PSTs, it has been observed that a great number of those entering the work of teaching do so with what seems to be a moral objective: improving the lives of students, in part by helping them become more knowledgeable and skilled, better human beings (Rissanen *et al*., 2018). In order words, the moral work of teaching requires teachers to possess understanding of important aspects that contribute to facilitating learning and applying such understanding in the actual classroom teaching. This most importantly calls for assisting PSTs to develop moral language which empowers them to consider teaching practice as it is pedagogically expected (Stengel, 2013). Klaassen, Osguthorpe and Sanger (2016) identify two meaningful different channels in which the moral work of teaching might be engaged in. The first channel examines how a teacher conducts teaching practice in a morally sound manner and the second channel considers positive influences a teacher has on the development and moral functioning of the learners. Paying attention to moral work of teaching targets equipping PSTs

with the technique to both teach morally and teach morality (Johnson, Vare, & Evers, 2013). The two ideas combine what is learnt theoretically and thereafter put into practice to be evident in the ultimate outcome of enhancing learning among learners in the classroom. Putting this argument on learning to teach as a moral endeavour into the perspective of teaching PSTs how to teach, there is a moral obligation for teacher education programmes to teach prospective teachers both morally and the morality they need to embrace. I am arguing through this study that, teaching to PSTs a theoretical construct like PCK offers the opportunity to both teach morally and teach morality. It is therefore important for science teacher educators to be extremely aware that to teach PCK morally requires explicit description of what core aspects about PCK are enabling therefore to be pursued, and how the construct responds to the moral obligation of teaching – to help learners understand difficult concepts.

2.2 Conceptualization of PCK for teaching and learning

Over the last decades, researchers have been paying much attention to the practices and knowledge fundamental to effective teaching and learning particularly in the various programmes anchored by teacher education. Most importantly, PCK was introduced by Shulman (1986, 1987) in order to call the attention of researchers to the advantage of the unique amalgamation of general pedagogical knowledge and content knowledge needed by teachers to be the most effective teachers possible. He referred to PCK as the unique knowledge for teaching which differentiates teachers from scientists of similar content knowledge. Ever since that time, PCK has been regarded as a valuable construct in enhancing effective teaching and learning of science in several ways. For example, PCK encompasses teachers' understanding of learners revolving around common learners' misconceptions, pre-requisite knowledge and learning difficulties (Gunckel, Covitt, & Salinas, 2018). This means that, teachers' PCK is embedded in their understanding of what learners already know about a given topic and aspects relating to the topic where learners might possibly encounter difficulties in comprehending. In this regard, PCK is argued to result from the transformation of various knowledge bases for teaching (Aydin & Boz, 2013). As a result, PCK and its knowledge components are considered helpful for researchers to study teachers' knowledge during practice as they provide avenue to describe effective teaching with its underlying practices and also inform aspects of both the in-service and pre-service science teacher education programmes (Akın & Uzuntiryaki-Kondakci,

2018; Aydin *et al*., 2014). This understanding makes the development of PCK in teachers an important aspect which continually draws science teacher-educators and researchers' attention. As a matter of fact, the development of a well-established PCK is understood to be a continuing process which progresses through initial teacher education programmes and carries on through teaching practice and professional training (Adadan & Oner, 2014). With respect to that, the understanding of how specialized knowledge for teaching acquired by science teachers develops and translates into actual classroom teaching would be important in creating an effective science teaching and learning process. At the same time, gaining a deeper understanding of teacher knowledge and bringing the contributions of such knowledge into practicality requires uncovering aspects of teacher knowledge manifested in planning and actual teaching.

It is widely agreed upon among researchers that PCK is advantageous as a theoretical framework for researching and developing teacher knowledge for teaching (Chan & Yung, 2018; Nilsson & Loughran, 2012). However, different researchers seem to have different perspectives about and ways of describing PCK which portray its multidimensional nature. While some researchers accentuate the private and personal nature of PCK through observations of classroom teaching of individual teachers (Aydin *et al*., 2014), other researchers highlight that, in spite of the idiosyncratic nature of PCK, there is the possibility of having commonalities across PCK of a group of teachers which produces a more generic version of PCK (van Driel, Verloop, & Vos, 1998). In such cases, references have been made to cPCK by observing a group of teachers engage in classroom teaching (Cooper, Loughran, & Berry, 2015) and pPCK by studying individual teachers during teaching (Aydin *et al*., 2014). Some researchers came up with the idea of canonical PCK (Smith & Banilower, 2015), and others indispensable PCK (Park, Suh, & Seo, 2018) . Smith and Banilower (2015) describe canonical PCK as "PCK that is widely agreed upon and formed through research and/or collective expert wisdom of practice" (p. 90) which gives the understanding that PCK is defined normatively by researchers. Other researchers found out that, PCK exists at three distinguishable levels which include: discipline-specific level; domain-specific level; and topic-specific level (Nezvalova, 2011; Veal & Makinster, 1999). From these various perspectives, it could be noticed that while PCK is considered fruitful in exploring teachers' knowledge, "research about and application of PCK had been suffering from a lack of shared definitions and conceptualizations of the construct in the field" (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015, p. 28) . This makes it extremely difficult to

highlight what knowledge components specifically constitute PCK without any uncertainty. Meanwhile, emphasis is placed on developing PCK in PSTs as part of their professional knowledge (Evens, Elen, Larmuseau, & Depaepe, 2018). Consequently, there is the need to address PCK without ambiguity and distinguish between different researchers' perspectives about PCK in order to demonstrate sound understanding of the constituent knowledge components which must be emphasized to the PSTs in the course of introducing PCK as a construct to them.

2.3 Theoretical framework for this study

This study focused on the theoretical framework of PCK and its link to learner outcomes. As a result, the exploration of PCK theoretical framework was informed by the Refined Consensus Model of PCK and TSPCK construct. In an effort to bring together all the different conceptualizations of PCK, the science education researchers lately developed the Refined Consensus Model (RCM) of PCK (Carlson & Daehler, 2019) which is shown in the Figure 2.1 below.

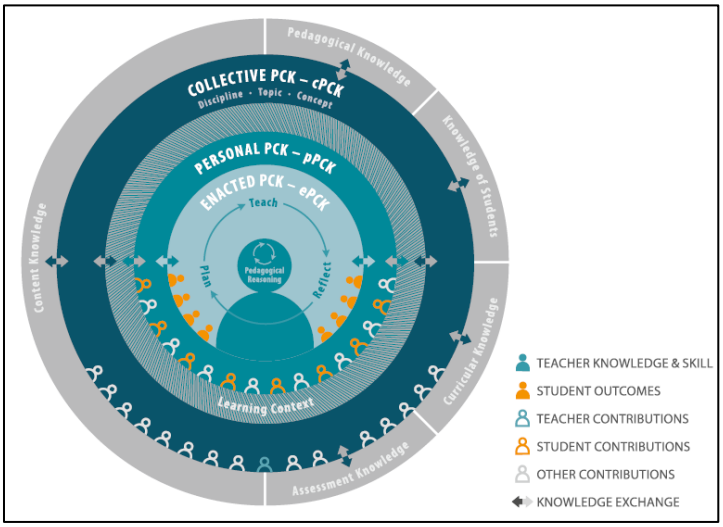


Figure 2.1: Refined Consensus Model of PCK (Carlson & Daehler, 2019, p. 83)

The RCM exemplifies complex knowledge and experiences in complex layers that shape teachers' practice and facilitate learner outcomes. The researchers' effort to develop RCM responds to criticisms levelled at PCK research for its focus on exploring what a teacher knows, without relating it to what the teacher actually does and what learners eventually learn (Park &

Suh, 2019). The criticism voices the same sentiment expressed by Lee Shulman in his review on PCK, that PCK should not only be viewed as a cognitive construct that exists in the teachers' heads, but also as a dynamic construct which explains the complex processes that teachers apply during the act of teaching (Shulman, 2015). On this note, RCM attempts to represent pictorially both the multi-dimensions of PCK and its projected development in teachers and influence on what the teacher does and the subsequent impact of that action on the learners' conceptual understanding. According to Carlson and Daehler (2019, p. 82),

> A key feature of this model is the identification of three distinct realms of PCK—*collective PCK (cPCK), personal PCK (pPCK),* and *enacted PCK (ePCK*)—which describe the specialised professional knowledge held by multiple educators in a field, to the personalised professional knowledge held by an individual teacher in science, and the unique subset of knowledge that a teacher draws on to engage in pedagogical reasoning during the planning of, teaching of, and reflecting on a lesson.

As shown in the Figure 2.1 above, the RCM of PCK recognises the different dimensions or teaching realms in which PCK is visible. The three distinct realms of PCK have been identified and named as: collective PCK (cPCK); personal PCK (pPCK); and enacted PCK (ePCK) with learner outcomes as a key downstream product. The RCM of PCK identifies cPCK as the first realm where in-service and PSTs get to know about a shared professional understanding about PCK (Mavhunga, 2019) . cPCK involves all forms of knowledge of teaching profession that teachers may acquire from coursework, text and other sources which are commonly agreed upon as teacher knowledge for effective teaching and learning process (Carlson & Daehler, 2019). In the case of PSTs who take coursework that focuses on developing their PCK, they are being taught cPCK which they could individually personalize to generate personal PCK (pPCK) mediated by filters and amplifies such as personal beliefs, varying extent of understanding of cPCK and other affective factors (Carlson & Daehler, 2019) . In order words, pPCK comprises individual PST's understanding of knowledge drawn from cPCK which could inform their pedagogical reasoning while planning to teach, during teaching and while reflecting on the enacted instructions. Teachers' pPCK portrayed while thinking about and planning for teaching has been commonly referred to as planned PCK (Aydeniz & Kirbulut, 2014; Park & Oliver, 2008). Teachers' ePCK has been described as PCK portrayed by teachers in the actual classroom teaching (Carlson & Daehler, 2019). Thus, cPCK, pPCK and ePCK represent the three distinct realms that must be explored in order to sufficiently describe the nature of teachers'

PCK leading to their development of professional knowledge for teaching (Chan & Hume, 2019).

It could also be observed that, RCM of PCK recognises topic specific PCK (TSPCK) as one of the grain sizes of PCK, along with discipline-and concept-specific reflecting the different levels in which teachers' knowledge operates (Carlson & Daehler, 2019). However, the PCK community is still being confronted with the challenge of conceptualizing the highlighted three grainsizes of PCK in a manner that distinguishes them from each other (Mavhunga, 2019). More so, there are still unanswered questions regarding the relationship between these grain sizes of PCK. Notwithstanding, to gain insights about PCK through the pattern outlined as shown in the Figure 2.1 above assists in understanding that, different knowledge is required by teachers in order to teach sciences as a discipline and also to teach different topics found in the discipline (Gess-Newsome, 2015). It is generally recommended in the science education literature to consider focusing on specific topics in developing teachers' PCK (Aydin *et al*., 2014) and using such knowledge as a core practice which should be passed on to the PSTs (Aydin et al., 2015). In spite of this widely accepted understanding among science education researchers, teaching PCK to the PSTs still remains ambiguous slightly because there is no clarity regarding the specific knowledge components to emphasize when discussing PCK in a topic (e.g. organic chemistry) versus PCK in a discipline (e.g. science). For this reason, this study considers a version of PCK which epistemologically addresses the topic specificity of PCK for developing PSTs' specialized knowledge for teaching science topics. This version of PCK has been referred to as Topic Specific PCK (TSPCK) (Mavhunga & Rollnick, 2013).

This study was grounded on two important conceptualizations in the PCK literature. First, it was based on the Shulman's (1987) argument that, "comprehended ideas must be transformed in some manner if they are to be taught" (p. 16). Second, it was based on the understanding that the value of 'pedagogically transformed content understanding' lies in its desired effect in enhancing learners' conceptual performances (Rollnick & Mavhunga, 2015). By focusing on these conceptualizations, Mavhunga and Rollnick (2013) developed TSPCK model which places PCK at a topic specific level as shown in the Figure 2.2 below.

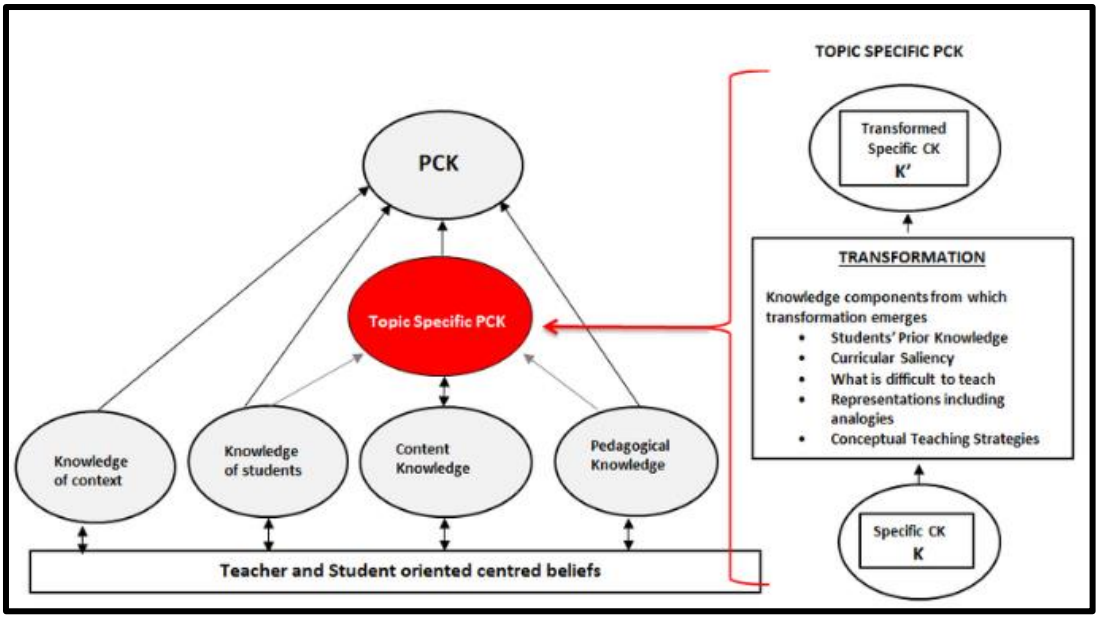


Figure 2.2: TSPCK Model (Mavhunga & Rollnick, 2013)

As shown in the Figure 2.2 above, TSPCK model identifies five content-specific knowledge components from which the pedagogical transformation of content knowledge (CK) of a given topic emerges. The five content-specific knowledge components are: learner prior knowledge; curricular saliency; what is difficult to teach or understand; representations; and conceptual teaching strategies. There are three key features of TSPCK model which makes it epistemologically suitable to be integrated in the RCM of PCK and therefore, used in this study to clearly define PCK at a topic specific level. The first key feature is that, TSPCK model places PCK at a topic specific level and hence, differentiates it from the broader PCK (i.e. discipline-specific PCK) considering the consensus among science educations researchers that "PCK is defined as both a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context" (Gess-Newsome, 2015, p. 42). The second key feature is that, while Shulman (1987) argues for the pedagogical transformation of content knowledge without specifically identifying the knowledge components needed, TSPCK highlights five specific knowledge components from which the pedagogical transformation of content knowledge emerges. The conceptualization of these knowledge components was similar to the 'multitude of particular things' that Geddis (1993, p. 676) referred to while discussing elements involved in the teachers' transformation of subject matter knowledge. The third key feature is that, it has been empirically argued and proven that, TSPCK can be taught to the PSTs to generate 'learned TSPCK' (Rollnick & Mavhunga, 2015) which is similar to the 'planned

PCK' referred to by (Park & Oliver, 2008) . In order words, thinking soundly about content knowledge (CK) of a given topic (e.g. organic chemistry) through the content-specific knowledge components produces transformed content knowledge (CK′) which is specific to the topic in question (Rollnick & Mavhunga, 2014). This transformed specific content knowledge CK′ is the TSPCK which is embedded as a shared professional understanding of cPCK at a topic specific level in the RCM of PCK shown in the Figure 2.1 above. Thus, by focusing on the topic specificity of PCK, this study explored the TSPCK-learner outcomes link by following the PSTs' TSPCK development through the cTSPCK-pTSPCK-eTSPCK trajectory while learning to teach and its ultimate influence on learners' conceptual performances. Such an exploration is particularly important in the cases of PSTs who are always confronted with the challenge of overcoming the gap between the acquired theoretical knowledge and application of the knowledge in practical learning in order to enhance learners' conceptual understand (Stürmer & Seidel, 2017). Therefore, the three realms of PCK were of interest in this study as they display the developmental trajectory through which the TSPCK-learner outcomes link could be explored.

2.3.1 Understanding content-specific knowledge components in teaching

Each content-specific knowledge component highlighted in the TSPCK model speaks to a certain aspect of teacher knowledge that constitutes understanding to pedagogically transform content knowledge of a given topic. First, the knowledge component '*Learner Prior Knowledge*' constitutes all forms of learners' conceptions including correct existing knowledge and misconceptions. In his conceptualization, Shulman (1986) described learner prior knowledge as the conceptions and preconceptions that learners of different backgrounds and ages bring with them into the classroom learning of topics and lessons. While explaining the role of prior knowledge in applying or creating new knowledge, Amelia, Handayanto and Muhardjito (2016) points out that, prior knowledge is important for eliminating ambiguity associated with concepts and making connections among different and similar ideas. As knowledge component of teachers' PCK in a specific topic, Aydin and Boz (2013) reveal that PCK reflects in the teacher taking cognisance of learners' misconceptions, previous knowledge and difficulties. In other words, learners' understanding of current concepts is related to their thinking and prior experiences which teachers should be knowledgeable about. Second, the knowledge component '*Curricular saliency*' entails learning of topics relative to the curriculum as a whole where focus

is on understanding what concepts are most core and which concepts are peripheral, the needed immediate concepts and logical sequencing of concepts (Mavhunga, 2016). Similar to this, Geddis and Wood (1997) referred to this component of teachers' knowledge as the understanding of topics and concepts in the curriculum making it an important PCK component as Geddis, Onslow, Beynon and Oesch (1993) highlighted. As one key aspect of curricular saliency, Loughran, Berry and Mulhall (2012) refer to Big Ideas as the core concepts in a topic on which other concepts regarded as subordinate ideas build to bring about understanding of the topic. Showing the importance of this knowledge component, Mthethwa-kunene, Onwu and de Villiers (2015) in their study of biology teachers' PCK found out that the participants' curriculum knowledge assisted them in planning and sequencing of concepts thereby influencing their PCK. Likewise, Penuel, Gallagher, Moorthy, Gallagher and Moorthy (2011) in their study reported that the participating teachers' curricular knowledge improved learning outcomes. It could then be argued that, teacher knowledge of curricular saliency is important in describing his/her TSPCK. Third, the knowledge component '*what is difficult to teach or understand*' comprises the understanding of specific gate-keeping concepts within a given topic which are difficult to understand and not necessarily misconceptions, and it triggers dedicated awareness and possible interventions for teaching them (Mavhunga & Rollnick, 2013). In this line of thought, Shulman (1986) indicates that reflections on personal conceptual difficulties are parts of expert teachers' reasoning that eventually describe their knowledge for teaching. Similar to that, Depaepe, Verschaffel and Kelchtermans (2013) describe understanding conceptual difficulties as an important component of PCK as it involves thorough investigation. This makes teacher knowledge of what is difficult important in stirring awareness of possible challenges that may hinder good understanding of a specific topic and therefore require attention. Fourth, the knowledge component '*representations*' comprises of teachers' understanding of a range and different levels of representations including illustrations, simulations, analogies and models which could be used to explain concepts in a topic in order to enhance learning (Mavhunga, 2018). These levels of representations include macro-representations (e.g., use of laboratory equipment), symbolic representations (e.g., use of equations, diagrams) and micro representations (Cheng & Gilbert, 2009). In their illustrations, Prain and Tytler (2012) highlight how the use of representations is linked to motivating the interest of learners by engaging them in constructive and critical thinking. This in turns enhances learners' understanding of the

concepts. Fifth, the knowledge component '*conceptual teaching strategies*' consists of effective teaching methods which identify learners' misconceptions and then address the misconceptions by emphasizing key concepts that must be understood using levels of representations in order to prevent the occurrence of such misconceptions in the course of teaching concepts considered difficult and confusing (Mavhunga & Rollnick, 2013). In order words, conceptual teaching strategies draw on other content-specific knowledge components in teaching content such that it becomes understandable for learners. These also involve the understanding to apply variation theory in teaching by discussing two concepts side by side in order to make learners understand the difference and similarity between the concepts (Bussey, Orgill, & Crippen, 2013). These five content-specific knowledge components have been considered important in pedagogically transforming the content knowledge of a given topic while planning to teach the topic and during actual teaching of the topic.

2.3.2 Pedagogical transformation competence

According to Shulman (1987), there is the need to recognize teaching as a complex cognitive process which requires more than applying just teaching techniques and content knowledge. He outlined the complexity of domain of knowledge on which teachers have to dwell in reasoning, planning, teaching and reflecting on their teaching practice. He explained his consideration for processes which underpin pedagogical reasoning and posited that certain actions were required to be performed by teachers for them to transform their individual comprehension of content into understandable forms for learners. It is important to note that separating reasoning and action should be misinterpreted for theory-practice separation rather it should be seen as analytical and semantic division of a multidimensional process involved in teaching (Holmberg, Fransson, & Fors, 2018). Sharing the same thought with Lee Shulman, Schön (1983) described the process as ongoing reflective conversations with situations in such a way that a teacher reflects on his or her understanding and actions in a unified multifaceted process. The processes involved in pedagogical reasoning go beyond ordinary thinking about teaching. In line with the perspective of Wilson, Shulman, Richert and Calderhead (1987), Shulman (1987) is of the opinion that, pedagogical reasoning consists of processes in a cyclic form. The processes start with comprehension which involves understanding facts, purposes and links between different ideas that make up a particular discipline. This is followed by the transformation of comprehended

understanding into sequenced bits of knowledge represented in order to promote learning. The next in the cyclic order is the actual lesson delivery and then, the evaluation of lessons followed by the reflection on the lessons and finally the new comprehension. This study particularly embraces the aspect of pedagogical transformation of content knowledge by teachers in order to make concepts accessible to learners. According to Oh and Oh (2011), teachers' pedagogical transformation refers to "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'' (p. 1124). This description is similar to the conceptualization of didactic transposition in the field of mathematics education research as Pansell and Bjorklund-Boistrup (2018) argued. In this regard, Shulman (1987) referred to pedagogical transformation as one step in pedagogical reasoning and action processes which is "the essence of the act of reasoning of teaching" (p.16). He is of the opinion that the process of transforming knowledge of content is the key in the teachers' demonstration of PCK and it takes place before the actual delivery of lessons. The development and emergence of PCK are also known to happen during the transformation of content knowledge with the aim of making students understand content (Wilson *et al*., 1987).

This idea of pedagogical transformation of content knowledge as the key in the teachers' PCK is well agreed upon by PCK researchers (Abell, 2008; van Driel *et al*., 1998). In support of this idea, Geddis and Wood (1997) posit that focusing on the transformation of subject matter is of great value because "it directs attention simultaneously to subject matter, learners and educational purposes, and to the interactions among these different kinds of teacher knowledge in the pedagogical encounter" (p. 612). In a similar exploration to Mavhunga and Rollnick (2013) , Mavhunga (2016) investigated the development of TSPCK in a group of PSTs focussing on the particulate nature of matter. The author found out a developing category of TSPCK as the product of explicit discussions held with them using the TSPCK construct. The PSTs' successful application of the acquired knowledge in transforming the content knowledge of another topic, chemical equilibrium was also observed. While PCK is topic specific and cannot be transferred from one topic to another, Mavhunga (2016) highlighted that, what is transferrable is the 'pedagogical transformation competence'. In this line of thought, Rollnick and Mavhunga (2015, p. 142) argue out that "what is transferable to another topic is the ability to use the five TSPCK components, where successful engagement with the concepts of the new topic is still

needed to improve TSPCK in the new topic". Thus, the transfer in this context does not denote the transferability of TSPCK but rather, the application of learned pedagogical transformation competence in producing TSPCK for the topic in question. In other words, what signifies the quality of TSPCK a teacher possesses for a given topic is the extent to which the teacher demonstrates interactive use of the knowledge components in making the concepts understandable. Similar opinion from the psychological view about learning posit that "If students can only solve specific problems which they have been taught to solve in the classroom, and fail to solve related problems in a series, one would not attribute mastery of the material to them" (Pea, 1987, p. 639). While this study focused on organic chemistry, the transferability of pedagogical transformation competence learned and demonstrated by the PSTs in planning was further examined in the actual classroom of organic chemistry for possible similarities and differences as a way of evaluating the efforts put into developing their TSPCK. This supports the opinion of an educational psychologist that "if someone learns to do any single thing well, he will also be able to do other entirely unrelated things well as a result of some secret connection" (Vygotsky, 1978, p. 82). Consequently, it sounds promising to make efforts towards enhancing PSTs' pedagogical transformation competence in the context of learning to reason and planning with the assumption that, they would be able to apply the learned competence in the classroom context in order to improve quality of instruction and ultimately, learner outcomes. While teachers' understanding of individual knowledge component of PCK is crucial, the ability to integrate the knowledge components is considered most important in developing PCK (Aydin *et al*., 2015; Park & Chen, 2012). Therefore, the PSTs' TSPCK developed and captured in this study focused on the extent of interactive use of content-specific knowledge components of TSPCK in the specific topic of organic chemistry. The review of studies on the interaction among knowledge components of PCK is provided in the next section below.

2.4 Quality of TSPCK

2.4.1 Quality of TSPCK as a description of interactions among knowledge components

In an attempt to describe the nature of teachers' quality of PCK, several studies have focused on the interaction among knowledge components based on their conceptualization of what PCK is. Aydin et al. (2015) regard the interactions among knowledge components as vital to PCK

development. This supports the understanding that in order to promote the teachers' development of PCK, emphasis should be on the interaction among knowledge components that form PCK as a whole rather than focusing on individual component (Park & Chen, 2012). In this line of research, Grossman (1990) examined teachers' integration of PCK components and found out that the "components are less distinct in practice than in theory" (p. 9). Building on the significance of practicality of cognitive knowledge, Fernández-Balboa and Stiehl (1995) posited that "it is not the separate existence, but rather the intersection and rightful integration of all these PCK components that comprises good teaching" (p. 294). In other words, good teaching is characterized by the interactive use of identified knowledge components which constitute PCK as a whole. In the classroom teaching of models of solar system, Henze, Van Driel and Verloop (2008) explored teachers' integration among knowledge components of PCK by focusing on two different kinds of science orientation in relation to other knowledge components which included knowledge of assessment, knowledge of learner and instructional strategies. In their observed type of teachers' PCK, the authors reported that teachers' knowledge of learners interacted strongly with instructional strategies employed. In a similar study, Park and Oliver (2008) observed that the teachers' knowledge of teaching strategies and assessment was shaped by their developed knowledge of learner including learners' misconceptions. By focusing on the lecturers of quantum chemistry in a university setting, Padilla and Van Driel (2011) found out there was strong link between participants' knowledge of instructional strategy, curricular knowledge and knowledge of learners. In clearly mapping out such interactions, Park and Chen (2012) observed a group of biology teachers' PCK demonstrated in the classroom teaching photosynthesis and heredity. The authors found out there was an idiosyncratic kind of interactions among the knowledge components which was also noticed to be topic specific (Park & Chen, 2012). Using the Park and Chen's (2012) method of mapping out and enumerating PCK components, Aydin and Boz (2013) qualitatively examined the nature of integration of two chemistry teachers' PCK components in teaching redox reactions and electrochemical cells. The authors observed that the knowledge of learners and instructional strategy were central in the integration which was noticed to be topic specific (Aydin & Boz, 2013). By using a scoring rubric, the authors were able to discriminate the complexity and quality of the integrations among the knowledge components of PCK for facilitating learners' understanding. Aydin et al. (2014) also examined the nature of teachers' PCK for teaching

electrochemical cells and nuclear reactions. The authors found out that although the observed teachers had similar PCK when compared to each other, there were differences in their PCK demonstrated in teaching the two topics. These differences were found in terms of the knowledge components interacting and shaping the observed PCK. The teachers' knowledge of instructional strategies, learner and curriculum were noticeably displayed (Aydin *et al*., 2014).

It would be observed that, most studies that have studied the interactions among knowledge components of PCK focused on the experienced teachers based on the understanding that PSTs are known to possess fragmented PCK (Lee, Brown, Luft, & Roehrig, 2007). However, the literature reveals the importance of supporting PSTs in order to enable them to develop the ability and understanding for integrating components of PCK (Aydin & Boz, 2013; Park & Chen, 2012). Among the studies that have made such an attempt was a quantitative investigation on how science PSTs' components of PCK inter-related while teaching ozone layer depletion investigated by Kaya (2009). By using a 3-crietrion based rubric to score the knowledge components observed in the participant PSTs' teaching, Kaya (2009) reported that while the correlation for intra-relationship among knowledge components was found to be moderate, there was a low relationship between other knowledge components and the participants' knowledge of assessment. Likewise, Aydin et al. (2015) examined interactions among the PCK components demonstrated by a group of PSTs during practicum course focusing on chemistry topic of rate of reaction and using Magnusson, Krajcik and Borko's (1999) model of PCK. The authors observed idiosyncratic nature of integrations among the knowledge components and the development of PSTs' PCK from fragmented to as more integrated and coherent one at the end of the course (Aydin *et al*., 2015). Likewise, Mavhunga (2018) studied the content-specific knowledge components of PCK at a topic specific level in the chemistry PSTs' planning to teach chemical equilibrium. The author employed an in-depth qualitative method of identifying moments of interactive use of two or more knowledge components, referred as the TSPCK episodes similar to PCK episodes in the Park and Chen's (2012) study. Mavhunga (2018) reported linear, interwoven and a combination of both the linear and interwoven structures of knowledge components which led to the PSTs' sophisticated level of TSPCK observed in lesson plans and explanations on CoRe prompts.

The review of previous studies presented in the above revealed that, teachers' PCK has been captured either in planning context or actual classroom context as the interaction among the knowledge components of PCK. It could be observed that, all the studies have either focused on either the planning context or actual classroom teaching context. A gap identified in this review is that, none of the studies provided insights about the link between the interactions among teachers' PCK components in planning and interactions among the same teachers' PCK components in the actual teaching. In an attempt to contribute, this study explored the PSTs' understanding of interactive use of content-specific knowledge components in planning and actual classroom contexts with the purpose of establishing the TSPCK-learner outcomes link through cPCK-pPCK-ePCK trajectory of developing TSPCK. Likewise, it could also be observed that, the use of PCK maps and in association, TSPCK maps has been shown to be advantageous in understanding and representing the interaction among knowledge components of PCK (Mavhunga, 2018; Park & Chen, 2012). Hence, in this study, the nature of interaction of content-specific knowledge components were described by identifying the particular knowledge components involved and visualizing them using TSPCK maps based on the arguments in the literature that PCK seen through coherent and integrated knowledge components stands is the key to effective teaching (Abell, 2008; Aydin et al., 2014).

2.4.2 Capturing and measuring quality of TSPCK

PCK and in association, TSPCK abstract knowledge which is embedded in the teachers' minds and experiences of teaching making the process of measuring it very challenging (Cooper *et al*., 2015). Hence, the literature consists of various tools developed by researchers in an attempt to capture teachers' thoughts about teaching in order to describe the teachers' quality of PCK. The related notable work in mathematics teaching and learning focused on developing measures of teachers' content knowledge through the analysis of the teachers' responses to a set of multiple choice question items in mathematics (Hill, Ball, & Schilling, 2008). For capturing science teachers' reasoning about teaching, Content Representations (CoRe) and Pedagogical and Professional experience Repertoires (PaP-eRs) were both developed by Loughran, Mulhall and Berry (2004). According to the authors, these two tools generate qualitative reflections into understanding teachers' pedagogical knowledge in planning for teaching. Loughran et al. (2004) referred to the use of CoRe as a tool used in research studies for examining and representing

content understanding of science teachers. For example, Williams, Eames, Hume and Lockley (2012) noticed that by encouraging PSTs to develop a CoRe through collaboration, they were able to focus on the important aspects of a given topic and methods of planning the topic for teaching. This is in agreement with Bertram and Loughran's (2012) recommendation regarding CoRe as a supporting tool to enhancing the experienced teachers' knowledge for teaching. It is known to be an extensively used tool for capturing teachers' PCK (e.g. Hume & Berry, 2013), however other methods such as the use of lesson plans which have been considered 'the lesson preparation method' (van Driel *et al*., 2014) have equally been employed. While it is essential to capture PCK, such methods only give insight into the qualitative nature of PCK at a descriptive level. Also, Rollnick and Mavhunga (2014) argue that, such tools are considered qualitative in nature and hence, they are most appropriate for capturing than measuring teachers' PCK in a specific topic. Meanwhile, in order to empirically establish the PSTs' TSPCK-learner outcomes link, this study requires a holistic qualitative and quantitative examination to be able to give a good description of the complex nature of TSPCK.

In an attempt to measure teachers' PCK, Kirschner, Borowski, Fischer, Gess-Newsome and Von-Aufschnaiter (2016) developed a test instrument to assess components of physics teachers' PCK. The authors found out that, the test results were only able to differentiate physics teachers from other groups being investigated; the results could not be explained by other variables like content knowledge and pedagogical knowledge. In order to measure teachers' levels of PCK, Park, Jang, Chen and Jung (2011) used a PCK rubric designed by Park, Chen and Jang (2008) and which is theoretically grounded in the pentagon model of PCK which defines PCK as one among the five integrated knowledge components (Park & Oliver, 2008). The rubric focused on the teachers' knowledge of student understanding and knowledge of instructional strategies and representations among the five knowledge components (Park *et al*., 2008). Riese and Reinhold (2009) developed a tool for measuring teachers' PCK in the subject of physics, Tepner and Witner (2011) equally developed a similar tool for the chemistry and Jüttner, Boone, Park and Neuhaus (2013) for biology. However, the models of PCK guiding the nature of the tools were developed at the discipline (subject) taxonomy level of PCK as classified by Veal and Makinster (1999). Such models and hence the tools are thus considered unsuitable on the epistemological ground for measuring teachers' PCK at a topic specific level.

Using the construct of TSPCK, Mavhunga (2012) developed a TSPCK research tool that captures PSTs' knowledge for teaching the topic of chemical equilibrium by considering five content-specific knowledge components. While each category in the tool requires qualitative explanations that demonstrate teacher understanding of a particular knowledge component, it also gives opportunity to gain insights into teachers' understanding of the interactive usage of other knowledge components. Alongside, Mavhunga developed a 4-criterion planned TSPCK rubric for categorizing the TSPCK captured by the TSPCK tool into different levels of quality. The categories help in describing qualitatively and then, they allow for measuring quantitatively the quality of TSPCK. According to the rubric criteria which emphasize varying extent of interactive usage of TSPCK components (Mavhunga & Rollnick, 2013), the quality of teacher's planned TSPCK as seen in the teacher's written responses could be categorized four different levels which are: Limited (1), Basic (2), Developing (3) and Exemplary (4). This means that, the Developing and Exemplary levels represent the higher levels of quality planned TSPCK. The good thing about Mavhunga's tool with her rubric is that, it is appropriate on the epistemological ground that, it captures qualitatively and then allows for quantitative measurement of the quality of PCK in a given topic as guided by the TSPCK construct. Based on this understanding, other TSPCK tools have been developed in the topic of organic chemistry (Davidowitz & Vokwana, 2014), particulate nature of matter (Pitjeng, 2014) and so on. Lately, Miheso (2018) in his PhD work developed and validated an enacted TSPCK rubric by observing experienced teachers' classroom in the topic of electrochemistry, organic chemistry and magnetic forces. The author reported that the quality of teacher's enacted TSPCK could be categorised as either simple, proficient or sophisticated based on the extent of interactive use of content-specific knowledge components identified as TSPCK episodes from the teacher's explanations during the teaching (Miheso, 2018). In an attempt to capture and measure the PSTs' planned TSPCK, this study adopted a validated TSPCK tool with its rubric designed by Davidowitz and Vokwana (2014) specifically for the topic of organic chemistry. The study also adopted the commonly employed CoRes (Loughran *et al*., 2012) for capturing the PSTs' thoughts about teaching organic chemistry. Likewise, the Miheso's (2018) enacted TSPCK rubric was adopted in this study to portray the quality of PSTs' enacted TSPCK in terms of simple, proficient and sophisticated TSPCK episodes, based on the extent of interactive use of TSPCK components. According to the rubric, the proficient and sophisticated TSPCK episodes represent higher categories of

quality enacted TSPCK. TSPCK construct enables defining categories of quality of TSPCK at a standardized level and thus, allows for the possibility of measuring teachers' TSPCK. Based on these reviewed studies, the quality of PSTs' TSPCK was has been captured and measured in the study as the understandings the PSTs demonstrated about the interactive use of content-specific knowledge components of TSPCK in pedagogically transforming the content knowledge of organic chemistry.

2.5 Understanding the teachers' cPCK-pPCK-ePCK trajectory

Shulman (1987) is of the theoretical proposition that the process which results in effective teaching of content commences before the actual classroom teaching itself, beginning with thorough pedagogical reasoning about the content. In his argument, PCK is embedded in the activities teachers engage in right "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). In other words, teachers' personal PCK manifesting as personal PCK (pPCK) could be visible as teaching knowledge in planning for teaching and then, demonstrated in the actual classroom teaching as enacted PCK (ePCK). Then, the Shulman's argument suggests understanding and exploring teachers' pPCK at the planning stage also referred to as 'planned PCK' (Aydeniz & Kirbulut, 2014) and then, ePCK in the actual classroom teaching (Alonzo *et al*., 2019). It is worth pointing out that, the possession of pPCK and at the topic specific level, pTSPCK does not automatically guarantee the enactment of such knowledge in the actual classroom teaching (Aydeniz & Kirbulut, 2014). Only when such specialized knowledge demonstrated in planning the content gets enacted in the actual teaching of the content could it be considered ePCK and hence, eTSPCK for a given topic. In this line of thought, Baxter and Lederman (1999) argue that, teacher's PCK goes beyond what he/she knows but it extends to "what a teacher does, and the reasons for the types of actions they take in relation to teaching a specific topic" (p. 158). This also supports the argument that, focusing on what teachers know is important in teacher education programmes but that knowledge on its own is not sufficient to ensure capability for developing PSTs' knowledge for teaching without simultaneously paying attention to what they eventually do in the classroom (Ball & Forzani, 2009; Mathewson & Reid, 2017). In other words, these two levels of PCK are

important in ensuring effective teaching and learning of content. This two category of teacher knowledge are tightly connected and difficult to separate in the sense that, while planned PCK is the kind of knowledge that teachers require for planning teaching, ePCK (ePCK) comprises knowledge teachers demonstrate in the actual teaching as they respond to the learners' learning needs (Aydeniz & Kirbulut, 2014; Park & Oliver, 2008). Even though pPCK cannot be fully separated from ePCK (Abell, 2008), the recognition of each level of PCK enables a deeper insights into understanding PCK development and implementation of the developed PCK in the actual classroom teaching. Both the selection of knowledge to teach and the actual teaching of the selected knowledge undergo complex pedagogical transformation processes occurring during the preparatory and actual delivery of lesson stages. As a result, the knowledge is differentiated from its sources in academic knowledge since what is ultimately seen in the actual classroom teaching is connected to the processes of pedagogical transformation which occur at the stage of planning.

More so, teachers' PCK is generally known among scholars as unique domain of knowledge which expands continuously as teachers engage in planning, carrying out and reflecting on teaching and learning (Nilsson & Loughran, 2012). In this line of discussions, special interest was developed in the studies which focused on developing PSTs' PCK in PST education programmes in attempts to improve the quality of science teaching and learning. One common concern raised among science PCK researchers while deliberating on the teacher professional knowledge was whether learned PCK (planned PCK) is transferable to actual classroom teaching (Gess-Newsome, 2015; Park & Oliver, 2008) following the teachers' exposure to collective PCK (cPCK) and in association, cTSPCK. There is the understanding that, critical insights represent the reasons which account for teachers' decisions and choices when it comes to evaluating the successfulness of teachers' teaching (Jang, 2011). It is then essential to understand the development of pedagogical reasoning in PSTs by engaging them in explicit discussions that targeting what constitutes cPCK. Such discussions could be used to rationalize instructional actions which they would be challenged to take when they are confronted with the complexity of actual classroom teaching and learning process. In this line of thought, some studies have reported a positive connection between pedagogical reasoning developed in teachers and their decision making in the actual teaching. An example is the study focusing on science teachers' development of technology, pedagogy and content knowledge which reported that the teachers'

pedagogical reasoning mirrored their pedagogical actions (Guzey & Roehrig, 2009). The observed teachers' reasons for their instructional decisions during teaching were strictly connected to what they conceived of science, effective teaching of science and instructional techniques and learning among learners. Likewise, in an attempt to determine the transfer of learned TSPCK to classroom practice, Rollnick and Mavhunga (2014) followed the teaching of two PSTs who were part of those exposed to the TSPCK construct during an intervention. The authors reported that, there was an improvement in the PSTs' planned TSPCK to a developing level in the topic of the intervention and a similar level of quality of TSPCK was observed in through the actual classroom teaching of the same PSTs (Rollnick & Mavhunga, 2014). The reviewed studies (Guzey & Roehrig, 2009; Rollnick & Mavhunga, 2014) could be seen to be consistent in terms of improvement in the reported planned TSPCK and the TSPCK demonstrated in the actual teaching (enacted TSPCK). Lately, Alonzo et al. (2019) observed a relationship between a group of teachers' pPCK and ePCK while exploring the complexity of science teachers' PCK in action. Likewise, Mazibe, Coetzee and Gaigher (2018) studied physics teachers' PCK (referred to as reported PCK) displayed in developing CoRe tool and during interviews versus the PCK demonstrated by the same teachers in the actual classroom teaching of graphs of motion. However, the authors found out that, as it was observed, the reported PCK was not necessarily a reflection of enacted PCK as the reported PCK was noticed to be similar or lower than the teachers' enacted PCK (Mazibe *et al*., 2018). It could be observed that most of these previous foundational studies have investigated PCK in either a single realm (e.g. Park & Chen, 2012 in a classroom context) or at most across two of the PCK realms e.g. Mavhunga and Rollnick (2013) focusing on cPCK-pPCK), also Alonzo et al. (2019) focusing on pPCK-ePCK. However, the newly developed RCM of PCK calls for exploring cPCK-pPCK-ePCK and also linking this to learner outcomes in order to provide a rich understanding about the teachers' nature of PCK and its influence on learning (Carlson & Daehler, 2019). Such limited understanding creates a gap in the PCK literature and this further contributes to the persistent issue of theory-practice gap which has been a challenging task in educational research (Barradell & Kennedy-Jones, 2015; Tang & Choi, 2005). At the center of this matter is the acknowledgement of dissonance coming in-between knowledge acquired while learning to teach content and knowledge enacted in the actual classroom teaching of content. Such disagreement describes the disconnection between the two kinds of knowledge referred to as 'episteme' and

'phronesis' conceptualized by Aristotle (Eisner, 2002; Kinsella & Pitman, 2012). In an attempt to contribute towards addressing the gap, this study focused on the development of PSTs' TSPCK through cPCK-ePCK-pPCK trajectory an in effort to provide understanding about TSPCK-learner outcomes link.

2.6 PCK and learner outcomes

Over the years, researchers have directed attention more on teachers' knowledge rather than teachers' behaviours and how the knowledge influences pedagogical decisions (Abell, 2008; Chan & Yung, 2018; Abell, 2008). Ever since it was conceptualized by Shulman, PCK has attracted much interest as a significant domain of knowledge that teachers must possesss for effective teaching as alluded to in the sections above. There are good theoretical reasons to assume that, teachers' PCK will positively influence learner outcomes. First, teaching goes beyond someone knowing the subject matter and being able to transfer the knowledge to other people. I have personally attended a lecture, as a student, in which a brilliant scholar was unable to translate his expertise in a comprehensible manner to novices like myself. In connection with such an experience, Shulman (1986) raised a concern with regards to the association between knowledge of content and knowledge for making content accessible during teaching by asking how teachers draw upon expertise in subject matter in the actual classroom teaching process. His introduction of PCK addressed the question as it talks to the "particular form of content knowledge that embodies the aspects of content most germane to its teachability" (p. 9). In other words, PCK is what allows excellent teachers to make disciplinary ideas comprehensible to non-experts and it distinguishes a teacher from disciplinary experts, as well as from colleagues who teach other subjects (Cooper *et al*., 2015). Second, after PCK was defined by Shulman (1986), there have been various conceptualizations of this theoretical construct by numerous researchers as reviewed in the section 2.2 above. Most importantly, at the heart of all concepualizations are two essential elements: knowledge of student learning difficulties and knowledge of instructional representations (Gess-Newsome, 2015; van Driel *et al*., 1998) which practically focus ensuring learners learn the content being presented to them. These elements are thought to trigger teachers' instructional decision-making from planning how best to present content to learners to interacting with them in the midst of classroom instruction (Aydin *et al*., 2014; Chan & Yung, 2015). Moreso, while only content knowledge might be adequate in a transmission model of

teaching, the currently accepted theories of teaching and learning require complex interactions between content, teacher, and learners that rely heavily upon teachers' PCK (Alonzo, Berry & Nilsson, 2019; Daehler, Heller & Wong, 2015). A number of scholars have articulated valued instructional practices that are thought to be impacted by teachers' PCK (e.g. Lancaster & Bain, 2019; Gess-Newsome *et al*., 2019). For example, Osborne et al. (2003) related attitudes towards science to the quality of teaching learners experienced in school and identified "helping students to contextualize content in terms of their own experience and knowledge, as well as in terms of other teaching goals and learning experiences" (p. 1067) as one hallmark of effective teaching. This ability to connect science content to learners' own experiences in ways that make the content meaningful is a key component of PCK. Hence, there is the rationale for the theoretical assumption that teachers' with sound PCK would be able to effectively support learners in achieving outcomes. The outcomes in various contexts have been described using different terminologies which include students' motivation and attitudes (Osborne, Simon & Collins, 2003); students' perceptions (Jang, Guan & Hsieh, 2009); student learning (Roth *et al*., 2011); student interest (Swarat, Ortony & Revelle, 2012); student progress (Baumert et al., 2010) and most commonly, student achievement (Liepertz & Borowski, 2019; Gustafsson & Nilsen, 2016; Hill *et al*., 2005). The learner outcomes have been measured in this study has both the learner achievement in organic chemstry and learners' views about the PSTs' teaching in the same topic.

The link between teachers' PCK and learner outcomes

In spite of the various researchers' activities on developing tools and identifying vital aspects of teacher knowledge, it has been incredibly difficult to directly link teacher knowledge to learner outcomes in sciences (Cross & Lepareur, 2015) and mathematics (Callingham, Carmichael, & Watson, 2016). The difficulty is associated with myriad of factors such as teachers' experience, learners' interest and readiness to learn, teacher beliefs, teacher education background, teachers' content knowledge, pedagogical content knowledge and pedagogical knowledge all of which influence the complexity of classroom and learning (Blömeke *et al*., 2016; Gustafsson & Nilsen, 2016). In the theoretical models of instructional quality, teachers' professional knowledge has been described as a factor which influences quality of instructions and hence, learner outcomes (Helmke, 2014; Kunter, Klusmann, Baumert, Richter, Voss & Hachfeld, 2013) . Particularly, teachers' PCK which is considered the "special amalgam of content and pedagogy that is

uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8) has been known for enhancing teachers' capability to enact instructions of high quality in the classroom. PCK is acceptably viewed as the central component of teacher development of knowledge for effective teaching (Park & Oliver, 2008) and accordingly, Richardson, Byrne and Liang (2018) argued that, highly developed PCK would produce superior instructional experiences for learners. Studies in science education (e.g. Keller, Neumann, & Fischer, 2017) and mathematics education (e.g. Baumert, Kunter, Blum, Brunner, Voss, Jordan, Klusmann, Krauss, Neubrand & Tsai, 2010; Hill, Rowan, & Ball, 2005) have been conducted to show that PCK demonstrated by teachers is one influential factor which contributes to learning and learner outcomes.

Studies on PCK-learner outcomes link in mathematics education

Hill et al. (2005) investigated the effects of teachers' mathematical knowledge for teaching on student achievement in American elementary schools. Using a linear mixed-model methodology, it was found out that teachers' mathematical knowledge was significantly related to student achievement gains in both first and third grades after controlling for key student- and teacher-level covariates (Hill *et al*., 2005). Similar to that, Baumert *et al*. (2010) investigated the significance of teachers' content knowledge and PCK for high-quality instruction and student progress in secondary-level mathematics in German classrooms. The study reported that Multilevel structural equation models revealed a substantial positive effect of teachers' PCK on students' learning gains which was mediated by the provision of cognitive activation and individual learning support (Baumert *et al*., 2010). In another study, Luna and Aclan (2015) explored the influence of Philippines mathematics teachers' PCK training on learners' achievement in mathematics. The authors used a teacher made test administered as a pre-and post-test prior to and following the training respectively to assess the participant teachers' PCK. It was found out in the study that, the experimental group of teachers had significantly higher PCK than their counterparts without training (Luna & Aclan, 2015). It was also reported in the study that, the learners taught by the teachers who underwent training had significantly higher score than the learners under the teachers without training (Luna & Aclan, 2015). Likewise, Callingham et al. (2016) investigated the influence of teachers' PCK on middle-years learners' learning outcomes. The participant learners in the study wrote a pre-test, post-test and

longitudinal retention test over a period of 2 years. The participant teachers were asked to complete a survey which measures PCK for teaching statistics, an aspect in the curriculum for mathematics. The authors found out that, the participant learners experienced conceptual improvement in the tests and the participant teachers' PCK in statistics was associated with their learners' learning outcomes (Callingham *et al*., 2016).

Studies on PCK-learner outcomes link in science education

In science education, Roth, Garnier, Chen, Lemmens, Schwille and Wickler (2011) conducted a video based lesson analysis focusing on effective science professional development for teacher and student learning located in American elementary schools. The authors followed the participant teachers into the classroom after the professional development programme to observe their teachings with the purpose of identifying how teaching strategies linked PCK to students' learning outcomes (Roth *et al*., 2011) . It was found out that, the Multi-level HLM analyses used linked higher average gains in student learning to teachers' PCK about student thinking, and teaching practices aimed at improving the coherence of the science content storyline (Roth *et al*., 2011). Also, Park et al. (2011) conducted a study which tested a hypothesis focusing on whether or not teachers' PCK is a necessary body of knowledge for reformed science teaching in American high school classrooms. The study utilized a quantitative research method to investigate the correlation between a biology teacher's PCK level measured by Park, Chen and Jang's (2008) scoring rubric and the degree to which the teacher's classroom is reform-oriented focusing on photosynthesis and hereditary (Park *et al*., 2011). The rubric used by the authors only focussed on the teachers' knowledge of students' understanding and knowledge of instructional strategies and representations (Park *et al*., 2011) whereas in order to capture the complexity of PCK as a construct, any measure of PCK should consider all the components (Aydin *et al*., 2014). Nonetheless, it was found out in the study that the level of a teacher's PCK was highly connected with the degree to which the teacher's instruction was reform oriented (Park *et al*., 2011) .

Likewise, Lange, Kleickmann and Moller (2011) explored elementary teachers' PCK and student achievement in German science classrooms by focusing on the states of matter and changes of state. In the study, both the teachers' PCK and student achievement were directly assessed with

the tests in the topic and multilevel regression analyses were performed to analyse the significance of teachers' PCK for students' progress in elementary science classrooms (Lange *et al*., 2011). It was reported in the study that teachers' PCK was significantly related to student achievement in elementary science after controlling for key student- and teacher-level covariates (Lange *et al*., 2011). The study conducted by Alonzo et al. (2012) investigated how PCK links to students' learning by focusing on the interactions between two German physics teachers' classroom teachings and their students in the topic of optics. By qualitatively linking what the participant teachers said to what students said during instruction, the authors found out that teachers' PCK positively enhanced students' achievement and motivation (Alonzo *et al*., 2012). The positive influence reported by the authors is in line with the understanding in the literature that "teacher-student interactions are fundamental to learning outcomes" (Tan, Whipp, Gagné, & Van-Quaquebeke, 2019, p. 169) . While one-way, monologic feedback assumes learners are passive and fails to address possible learners' misconceptions relating to the lesson, teacher-student interactions embedded in two-way dialogic feedback positively influences learners' higher order learning outcomes (Ajjawi & Boud, 2017; Boud & Molloy, 2013). Also, Sadler, Sonnert, Coyle, Cook-Smith and Miller (2013) investigated the influence of teachers' knowledge of student learning in middle school physical science American classrooms. In the study, the assessment instruments based on the National Science Education Standards with 20 items in common were administered several times during the school year to both students and their teachers (Sadler *et al*., 2013). It was reported in the study that there were moderate levels of gain observed in the students' knowledge of the concepts over the course of one or two semesters of middle school physical science although mastery was elusive for most students (Sadler *et al*., 2013). It was also discovered that, the teachers' subject matter knowledge and knowledge of students' misconceptions (an aspect of PCK) positively predicted students' achievement gains (Sadler *et al*., 2013) .

Furthermore, Förtsch, Werner, Von-Kotzebue and Neuhaus (2016) explored the effects of biology teachers' professional knowledge (CK and PCK) and cognitive activation on students' achievement. In the study, the participant teachers' CK and PCK on neurobiology were measured using valid paper-and-pencil tests and their teachings were videotaped (Förtsch *et al*., 2016). It was found out that teachers' PCK had a positive significant effect on cognitive activation, which, in turn had a significant effect on students' achievement (Förtsch *et al*., 2016).

However, it was reported that teachers' CK did not significantly influence cognitive activation, meaning that for cognitively activating teaching, mainly PCK was needed (Förtsch *et al*., 2016). Based on these results, the authors confirmed their hypothesis that a higher PCK of teachers, therefore, may lead to more cognitively activating instruction, which in turn may lead to higher students' achievement (Förtsch *et al*., 2016). Keller et al. (2017) examined the impact of physics teachers' PCK and motivation on the achievement and interest of a group of students in Germany and Switzerland. Using a multi-level structural equation modelling, they found that the observed teachers' PCK positively predicted students' achievement, the effect which was mediated by cognitive activation (Keller *et al*., 2017). Mahler, Großschedl and Harms (2017) examined the relationships between science teachers' professional knowledge and students' performance by focusing on system thinking in the context of biology teaching in German secondary schools. The three domains of teachers' professional knowledge focused on in the study included CK, PCK and curricular knowledge (Mahler *et al*., 2017). By using doubly latent multilevel analysis, the authors found a significant positive relationship between biology teachers' PCK and students' performance however, the results reveal no relationship between teachers' CK and curricular knowledge and students' performance (Mahler *et al*., 2017).

However, some studies have equally reported lack of relationship between teachers' PCK and learner outcomes. For example, Cross and Lepareur (2015) examined teacher-student interactions in relation to students' difficulties in an attempt to determine the relationship between a physics teacher's PCK and students' achievement focusing on the electric circuits in a French classroom. It was reported in this study that, having PCK does not mean a teacher would give effective feedback to the students and consequently, there was no linear relationship observed between the teacher's PCK and student outcomes (Cross & Lepareur, 2015). Based on this finding, the authors argued that "studies trying to relate the amount of PCK a teacher holds to students' outcomes may well never succeed in showing that, the more a teacher has PCK the better the students' outcomes" (Cross & Lepareur, 2015, p. 58). In another study, Liepertz and Borowski (2019) investigated the relationships among physics teachers' professional knowledge (CK, PCK and pedagogical knowledge, PK), interconnectedness of content structure and student achievement. In the study, both the participant teachers and their students took paper-and-pencil tests and the lessons taught by the teachers were videotaped and analysed (Liepertz & Borowski, 2019). As reported in the study, the general learning gains of the classes measured by the tests

were rather low, there were no significant differences between the mean Rasch-scaled ability estimates in pre-test and post-test in 18 of 35 classes (Liepertz & Borowski, 2019) and this was found to be consistent with result of the study that investigated the quality of instruction in physics by comparing Finland, Germany and Switzerland Fischer (Labudde, Neumann, & Viiri, 2014). It was reported that interconnectedness of content structure could be verified as an indicator of instructional quality however, teachers' PCK showed a negative estimate and would therefore hinder the student outcomes (Liepertz & Borowski, 2019). Also, Gess-Newsome et al. (2019) conducted an intervention based studies with 50 experienced biology teachers in the same state in the united states of America using a mixed-methods data collection analysis. The authors reported that the participant learners' achievement scores increased significantly from the pre-test to post-test (Gess-Newsome *et al*., 2019). However, the authors found out that, only the teachers' academic content knowledge substantially influenced student learning, the findings did not support their assumption that teachers with strong PCK are more likely to positively affect student learning than those with weak PCK (Gess-Newsome *et al*., 2019).

2.7 The identified gap in the literature about PCK-learner outcomes link

The above reviewed literature on the PCK-learners outcomes link particularly in science education reported mixed findings, leaving the issue highly unresolved. While some studies (e.g. Alonzo *et al*., 2012; Lange *et al*., 2011) reported positive correlation between the teachers' PCK and learner outcomes, some other studies (e.g. Gess-Newsome *et al*., 2019; Liepertz & Borowski, 2019) observed lack of correlation between teachers' PCK and learner outcomes. These inconsistent findings have naturally sent a mixed signal to the PCK community. Several reasons could be assigned to the contradiction in the literature. It may be as a result of different operational definition of PCK and methodological strategies employed in examining the correlation. First, with respect to the operational definition of PCK, while Liepertz and Borowski's (2019) conceptualization of PCK revolves around 'special amalgam of content and pedagogy' (Shulman, 1987, p. 8) for teaching physics, Gess-Newsome et al. (2019) assumed that within PCK, there exists content knowledge, pedagogical knowledge and contextual knowledge for teaching photosynthesis and cell transport mechanisms in Biology. In hindsight, with the RCM in place, we now know that these studies used a different grain size of PCK, a discipline conceptualization while working with topics. In this study, PCK was conceptualized and

operationalized as being topic specific (Gess-Newsome, 2015), thus referring to the grainsize of topic specific PCK and accordingly using only content specific components rather than reference to components that are generic and subject specific. Furthermore, the evidence of PCK has been consistently being associated with visible interactive use of these content-specific knowledge components to pedagogically transform the content knowledge in all the context (planning and in classroom enactment) (Mavhunga, 2018). Second, with respect to the method of measurement, Liepertz and Borowski's (2019) used paper-and-pencil tests to measure both the professional knowledge (i.e. CK, PCK and PK) of teachers and the learners' achievement**.** In terms of the RCM, we now know that the PCK measured could have been in the realm of planning to teach. In the case of Gess-Newsome et al. (2019), PCK was measured through written reflections, interviews and observations of classroom practice using a PCK rubric and learner achievement test drawn from a large bank of question items. In this study, in an effort of minimizing the effect of all other factors, careful filtering of only the PSTs' TSPCK episodes that had a link with test items was followed using the in-depth qualitative method of identifying (Park & Chen, 2012).

Nevertheless, the link between teachers' PCK and learner outcomes has been reported in the literature with mixed findings, leaving the issue highly unresolved as hinted in the rationale for conducting this study. Therefore this study attempted to address these gaps through the cPCK-pPCK-ePCK trajectory followed in exploring the TSPCK-learner outcomes link in a group of PSTs who were learning to teach organic chemistry.

CHAPTER THREE

3. RESEARCH METHODOLOGY

This chapter consists of a detailed record of the methodological tactics engaged in carrying out this study. In doing this, both the identified research problem and research questions were first recalled and taking into consideration. Based on that, decisions on the research design, sample size and research methods were taken. Likewise, there are discussions on the research tools, methods of analysing the data collected, validity and trustworthiness of the measures obtained. This chapter ends by describing the ethical issues observed and summary of the entire research processes.

3.1 Introduction

This study explored the TSPCK-learner outcomes link by following the development of TSPCK in PSTs through the cPCK-pPCK-ePCK trajectory while learning to teach the topic of organic chemistry. In relation to the research questions guiding this study, the current chapter presents discussions on the research design, the methods of collecting data, participants involved, methods of analyzing data and it closes the ethical issues. The design of this study was based on the perspective of pragmatic research (Frels & Onwuegbuzie, 2013) and it was carried out in two major stages towards answering the three research questions guiding this study (see Figure 3.1).

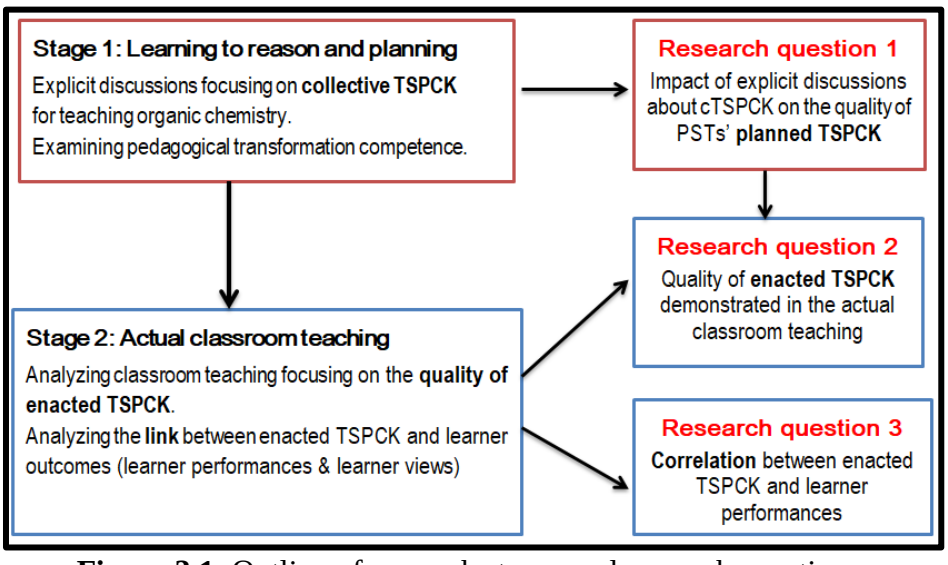


Figure 3.1: Outline of research stages and research questions

As shown in the Figure 3.1 above, this research represents a two-phase study consisting of an intervention (learning to reason and planning stage) conducted in a pre-service teachers education programme at a South African University and then implemented in a South African high school (actual classroom stage). The planning for research began in January 2017 by discussing the purpose of the research with the coordinator and lecturer for the Bachelor of Education (Physical sciences) methodology courses. The discussion was based on the possibility of running a 6-weeks intervention that explicitly explains the TSPCK construct to the 3rd year physical sciences methodology students referred to as the pre-service teachers (PSTs). The intervention program was drafted with the assistance of the coordinator being a TSPCK researcher and it was finalized in consultation with the course lecturer who happened to be the content lecturer. The consultation assisted in validating the quality of cognitive demands for the PSTs in accordance with the requirements for the methodology course. The course has as one of its objective to develop PCK in a selection of core topics. Afterwards, there were discussions with the registered PSTs on the ethical issues regarding the research and intervention activities. I conducted the intervention starting from the first week of March 2017 until the first week of April 2017 for six weeks with the participant PSTs. Following the intervention, the lessons delivered by a subset of 4 participant PSTs on organic chemistry were observed in the actual classroom context. The classroom teaching in the high school was preceded by an appropriate ethical arrangement with the school authorities. In August 2017, the entire data collected for the research was coded and duplicated to enable safe storage and ease of scoring by multiple raters to enhance credibility. This was followed by the process of analysing the data and writing thesis chapters. The sections in the chapter discuss in details these research processes starting with the research design in the next section below.

3.2 Research design - Mixed Methods Paradigm

Mixed-methods research is employed in this study as the research design. The philosophical orientation associated with this design is within the pragmatist paradigm. From the pragmatists' perspectives, integrating research methods in a study assists in providing a holistcal view about the problem under investigation and providing sufficient answers to answering the research questions guiding the study (Creswell & Clark, 2017). Mixed method research involves gathering qualitative and quantitative data, employing both the qualitative and quantitative

methods of analysis, integrating the two methods and drawing conclusions from them by considering their strengths towards understanding the outlined research problems (Creswell & Clark, 2017). While the qualitative research (narrative descriptions) draws from the positivistic belief that people construct knowledge as they interact and make meaning of an activity, the quantitative research (statistical descriptions) inclines to naturalistic belief that knowledge is already existing and only needs to be discovered (Merriam & Tisdell, 2016). Specifically, a concurrent embedded mixed method (Creswell & Clark, 2017) has been chosen as the type of mixed method design employed in this study. As Terrell (2012) argues, the concurrent embedded mixed method seeks to establish any convergence, variances or combinations of the research results. This type of design involves collecting both qualitative and quantitative data simultaneously and analysing them separately to produce a richer understanding of issues being investigated. In this line of thought, Teddlie and Tashakkori (2009) refer to the '*mixing*' (also called the '*integration*') as the primary criterion for determining the status of a mixed method design. According to Creswell (2013), mixing involves merging qualitative and quantitative data either on one end of the continuum, keeping them separate on the other end of the continuum or combining them in some way between the two extremes. The choice of a mixed method design in this study was based on the understanding that exploring an issue holistically from diverse viewpoints requires different research techniques (Okeke & Wyk, 2015). Sharing the same view, Frels and Onwuegbuzie (2013) point out that the ultimate goal of integrating two research methods is such that there may be a comprehensive understanding of the complex issue under investigation than using a single method. This was particularly important in unravelling the complexity of PSTs' PCK in a specific topic as it manifests while learning to teaching, during actual teaching and its influence on learner achievement. It was important to adequately extract all aspects of the TSPCK construct which may not be easily accessed singly by either qualitative or quantitative method. This understanding was informed by the argument that "PCK is a complex, multidimensional construct specific to a topic/idea" (Smith & Banilower, 2015, p. 99) and hence, TSPCK in this study. For instance, to adequately describe PSTs' constructive reasoning ability as they formulated responses to the written teacher tasks, narrative qualitative techniques were considered appropriate in capturing and analysing data. The techniques were also suitable in the in-depth descriptions of the nature of the PSTs' enacted TSPCK in the actual classroom contexts. Supporting that, the quantitative techniques were

most appropriate in establishing possible shifts in the extent of the PSTs' understanding of interactive use of content-specific knowledge components prior to and following the intervention. Thus, mixing both the qualitative and quantitative methods in this study stands as the key feature that mixed method research design exhibits. Furthermore, O'Cathain (2010) added that integrating findings from the two methods alters differences between the two methods and thus influences the credibility of the quality criteria tailored for each method. In support, Greene, Benjamin and Goodyear (2001) as well as Caruth (2013) posited that mixed method is of great benefit by enhancing the validity, producing credible findings and providing insightful understanding of the issues being investigated. Mixed methods approach has thus been employed in this study towards enhancing the possibility of generating reliable, valid and high level of confidence in the findings that would emerge from this study. With all the advantages of mixed-methods research design outlined, its limitations were acknowledged in this study. Creswell and Clark (2017) called special attention to integrating findings from both qualitative and quantitative methods with the argument that such could be so challenging and hence requires cautious process of transforming data. Likewise, Terrell (2012) pointed out that the possibility of having discrepancies and hence unequal evidence in the course of comparing the two categories of data obtained as a result of unequal priority assigned to the two methods involved. As these limitations have the possibility of influencing the findings from this data negatively, equal priority was assigned to the methods involved and they were carefully considered throughout the stages of data transformation in this study.

3.2.1 Research strategy – Case study

This mixed-methods research was a case study of TSPCK and its influence on learner outcomes, measured as both the learner achievement and learners' views about teaching. The case study was chosen as a research strategy because of the benefits it naturally offers. One of its key benefits is that it promotes quantitative and/or qualitative methods in the in-depth exploration of a complex issue (McMillan & Schumacher, 2014). It is understood that, learning about TSPCK construct is complex in the sense that, it entails understanding the individual content-specific knowledge components and then, their interactive usage in transforming the content knowledge of a given topic. This is coupled with the complexity of actual classroom teaching and learning and how various factors come to play when investigating the link between teacher knowledge

and learner outcomes. In the description of a case study as an in-depth exploration of a bounded system (Creswell, 2012), McMillan and Schumacher (2014) referred to the bounded system' as the uniqueness of a case being studied in terms of the place, time and other influential physical boundaries which must be clearly identified and defined by a case study researcher. In this study, the case of TSPCK-learner outcomes link was studied by focusing on a group of PSTs a group of PSTs who specialized on the same subject (physical sciences), studying for the same course duration (4-years of Bachelor of Education degree), at the same time and in the same university. These features represent the physical boundaries that were fixed throughout the period of conducting this research. The conditions also happened to be official such that they guide students in the universities and they are in accordance with the South African Qualification framework policy. The participant PSTs were also observed to have been posted to high schools in South African on three different occasions for practicum and thus, they were assumed to be familiar with teaching conditions as well the associated challenges to some extents; being undergraduate students in their third year of studies, they should have learnt about 60 percent of the physical science core topics. Since the PSTs were being taught the topic of organic chemistry in the content class concurrently with the intervention, they were assumed to have acquired basic content knowledge particularly for the topic; and also, being students of education, they should have learnt general pedagogical ways of teaching from other methodology courses. However, a case study is not without its limitations. Creswell (2012) argued there are criticisms regarding how credible the findings from a case study are. Among the criticisms is the soft data that a case study produces due to its lack of rigour since it focuses on qualitative and interpretative measures rather than quantitative; processes rather than measurable data (Denscombe, 2008). In this study, both the qualitative and quantitative procedures were richly dwelt on in collecting and analysing data and thus, the use of mixed-method research design. Another associated shortcoming revolves around the historical disapproving attitude towards a case study based on the generalizability criticism (Punch, 2009). To minimize this limitation, the entire class of physical science PSTs was used as a research sample as much as it was possible and this also was guided by the specific sub-research questions explored in this study. In addition, thick descriptions of all events were provided prior, during and after the intervention.

3.3 Stages of implementation of research design

This study was conducted in two stages. The first stage comprises the examination of PSTs' personal TSPCK (pTSPCK) visible as planned TSPCK in the context of learning to reason and planning to teach organic chemistry. The second stage consists of the examination of PSTs' personal TSPCK visible as enacted TSPCK (eTSPCK) demonstrated in the actual classroom teaching of organic chemistry in relation to learner achievement. Each of these stages is fully discussed in the sub-sections below together with the respective sample size and data collection strategies.

3.3.1 Learning to reason and planning to teach stage

As alluded to in the literature review chapter, PSTs are generally known to have little or no PCK because of the insufficient teaching experiences in the real classroom context. As a result, this research first focussed on developing the PSTs' competence for pedagogical transformation of content knowledge in the topic of organic chemistry. The competence entails understanding the individual content-specific knowledge components and then, their interactive use in pedagogically transforming the content knowledge of a given topic in order to make the content accessible to learners (Mavhunga, 2016). Such competence is used to generate TSPCK specifically for a given topic. The extent to which the understanding of pedagogical transformation competence is demonstrated by an individual person (PST) is captured in this study as the quality of the person's TSPCK (Park & Chen, 2012) as alluded to in Chapter 2. This research was conducted in a South African university during the 2017 academic session and it was specifically situated in a physical science methodology course. The course has been initially designed by the University for the Award of the Bachelor of education degree in physical sciences. The course has the purpose of developing a specific depth and specialization of knowledge in PSTs, equipping them with practical skills for teaching core topics (Mavhunga & Rollnick, 2017). The course was observed to have the same purpose as this study, developing the PSTs' TSPCK planning and actual teaching of a specific physical science topic. There were 17 PSTs who took the course and participated in this study. The methodology course for the semester normally runs in parallel with the content course in organic chemistry. So, all the physical science education students who registered for the methodology course also took the

content course concurrently. Both the methodology and content courses focus on the physical science topic of organic chemistry. While the content course is meant to provide the PSTs with the adequate content knowledge, the methodology course exposes them to the pedagogical strategies for transforming the content knowledge. The explicit discussions on the knowledge needed to transform the content knowledge of organic chemistry have been referred to as the Intervention in this study. The intervention is discussed as follows.

The intervention

In the institution where this study was carried out, the intervention course has been published as a signature methodology course alongside other institutions methodology course across several countries (Mavhunga & Rollnick, 2017). Further attesting its credibility, separate independent courses that explored TSPCK in different science topics recorded positive impact on both the participant PSTs (e.g. Mavhunga, 2016; Mavhunga & Rollnick, 2013) and in-service teachers (Pitjeng-Mosabala & Rollnick, 2018). In this study, the intervention majorly centred on understanding the content-specific components of TSPCK and their interactive use in transforming the content knowledge of organic chemistry. There was also reference made to how TSPCK construct differs from the broader PCK construct by considering five content-specific knowledge components for transforming content knowledge of a specific topic. While the broader PCK operates majorly at a discipline level, TSPCK is at a topic specific level. As indicated in the rationale, organic chemistry was chosen as the topic of the intervention due to its importance as one of the core topics in physical sciences. The topic has also been reported to be problematic for learners to understand due to its abstract nature and the fact that it requires extensive use of representations and analogies for deeper conceptual understanding. So in this study, TSPCK construct has been adopted as it promotes logistics for identifying misconceptions, addressing the misconceptions by considering important concepts, learning difficulties and conceptual use of different levels of representations. To ensure adequate understanding of knowledge components, the intervention was planned for sequential discussions over a period of six weeks systematized into overall 12 sessions of 50 minutes each. The first five weeks were used to discuss the five content-specific knowledge components of TSPCK one after the other. Each week was designed to have three sessions organized into one period of lecture at the beginning of the week and a double period of lectures at the end of the

week. Every single period of lecture was used to introduce a specific knowledge component. Every double period of lecture was used to develop the understanding of how a specific knowledge component could be applied in transforming content knowledge of the topic of organic chemistry. Every first single period of lecture, which was planned to introduce a content-specific knowledge component, consisted of teacher-learner centred discussions with supporting resources from the literature. During these discussions, the participants were divided into smaller groups to deliberate on the knowledge component in question for that week. Such group deliberations lasted for about 15minutes after which the entire class was called to share ideas and the course lecturer was to consolidate the whole deliberations. These instances of consolidation emphasized how discussions on a knowledge component has incorporated spontaneous emergence of other knowledge components and consequently influenced the quality of explanations based on concepts in the topic. While at a time, the focus was on a knowledge component, it was ensured that the quality of explanations given to the PSTs encouraged spontaneous occurrence of other content-specific knowledge components. Efforts were made during the discussions to recognize the occurrence of other content-specific knowledge components irrespective of whether they have once been fully discussed in the previous session or they would be discussed in the next session. The aspects of content knowledge of organic chemistry that were focussed on during the discussions include: carbon unique nature; IUPAC naming of organic compounds and functional groups; physical properties of organic compounds and structures; isomerism; and reactions of organic compounds. The Table 3.1 below shows the week, lecture sessions, knowledge component discussed, activities and aspects of content knowledge focussed on during the intervention conducted with the PSTs in this study.

Table 3.1: The description of TSPCK intervention activities

Week	Session	TSPCK component targeted	Intervention activities	Aspects of content knowledge focussed
1	1	Administration of pre-TSPCK and CK tests	Formal introduction of research, discussions of TSPCK construct and ethics issues	Administration of pre-TSPCK and CK tests
	2	Learner Prior Knowledge	Discussions were based on the widely researched common learners' misconceptions in organic chemistry as in the literature. The participant pre-service teachers were allowed to share their experiences and views on the identified misconceptions. There were group discussions on the misconceptions followed by presentations of suggesting teaching strategies to address the identified misconceptions. Where a strategy naturally draws on other TSPCK component, such moments were explicitly highlighted to the pre-service teachers.	Common misconceptions associated with the IUPAC naming of organic (e.g. identifying the longest continuous carbon chain in aliphatic hydrocarbons), effects of type of bond on the reactivity of homologous series
2	3 and 4	Curricular saliency	Discussions were geared towards understanding that every topic, for instance, organic chemistry has 'big ideas' these are based on the main core concepts and 'subordinate concepts' that are important for the topic to be well understood. Also, there was emphasis on sequencing of these ideas, awareness of the foregrounding concepts and understanding what is most important in each big idea. It was emphasized that the knowledge of a topic in terms of its big ideas, subordinate ideas, prior concepts and sequencing is what is referred to as the 'curricular saliency'. Group completion of CoRe prompts on learner prior knowledge and curricular saliency	**Key concepts:** - carbon unique nature - functional groups - reactions of organic compounds (e.g. substitution, addition and elimination) Subordinate concepts e.g. - Isomers and homologous series - Alkanes and its members **Prior knowledge needed** - chemical bonding: covalent bonding. -chemistry of carbon as an element. - intermolecular forces
3	5 and 6	What is difficult to teach	Exploration of concepts considered difficult to learn, and identifying actual issues which make understanding difficult. This was more than settling on the abstractness of concepts but pin-pointing the actual difficulty. The pre-service teachers were made to understand that this is different from misconceptions but it refers to potential learners' difficulties in	- Molecular and structural formulae - organic compounds with similar functional groups -IUPAC naming of organic compounds - isomerism

			accurately understanding the full meaning of a big or subordinate idea, for example, functional groups of aldehyde and ketone due to their similarity. Group completion of CoRe prompts on what is difficult to teach or understand.	
4	7 and 8	Representations	Introduction of different levels of representations including the macroscopic, sub-microscopic and symbolic representations. There was emphasis placed on the concurrent use of these forms of representations in explaining each concept involved in organic chemistry. Group completion of CoRe prompts on representations.	Representing organic compounds (e.g. isomerism) at molecular, structural and microscopic levels.
5	9 and10	Conceptual teaching strategies	Discussions emphasized generated knowledge from other four knowledge components including identifying misconceptions, pointing out related key concepts that must be understood, identifying learning difficulties and using different three levels of representation in explaining in addressing the misconceptions. This strategy is conceptual rather than general pedagogy and logistics. Group completion of CoRe prompts on conceptual teaching strategies.	Administration of post-TSPCK and CK tests
6	11	Pulling it all together	Pulling all the weekly intervention tasks that summed up into a coherent CoRe. CoRe discussed explicitly as a tool to organize one's thoughts when reasoning through a topic	The CoRe template using the above listed big ideas on the TSPCK component of curricular saliency.
	12	Administration of post-TSPCK and CK tests	Formal closure and sharing of the next steps of action by the researcher in the research study – This included logistics and seeking consent for participation in the next stage of the study in the upcoming teaching experience (practicum).	

In this study, the TSPCK intervention followed the procedures highlighted in the Table 3.1 above and it was conducted with all ethical protocols observed. The detailed discussions on the intervention activities, how content of organic chemistry was presented with appropriate references in the literature and the PSTs' responses at each stage have all been provided in the

next chapter, Chapter 4. The Chapter also highlights how learning to reason happens among the PSTs in the course of the intervention. The next section below presents the classroom teaching stage following the intervention.

3.3.2 Classroom teaching stage

Following the intervention, four PSTs (pseudonyms: Ruth, Hope, Rose and Mark) who suited the sample profile discussed in section 3.2.1 were followed into the classroom of organic chemistry. The classroom teaching was a mini-case study conducted with the subset of 4 PSTs from the cohort of 17 participant PSTs who took part in the intervention sessions. This subset of 4 PSTs attended all the intervention sessions, they participated in completing CoRe tool, pre-and post-TSPCK tool and CK tool. Following the intervention, Ruth, Hope, Rose and Mark were observed to have had their planned TSPCK improved from 'Limited (1)' in the pre-test to 'Developing (3)' in the post-test as later analysed in Chapter 5. They were also noticed to have scored high marks of 80% and above in the post CK test as presented in the Table 3.2 below, pointing to their adequate conceptual knowledge of organic chemistry, a precursor for the development of PCK.

Table 3.2: Performances of PSTs in the pre-and post-CK tests

PST	**Performances in the CK tests**	
	Pre-test score (%)	Post-test score (%)
Ruth	58	83
Hope	40	90
Rose	45	88
Mark	47	85

It was then assumed that the 4 participant PSTs would draw on their good CK in classroom teaching of the same organic chemistry since CK has been regarded as the precursor for PCK and hence, TSPCK (Kind & Chan, 2019). With good CK and exposure to TSPCK construct for transforming CK of organic chemistry, it was envisaged that having the PSTs teach the same concepts of organic chemistry would give them a better chance to demonstrate their enacted TSPCK. These 4 PSTs were in their 3rd year studying for the degree of Bachelor of Education (Physical Sciences) as at the time this study was conducted and they all actively participated in the intervention. There were two notable things about the case of these 4 participant PSTs. First, it was for the first-time this group of PSTs would teach organic chemistry and so, it was assumed

that they had minimal prior eTSPCK for teaching (Aydin *et al*., 2015). Under such conditions, it would be more likely for them to draw on the pedagogical transformation strategies they learned during the TSPCK intervention conducted in this study as also confirmed by the findings in Chapter 5. Second, the PSTs were requested to teach the same topic of organic chemistry which was focused on during the intervention and in which their planned TSPCK has also been established, shown as a gain in TSPCK in Chapter 5.

The classroom teaching conducted by the PSTs took place twice with physical sciences learners between the age of 14 and 16 at a township school in South Africa. With all ethical protocols observed, the classes were specially organized on a Saturday in order not to interrupt with the normal school programmes. Historically, township schools are known to be occupied by black South African learners, less resourced with insufficient number of trained teachers and hence, most of the schools produce poor academic results (Jawahar & Dempster, 2013; Ramnarain & Fortus, 2013). In deciding what concepts to focus on during the actual classroom teaching, the PSTs were presented with the Big Ideas on which they had completed Content Representations during the intervention (See Chapter 5). The concepts they individually chose eventually became the focus of their lessons. This assisted in examining how the quality of their planned TSPCK demonstrated while learning to teach organic chemistry relates to the quality of their enacted TSPCK in the same topic of organic chemistry. The detailed discussions on the Content Representations tool are later provided in this Chapter. The first classroom teaching was conducted by Ruth and Hope in June, 2017 on the same day at the same school and at the same time. Ruth taught a class of 30 Grade 12 physical sciences learners. Hope taught a class of 30 Grade 11 physical sciences learners as presented in the Table 3.3 below.

Table 3.3: Information about the first classroom teaching

Focus of the lesson: Concepts of functional groups and IUPAC nomenclature							
Pre-service teacher				**Participant learners**			
Pseudonym	Sex	No of lessons	Lesson duration	School Grade	Number of Female	Number of Male	Total
Ruth	Female	2	1hr20min	12	17	13	30
Hope	Female	2	1hr20min	11	18	12	30

Ruth and Hope delivered two lessons each focusing on functional groups and IUPAC nomenclature of organic compounds in their respective classes. The lessons lasted for total time

duration of 120minutes in each case of Ruth and Hope. The second classroom teaching was conducted by Rose and Mark in July 2017 on the same day and at the same school. Rose taught a class of 14 Grade 12 physical sciences learners. Also, Mark taught another class of 14 Grade 12 physical sciences learners as presented in the Table 3.4 below.

Table 3.4: Information about the second classroom teaching

Focus of the lesson: Physical properties and structures of organic compounds							
Pre-service teacher				**Participant learners**			
Pseudonym	Sex	No of lessons	Lesson duration	School Grade	Number of Female	Number of Male	Total
Rose	Female	2	1hr20min	12	9	5	14
Mark	Male	2	1hr20min	12	7	7	14

Rose and Mark delivered two lessons each focusing on physical properties and structures of organic compounds in their respective classes. The lessons lasted for total time duration of 120 minutes in the case of Rose and Mark. In South Africa, Grade 12 is the exit grade in high schools after which the learners write the matric (National School Certificate) and organic chemistry is one of the core physical science topics covered at this grade. While Grade 11 is a lower grade, the school record showed that both the participant Grade 11 and Grade 12 learners had already covered important pre-concepts such as chemistry of carbon as an element, chemical bonding and intermolecular forces necessary for understanding organic chemistry concepts and this made them cognitively appropriate to learn organic chemistry in this study. It was also discovered that, prior to the PSTs' teachings, the Grade 12 learners had only been introduced to the concepts of hydrocarbons by their teacher but they had not learnt the details about IUPAC naming, functional groups, physical properties and structures of organic compounds on which the PSTs' lessons focused. The sources of data collection for this study are discussed in the next section below.

3.4 Research tools for data collection

As discussed in the sections above, there were two major stages involved in this study: the learning to reason and planning stage; and the actual classroom teaching stage. The research tools used to collect data for each stage are discussed below.

3.4.1 Research tools for learning to reason and planning stage

TSPCK tool in organic chemistry

A validated TSPCK tool in organic chemistry (see Appendix I) designed by Davidowitz and Vokwana (2014) was adopted in this study. The authors developed the tool to capture teachers' quality of planned TSPCK while thinking about teaching organic chemistry concepts. In the same way, the tool was used in this study to examine the quality of participant PSTs' planned TSPCK in organic chemistry prior to and following the intervention. The development of the tool by the authors was done in such a way that it captures the participants' written explanations which form qualitative data. In structure and organization, the tool is similar to other existing TSPCK research tools in other physical science topics like chemistry equilibrium (Mavhunga & Rollnick, 2013), particulate nature of matter (Pitjeng, 2014) and electric circuits (Zimmerman, 2015). It consists of five categories (A – E) each representing a content-specific knowledge component of TSPCK construct that facilitates the transformation of content knowledge of organic chemistry in planning for teaching. The category A is based on the knowledge component *Learner Prior Knowledge* (LP) consisting of two question items which deal with the learners' common misconceptions in organic chemistry. An extract of the first question item is provided as shown in the Figure 3.2 above.

Category A – Typical Student Responses

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

1 CH_3-OH	2 $CH_3-\overset{\overset{O}{\|}}{C}-OH$	3 $CH_3-\overset{\overset{O}{\|}}{C}-H$	4 CH_3-CH_2-OH
5 $CH_3-\overset{\overset{O}{\|}}{C}-CH_3$	6 $H-\overset{\overset{O}{\|}}{C}-O-CH_3$	7 NaOH	8 $CH_3-\overset{\overset{O}{\|}}{C}-O-CH_3$

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? Write your response in the space below.

Figure 3.2: An extract of question item on Learner Prior Knowledge (LP)

As shown in the Figure 3.2 above, the first question item on LP centres on addressing a learners' misconception regarding using hydroxyl functional group to distinguish alcohols from other organic compounds and inorganic compounds that containing hydroxide ion (OH^-). The second question item deals with attending to learners' understanding regarding the naming of alkanes. In each case, the participant PSTs in this study were expected to give their views on the learners' responses, identify and address misconceptions accordingly. The category B in the TSPCK tool is based on the knowledge component *Curricular saliency* (CS) consisting of five question items. The question items required the participant PSTs to select pre-concepts necessary for understanding organic chemistry, identify three big ideas, sequence the ideas in the order of logical teaching, draw a concept map and state the reasons for learning organic chemistry. The category C is based on the knowledge component *what is difficult to teach or understand* (WD) consisting of organic chemistry concepts from which the participants PSTs were required to choose concepts they considered difficult with reasons. The category D is based on the knowledge component *Representation* (RP) consisting of five different ways of representing an organic compound. The participant PSTs were expected to explain how they would use each of the representations in their teaching and indicate the one they found to be most useful. The category E is based on the knowledge component *conceptual teaching strategies* (CT) asking the participant PSTs to explain how they would teach a lesson about explaining and representing organic molecules to their learners. Using the tool in this study provided the opportunity to collect qualitative data which was analysed qualitatively and quantitatively.

CK tool in organic chemistry

A validated Content knowledge (CK) tool in organic chemistry (see Appendix II) designed by Davidowitz and Vokwana (2014) was also adopted in this study. As reviewed in the literature section, teachers need a solid content knowledge of a specific topic as the basis for generating PCK to teach effectively (Oh & Kim, 2013). Research studies have also established that content knowledge is very important in developing PCK (Kind & Chan, 2019) and in association, TSPCK. Based on this understanding, Davidowitz and Vokwana (2014) developed a CK tool concurrently with the TSPCK tool explained in the previous section above. The CK tool designed and validated by the authors was adopted (see Appendix II) in this study. The authors developed the tool to serve as a research instrument for measuring physical science teachers'

conceptual understanding of organic chemistry. This was done in the context of South African Physical science curriculum in which physics and chemistry are being taught to learners as a single subject. The items in the tool were drawn from repeatedly used achievement tools in the literature which examined learners' understanding in the topic of organic chemistry. While the contents of the CK tool were extracted from valid test instrument, the authors further piloted and validated the developed tool, adding to its credibility and trustworthiness. The content of the tool covers the concepts of hydrocarbons, functional groups, nomenclature, isomerism and reactions of organic compounds. This consists of twenty (20) question items with single correct answers. In this study, the participant PSTs' answers to the items in the CK tool were analysed in order to determine their conceptual understanding of organic chemistry.

Content Representations (CoRe) tool

This study adopted a Content representation (CoRe) (see Appendix III) originally designed by Loughran et al. (2000), later modified and validated by Mavhunga (2016) based on the construct of TSPCK. The broader concept of PCK is regarded as tacit and hidden (Kind, 2009) in teachers as they plan and teach their lessons. Kind (2009) further explains this nature of PCK by arguing that when a teacher is preparing lessons to teach, he or she says, 'I am preparing a lesson' not 'I am using my PCK' (Kind, 2009, p. 170). In association with the broader PCK, teachers' TSPCK appears abstract as it is rooted in the teachers' minds and teaching experiences (Rollnick & Mavhunga, 2014). In capturing and portraying such tacit and hidden teacher knowledge, the Content representation (CoRe) as a tool was originally developed by Loughran et al. (2000) for this purpose. For TSPCK studies, it was adapted by Mavhunga (2016) such that the modified version clearly identifies and arranges the five content-specific knowledge components of TSPCK. Since this study used the theoretical framework of TSPCK for developing the PSTs' knowledge, the modified CoRe (Mavhunga, 2016) (see Appendix III) was adopted in this study. A sample of the adopted CoRe is displayed in the Figure 3.3 below.

Components of Topic Specific PCK		Big Idea 1	Big Idea 2
All these questions including formulation of Big Ideas are considered to be elements of the component of TSPCK called curricular saliency	What would you consider as Big Ideas for this topic?		
	What do you intend the learners to know about this idea?		
	Why is it important for learners to know this big idea?		
	What concepts need to be taught before teaching this big idea?		
	What else do you know about this idea (that you do not intend learners to know yet)?		
What is difficult to understand	What do you consider easy or difficult in teaching this Big Idea? Provide reasons.		

Figure 3.3: A sample of adopted CoRe (Mavhunga, 2016)

CoRe as a tool was of benefit in this study as it explicitly captures the understanding of a teacher considering individual content specific knowledge components that interactively describes the TSPCK construct. It is a grid description of teacher knowledge for teaching concepts in a topic and it consists of eight prompts and rationales for how such concepts might be taught to the learners. It comprises teachers' understanding of big ideas in a topic, possible learners' pre-conceptions that may influence the teaching of the topic, difficult concepts in the topic, choice of representations and conceptual instructional strategies (Loughran, Berry, Mulhall, & Woolnough, 2006). The adopted CoRe attached as Appendix III was used in this study to monitor and capture the PSTs' development of TSPCK as they were exposed to the use of content-specific knowledge components in transforming CK of organic chemistry. It was used to collect developing reasoning of the PSTs as it happens in each component and it was introduced to them as a planning tool which they could use for planning their subsequent lessons for teaching.

3.4.2 Research tools for the actual classroom teaching stage

(a) Research tools for collecting data on PSTs' eTSPCK

First, the PSTs' actual classroom teachings served as the major channel for capturing and examining eTSPCK as teacher knowledge demonstrated in practice. The observations of teachings conducted by the PSTs assisted in gaining access to the PSTs' eTSPCK. Cohen, Manion and Morrison (2013) argued that observational data are advantageous as they offer the

researcher the opportunity to gather live data as things occur in the real-life situations. This was employed in this study without interfering in the classroom activities. As Driscoll (2011) suggested, the observation of people in a specific setting can be done either through 'participant observation' or 'unobtrusive observation'. While in participant observation, the researcher interacts with the people his/she is observing, in unobtrusive observation however, the researcher does not have to interact but rather watch and record the events (Driscoll, 2011). In this study, an unobtrusive observation with video recording of teachings was used to capture all that happened between the individual PSTs and their learners during the lessons. The use of video recording in observations was beneficial in that the videos were available to watch repeatedly and then transcribe to provide rich data and check against any forms of misinterpretation or bias (Opie, 2004). Cohen et al. (2013) further added that when observations are used as a research instrument, they enhance the production of rich data such that the researcher can give full accounts of all that happened in the research field. So, being present in the classroom to observe the lessons opened the door to reporting exactly what was observed about the PSTs' and learners' actions. The use of a video recorder was employed for capturing and recording observations of all the classroom events as the lessons unfolded. As Star and Strickland (2008) argued, watching video-recorded lessons provides opportunities for observing classroom events, content of the lessons being focused on by the teacher and teacher-learner interactions during teaching. There is also an understanding in the literature that, by using videos, teachers' reflections on the strength and weakness of their lessons are encouraged thereby increasing the level of awareness about teaching and learners involved (Liu, 2012; Savas, 2012). In their examination of collaborative construction of knowledge, Kuter, Gazi and Aksal (2012) reported that, involving PSTs in collaborative conversation following the observation of their video-recorded teachings assisted them to identify and improve on their areas of weakness in planning and actual lessons delivered. Moreover, using video recording of teachings offers rich data which captures the complexity of teacher-learner non-verbal interactions and also allowing two independent observers to watch the same video separately (Stingler, Gallimore, & Hiebert, 2000). In this study, the highlighted opportunities offered by the use of video recordings of teachings assisted in sharing the PSTs' video-recorded lessons among the team of independent raters involved in analysing data and this contributed to enhancing the credibility of emerging findings. Nevertheless, one limitation of an observation with video recording lies in that the

people being observed may change their behaviour either consciously or unconsciously in the process (Opie, 2004). This effect was minimised in this study by sitting far back behind the learners as an observer and movement was avoided. The video camera was also positioned at a stationary point where all classroom events and voices could be well captured without either interfering in the classroom teaching or distracting learners' attention at any point in point. Another limitation usually indicated whenever PCK is being studied from video recordings is that, such observational data does not normally provide a complete portrayal of teachers' PCK (Baxter & Lederman, 1999; Cross & Lepareur, 2015). Baxter and Lederman (1999) argued that in an attempt to examine teachers' knowledge of best examples, observational data cannot be exclusively relied on. The authors linked the reason to the fact that, in a given teaching segment, the teachers observed might have used a small portion of their accrued best examples such that, it becomes difficult for an observer to see other examples which were not used by the teachers (Baxter & Lederman, 1999). Likewise, an observational data alone would not reveal why a particular teacher chose to use some examples while leaving some other examples behind (Cross & Lepareur, 2015). In addressing the first limitation highlighted, this study followed the Alonzo et al.'s (2012) suggestion that studying teachers' PCK from video recordings provides the opportunity to capture PCK at the moment when it is most significant, during teacher-learners interactions. This was ensured in this study to gain insights into how the PSTs' TSPCK influenced learners' performances. In addition to the video recordings, other sources of data which included the lesson plans and interviews which were collected for a better understanding of the PSTs' eTSPCK.

Second, in addition to the observational data, the four participant PSTs who conducted lessons on organic chemistry were requested to develop lesson plans using the lesson design template (see Appendix IV) based on the rationale for TSPCK taught followed in physical science methodology courses (Mavhunga & Rollnick, 2017). The lesson plan meant to provide useful information about the PSTs' understanding of the content to teach with respect to the five content-specific knowledge components of TSPCK. The qualitative data from the lesson plans assisted in exploring the PSTs' understanding of the interactive use of knowledge components of TSPCK in planning to teach organic chemistry.

Third, there were two types of interview tools used in this study for collection of data relating to the PSTs' actual classroom teachings. These included a pre-lesson interview protocol guide consisting of five standardised open questions (Webb, 2015) attached as Appendix V and a post-lesson video-stimulated recall interview protocol guide consisting of four standardised open-ended questions (Chan & Yung, 2015) attached as Appendix VI. The protocol guide for pre-lesson interview asked the participant PSTs about what they intended learners to learn from the lesson, why such concepts are important, teaching strategies to be employed, reasons for such teaching strategies and possible difficulties about learners' thinking which may influence the teaching (Loughran *et al*., 2004). The protocol guide for post-lesson interview asked the participant PSTs to recall certain instances of the teaching relating to whether the intended lessons were achieved, what assisted them in explaining concepts, the challenged faced during teachings and what they would do differently next time.

(b) Research tools for collecting data on learner outcomes

Learner achievement tests

As discussed in section 3.3.2, the first teaching conducted by Ruth and Hope focussed on functional groups and IUPAC nomenclature of organic compounds. The second teaching conducted by Rose and Mark focussed on physical properties and structures of organic compounds. For each teaching, there was a pre-and post-achievement test conducted with the participant learners taught by each PST. The literature was reviewed for validated tools consisting of test items focusing on organic chemistry concepts taught by the PSTs in this study. The relevant literature reviewed included Vachliotis, Salta, Vasiliou and Tzougraki (2011), Hrin, Milenković and Segedinac (2016), Davidowitz and Vokwana (2014) and past questions repeated used in the National Certificate Examinations in South Africa. For example, (Vachliotis *et al*., 2011) developed and validated assessment schemes that examined Grade 11 learners' understanding of organic chemistry concepts from a public urban high school in the Athens area. The concepts included chemical classes of homologous series, IUPAC nomenclature for naming organic compounds, isomerism, and reactions of organic compounds. The authors found the tool to be valid and reliable, estimating the item validity using Pearson's correlation coefficient ($r > 0.40$) and reliability for each test with Cronbach's alpha, found to be 0.76 and 0.83 for the first

and second test respectively. A similar study with a valid and reliable tool was conducted by Hrin et al. (2016) where the effects of systemic synthesis questions on learner achievement and meaningful learning in secondary organic chemistry was explored. The test items in the validated tools as reviewed in the literature were considered in this study to make up the administered learners' achievement test. The achievement test focusing on functional groups and IUPAC nomenclature used in this study consists of 17 question items with single correct answers (see Appendix VII) as summarized in the Table 3.5 below.

Table 3.5: Test items on functional groups and IUPAC nomenclature (n=17)

Test Item	Description
	Identify functional group on the given organic molecule
Item 1	Ethanoic acid
Item 2	Ethyl ethanoate
Item 3	Butanal
Item 4	2-Butanol
Item 5	2-Bromobutane
	Draw simple organic molecule containing the functional group of
Item 6	Cycloalkane
Item 7	Ketone
Item 8	Ether
Item 9	Thiol
Item 10	Aldehyde
	Name of the structure of the given compound of
Item 11	2,5 dimethyl 3-bromohexane
Item 12	1-bromo 3-methylbenzene
Item 13	2-chlorobut-1-ene-3yne
	Write structural formula for
Item 14	Dichloromethane
Item 15	Butane-1,4 diamine
Item 16	Diethyl ether
Item 17	1-butene

The question items cover the aspects of identification of functional groups in organic molecules, drawing simple molecules of organic compounds, providing IUPAC names for the structures of organic molecules and writing structural formula of organic compounds. A sample of the achievement test is provided as shown in the Figure 3.4 below.

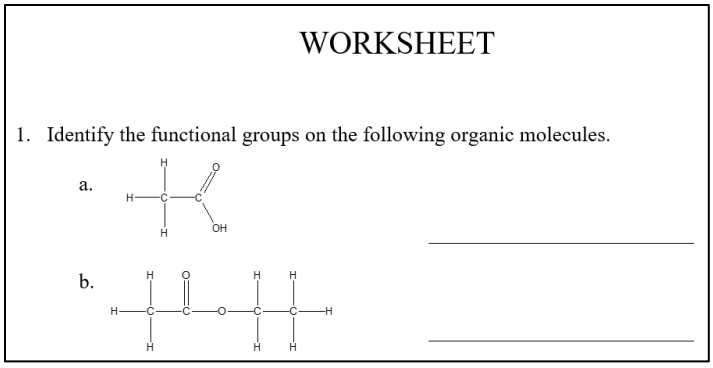


Figure 3.4: A sample of achievement test on functional groups and IUPAC nomenclature

Likewise, the achievement test for the teaching focusing on physical properties and structures of organic compounds consists of 14 question items (see Appendix VIII) as summarized in the Table 3.6 below.

Table 3.6: Test items on physical properties and structures of organic compounds (n=14)

Test Item	Description
Item1	Describing the pattern across alkanes
Item 2	Explaining the reason for the pattern in Item 1 above
Item 3	Describing the pattern across the alcohols.
Item 4	Explaining the reason for the pattern in Item 3 above
Item 5	Describing the pattern between alkanes and alcohols.
Item 6	Explaining the reason for the pattern in Item 5 above
Item7	Explaining the reason for higher boiling point of hexane than hexanol.
Item 8	Explaining the reason for lower boiling point of methanol than hexanol.
Item 9	Boiling point of a carboxylic acid/alcohol
Item 10	Explain your answer in 9 above.
Item 11	Arrange hexane, hexanol and hexanoic acid according to solubility.
Item 12	Reason for the order in 11 above.
Item 13	Arrange phenol, benzene, benzaldehyde and benzoic acid according to boiling points
Item 14	Reason for the order in 13 above.

The question items cover the aspects of describing the boiling points and melting points of alkanes, alcohols and carboxylic acids, arranging with reasons alkanes, alcohols and carboxylic acids according to their solubility and arranging with reasons phenol, benzene, benzaldehyde and benzoic acid according to their boiling points. A sample of the achievement test on physical properties of organic compounds and structures is displayed in the Figure 3.5 below.

A. Study the following table and answer the question 1- 10 below:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

1. Describe the pattern across the alkanes.

.....

2. Explaining the reason for your answer in question 1 above.

.....

Figure 3.5: A sample of achievement test on physical properties

The achievement tests were meant to measure the participant learners' conceptual performances on the concepts of organic chemistry focused on during the teachings. For content validation, the drafted achievement tests were sent to two chemistry content experts who are physical science teacher educators. The experts gave positive recommendations in terms of the cognitive demands, coverage of the concepts expected to be taught by the PSTs and meeting the stipulated requirements of the current physical science Grade 12 curriculum used in South African high schools (Department of Basic Education, 2012). The tests were also administered to 15 Grade 12 physical science learners of similar social background drawn from a school not participating in the study to check the test items for clarity.

Learners' views

There were efforts were made in this study to explore from the learners' perspective, things done by the PSTs that promoted or hindered their understanding of the concepts. Senocak (2009) reported that capturing learners' perceptions about teaching would assist the teacher improve on his/her teaching as it relates to learners' understanding. In the same line of that, Halim et al. (2014, p. 228) argued that the "students' views on what are needed of their teachers in promoting science learning could also provide information on the quality of their teachers' PCK" and I point to the PSTs' TSPCK in this study. The participant learners in this study were presented with four open-ended question items (see Figure 3.6 below) adopted from the validated tools

designed by Senocak (2009) and Halim et al. (2014) in order to capture their views about aspects of the PSTs' teachings that contributed to or hindered their conceptual understandings.

QUESTIONS

1. What did the student-teacher do, that helped you to understand the concepts? Give an example
2. What was done in the class by the student-teacher that you liked most?
3. What was done in the class by the student-teacher that you did not like?
4. What do you think would help you to understand better?

Figure 3.6: Questions for collecting learners' views

The drafted list of question items on learners' views was first sent to two experienced chemistry teachers who gave positive recommendations about using the item questions to capture learners' views on their understanding of the lessons. It was later administered to the 15 Grade 12 physical science learners of similar social background drawn from a school not participating in this study to check the test items for clarity.

3.5 Methods of data collection

3.5.1 Data collection during the learning to reason and planning stage

The TSPCK tool, CK tool and CoRe used for collecting data during the learning to reason and planning state were administered to the 17 participant PSTs who took part in the intervention in this study. These research tools generated purely qualitative data that assisted in examining the quality of PSTs' planned TSPCK with the purpose of answering the first research question guiding this study and stated as - *How does an intervention, which focuses on developing competence to pedagogically transform content knowledge of organic chemistry, influence the quality of pre-service teachers' TSPCK in the context of learning to reason and planning*? The discussions on the data collection process are provided below.

(i) Data collection prior to the intervention

On the first day of the intervention, research purpose and ethical issues were discussed with the participant PSTs. It was explained to them that the study focussed on developing TSPCK for planning and teaching organic chemistry and determining how it relates to learners' conceptual performances. They were assured of the alignment of the research with the objectives of the methodology course and that, the activities originally designed for the course would continue as planned. After the PSTs indicated their willingness to participate, they were administered with the TSPCK tool in organic chemistry right there in the lecture room as the pre-test. The test served as the baseline assessment in determining the participants' level of TSPCK before the intervention commenced. They individually completed the tool without allowing them to consult other materials or discuss among one another. They naturally took time to complete the tool and also on average time they took 45 minutes to complete the tool. Just after that the participant PSTs had returned the completed TSPCK tool, the intervention began with the introduction of TSPCK construct as they key for transforming content knowledge of a specific topic (see Table 3.1 above). Following the discussion, the organic chemistry CK tool was administered to the participant PSTs as pre-test take home assignment which they handed in the following week before the lecture commenced. This was done due to the limited time allocated for the lecture and the fact that, since the content course runs in parallel to the methodology course, content knowledge was not the focus of the intervention. All the 17 participants got the tool, completed it and handed it in the following week as instructed. There was the possibility that the participant PSTs who got the tools copied one another, textbooks or other sources. However, within that possibility, this study was interested in examining any possible shifts in the quality of their written explanations in the pre-test which could later be compared to their written explanations in the post-test. Where the participants provided explanations, it was easy to tell in situations where those sounded like text-book explanations as compared to post-tests where they seemed to have developed own voice.

(ii) Data collection during the intervention

After the first lecture during which the TSPCK construct was introduced to and the completed tools handed in by the PSTs, the discussions of the knowledge components commenced as sequentially stated in the Table 3.1. Following the discussions on the TSPCK components of

learner prior knowledge and curricular saliency, the PSTs were divided into a permanent tutorial group of 4, where there were 5 members in group 1 to 3 and there were 4 members in group 4 as shown in the Table 3.7 below.

Table 3.7: Tutorial group for completing content representations (CoRe)

Tutorial Group	Members	Group leader
1	Semo, Ruth, Peta, Tuli, Jean	Ruth
2	Rose, Mark, Tato, Zasi	Rose
3	Hope, Bapa, Debi, Madi	Hope
4	Yola, Tabo, Tefo, Atoe	Tabo

Similar to the previous TSPCK studies, CoRe (Mavhunga *et al*. 2016) was used a tool in this study for building and portraying the PSTs' planned TSPCK. Unlike in the previous studies where CoRe was administered as a pre-and post-test, the PSTs were requested in this study to complete CoRe prompts in their Tutorial groups following discussions on a given TSPCK component. On weekly basis, the PSTs completed each CoRe prompt that corresponds to a particular TSPCK component discussed during each intervention session. They submitted the completed CoRe as a major task on the last day of the intervention. The qualitative data generated from completed CoRe tool assisted in gaining insights into how the PSTs' understanding of the interactive use of content-specific knowledge developed over the week, revealing their areas of strengths and weaknesses.

(iii) Data collection at the end of the intervention

In the sixth week of the intervention, the post-TSPCK test was conducted with the participant PSTs. The PSTs had already been informed after the pre-test that there was going to be another post-test by the end of the intervention but the content of the post-test was not discussed with them. The contents of both the pre-TSPCK test and post-TSPCK test were the same since the same TSPCK tool was used except that the cover page indicated different dates for each test. They were given same leeway to complete the tool and also on average time they took 45 minutes to complete the tool. All the 17 participants returned the completed tools after 45 minutes. Immediately after the post-TSPCK test, the PSTs were given the CK tool as a take home assignment which they handed in the following week. The data collected using the pre- and post-TSPCK test assisted in determining whether there was an improvement or not in the PSTs' understanding of the interactive use of content-specific knowledge components.

Likewise, the data collected using the pre-and post-CK test helped in establishing any shift in the PSTs' conceptual understanding of organic chemistry. Based on the findings from similar several studies (e.g. Mavhunga, 2016; Mavhunga & Rollnick, 2013; Pitjeng-Mosabala & Rollnick, 2018), a positive change was anticipated between PSTs' pre-and post-test in the cases of administered TSPCK and CK tools. Nevertheless, such a change was only envisaged to work towards creating a credible baseline from which TSPCK eventually seen in the classroom with its influence on learners' conceptual performances could be cautiously interpreted. The discussion below explains the data collection process during the actual teaching stage.

3.5.2 Data collection during the actual classroom teaching stage

As part of the purpose of this study, data were collected to describe the quality of PSTs' eTSPCK as teacher knowledge demonstrated in the actual classroom teaching of organic chemistry. There was also data collection to determine the learner outcomes, captured as both the learners' conceptual performances in organic chemistry and learners' views about the PSTs' teachings. The processes involved in collecting these data are discussed below.

(i) Data collection on the PSTs' eTSPCK

Using the TSPCK construct as the lens, the quality of PSTs' eTSPCK was examined by focusing on the interactive use of content-specific knowledge components in making content of organic chemistry understandable to learners. The PSTs' teachings were video-recorded with appropriate ethical procedures strictly adhered to. For the first teaching focusing on functional groups and IUPAC nomenclature of organic compounds, Ruth and Hope delivered two lessons each which lasted for a total period of 1hour 20minutes. Based on the set of questions attached as Appendix V, a pre-lesson interview was conducted with Ruth and Hope individually just before their teaching commenced. The interview took about 8-10 minutes in the case of each PST. The interviews were audio-taped so that it could be replayed to transcribe easily. Afterwards, the teaching commenced. Since the teachings were conducted at the same time and in the same school, the assistance was requested of one other TSPCK researcher from my research team. I was in the Ruth's class to observe her teaching while the other TSPCK researcher was in the Hope's class to equally observe her teachings. In each class, each of us as an observer sat far back behind the learners and movement was avoided. In each class, the video

camera was positioned at a stationary point where all classroom events and voices could be well captured without either interfering in the classroom teacher or distracting learners' attention at any point. Both Ruth and Hope handed in their lesson plans to me immediately after the teaching. One week after the teaching, Ruth and Hope were individually engaged in a stimulated recall interview based on the set of questions attached as Appendix VI. For this interview, we first engaged Ruth and then, Hope in a closed room where there was each of them at a time, myself and my research supervisor. During the interview, we played the video of the lessons taught by the PST to remind her of the teaching events. Based on the teacher's and learners' actions, we asked the PST specific questions as highlighted in the Appendix VI to understand the reasons for the actions observed. The interviews were audiotaped so that it could be replayed to transcribe easily. Three weeks later, Rose and Mark conducted their teaching at the same school and also for a period 1hour 20minutes focusing on the concepts of physical properties and structures of organic compounds. Based on the set of questions attached as Appendix V, I conducted a pre-lesson interview with Rose and Mark individually just before their teaching commenced. The interview took about 8-10 minutes in the case of each PST. The interviews were audiotaped so that it could be replayed to transcribe easily. The teachings commenced after the interviews. I was in the Rose's class to observe her teaching while the other TSPCK researcher was in the Mark's class to equally observe her teachings. In each class, each of us as an observer sat far back behind the learners and movement was avoided. In each class, the video camera was positioned at a stationary point where all classroom events and voices could be well captured without either interfering in the classroom teacher or distracting learners' attention at any point. Both Rose and Mark handed in their lesson plans to me immediately after the teaching. One week after the teaching, Rose and Mark were individually engaged in a stimulated recall interview based on the set of questions attached as Appendix VI. For this interview, we first engaged Rose and then, Mark in a closed room where there was each of them at a time, myself and my research supervisor. During the interview, we played the video of the lessons taught by the PST to remind him/her of the teaching events. Based on the teacher's and learners' actions, we asked the PST specific questions as highlighted in the Appendix VI to understand the reasons for the actions observed. The interviews were audiotaped for easy transcription. The pre-and post-lesson interviews conducted with the PSTs, lesson plans collected and video-recorded lessons all served as the sources of data used in this study to examine the PSTs'

eTSPCK in the actual classroom teaching of organic chemistry. The data were purely qualitative that assisted in answering the second research question guide this study stated as: *How does the competence to pedagogically transform content knowledge of organic chemistry that pre-service teachers learned during the intervention influence the quality of TSPCK seen in their actual classroom teachings of organic chemistry?* Further collections of data relating to learner outcomes are discussed below.

(ii) Data collection on learner outcomes

In this study, learner outcomes were measured as both the learner performances on the achievements and learner views about the PSTs' teachings. While the learner performances referred to the learners' content knowledge of organic chemistry, learners' views considered what the learners had to say about aspects of the PSTs' which had promoted or hindered their conceptual understanding of organic chemistry. In order to determine learner performances in organic chemistry, the appropriate achievement test was conducted with the respective learners taught by each PST as a pre-and post-achievement test prior to and immediately after the PST's teaching respectively. The data collected through the learners' achievement tests were both qualitative and quantitative in nature. The data was collected for two reasons. The first reason was to understand if there would be any improvement in the learner achievement following the lessons. The second reason was to examine the relationship between the learner achievement and PSTs' eTSPCK. The two reasons targeted providing an answer to the third research question guiding this study. Just after the post-achievement test has been conducted, the learners' views questions were administered with the learners in their respective classes. The data collected through the learners' views were qualitative in nature. The entire data collected through the achievement tests and learners' views helped in providing an answer to the third research question stated as: *How does the quality of pre-service teachers' TSPCK seen in the actual classroom teaching of organic chemistry influence learner achievement in organic chemistry?*

The overall stages of data collection and the types of data collected at each stage as discussed in the above paragraphs are summarized in the Figure 3.7 below.

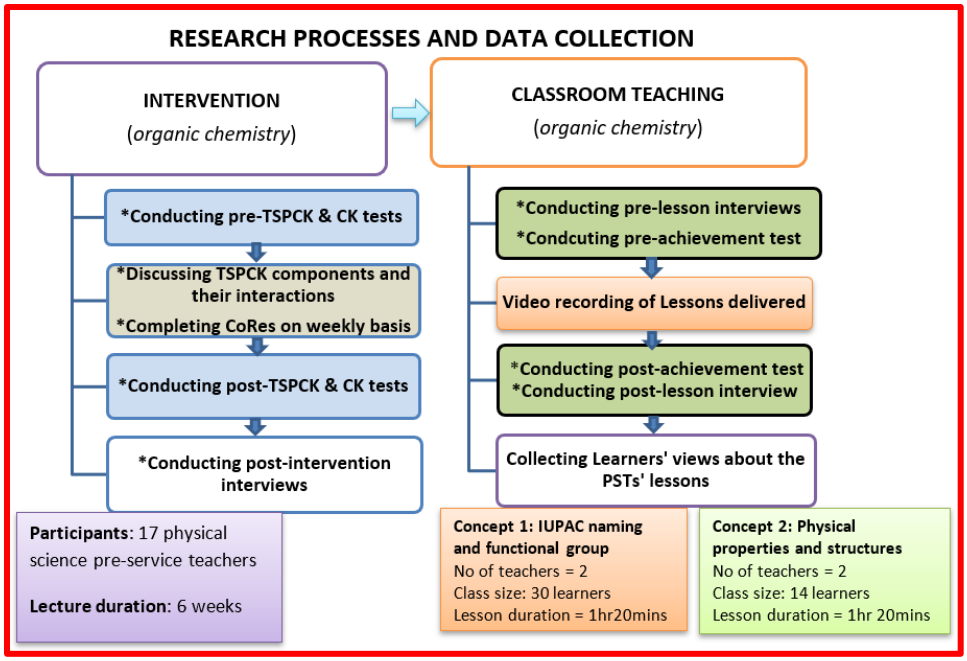


Figure 3.7: Stages of data collection and types of data collected

3.6 Analysis of data

In mixed methods research, different strategies are involved in the analysis of data thereby encouraging the integration of findings in order to generate holistic perspective of the issue being investigated (Cohen *et al*., 2013). Based on the mixed methods research design employed, the analysis of data collected in this study occurred within both the qualitative and quantitative research methods. The integration of findings through the two research methods helped in holistically examining the TSPCK-learner outcomes link by following the development of TSPCK in PSTs through the cPCK-pPCK-ePCK trajectory while learning to teach the topic of organic chemistry. The analysis of each data collected, with the purpose of providing answers to the research questions guiding this study, is sequentially presented in the sub-sections below.

3.6.1 Analysis of the impact of intervention on the PSTs' planned TSPCK

The quantitative and qualitative methods were applied in analysing the data collected during the stage of learning to reason about and planning the topic of organic chemistry. This was done to answer the first research question formulated as - *How does an intervention, which focuses on developing competence to pedagogically transform content knowledge of organic chemistry, influence the quality of pre-service teachers' TSPCK in the context of learning to reason and*

planning? The analysis of each strand of a mixed methods research approach employed is discussed as follows.

Qualitative analysis of data from TSPCK tool, CoRe tool and interviews

In the learning to reason and planning stage, there were a set of qualitative data generated through the administration of TSPCK tool, CoRe tool and the post-intervention interviews conducted with the PSTs. The data were basically the PSTs' written responses to the question items in the tools. A validated 4-criterion planned TSPCK rubric (Davidowitz & Vokwana, 2014) was adopted and used to score the PSTs' written responses to the question items in the administered TSPCK tool. A copy of the planned TSPCK rubric is attached as Appendix X. For illustrative purposes, an extract of the planned TSPCK rubric on the knowledge component 'Learner Prior Knowledge' is provided in the Figure 3.8 below.

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
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 drawing on more than one TSPCK component.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two other components of TSPCK interactively.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on three or more other components of TSPCK interactively.

Figure 3.8: An extract of the planned TSPCK rubric on Learner Prior Knowledge

The planned TSPCK rubric defines the quality of written responses in terms of the extent of interactive use of content-specific knowledge components in formulating written explanations. The criteria in the rubric emphasize the integration of knowledge components of TSPCK. This supports Abell's (2008) argument that PCK encompasses the interactions among its knowledge components rather than mere sum of the knowledge components. Per item in the tool, the rubric places the written explanations on level 1, 2, 3, or 4 representing Limited TSPCK, Basic TSPCK, Developing TSPCK or Exemplary TSPCK respectively. According the rubric, these levels portray the quality of PSTs' planned TSPCK demonstrated in the written responses in terms of the extent of interactive use of content-specific knowledge components. In other words, the

planned TSPCK rubric assisted in identifying TSPCK episodes from the PSTs' written explanations. According to Park and Chen (2012), an in-depth qualitative analysis identifies a PCK episode which represents the teaching segment where there are two or more knowledge components of PCK interacting. Similar to the previous studies on planned TSPCK (e.g. Mavhunga, 2018), the TSPCK episodes were examined in the PSTs' written responses. These represent explanations that demonstrate interactive use of two or more TSPCK components in formulating written responses on the teacher tasks in the TSPCK tool. Likewise, the PSTs' written responses on the prompts in the completed CoRe tool and their responses during the post-intervention interviews were examined for evidence of the interactions among the knowledge components of TSPCK. The TSPCK maps (Mavhunga, 2018; Park & Chen, 2012) were used in this study to visually represent the interactions among TSPCK components captured from the PSTs' written responses in both the cases of completed TSPCK tool and CoRe tool.

Quantitative analysis of TSPCK data (Rasch Analysis Model)

In addition to the qualitative analysis of TSPCK data, the quantitative method was also applied in order to confirm the pattern observed qualitatively. While the planned TSPCK rubric was used in qualitatively gaining insights into the interaction among the knowledge components of TSPCK, the quantitative analysis assisted in determining the extent of shift in the PSTs' conceptual understanding of the interactive use of these TSPCK components. In scoring the PSTs' written responses in the completed pre-and post-TSPCK tool using the planned TSPCK rubric, two other TSPCK researchers joined me. This was done to enhance the credibility of the findings emerging from the analysis of the PSTs' planned TSPCK. This was followed by the statistical process of validating the scores awarded by the three of us who independently rated the PSTs' written responses. For this validation, the Cohen Kappa inter-rater reliability was calculated (Landis & Koch, 1977). By convention, the statistical values used in rating the strength of agreement among independent rates range from poor (<0.00) to perfect agreement (1.00) when calculating Cohen Kappa inter-rater reliability (Landis & Koch, 1977, p. 165). After obtaining an acceptable reliability for the scoring of PSTs' written responses, further statistical analyses were performed using the agreed TSPCK scores.

The TSPCK data generated from the scoring were ordinal (non-linear) data because of the tacit nature of teacher knowledge under investigation and the types of questions in the administered TSPCK tool. For this purpose, the TSPCK scores were analysed using Rasch Analysis Model, RAM (Boone, Staver, & Yale, 2014). RMA converts ordinal data into linear measures such that the imperfect unidimensionality and other threats to linear measurement can be assessed by means of fit statistics (Boone *et al*., 2014). Unlike the raw data commonly associated with the greatest margin of error at either end of the scale, RMA provides a more accurate measure of person performances (Bond & Fox, 2015). Compared to other probabilistic measurement models, RMA is considered the only statitsical analysis which generates the required objectivity for constructing a scale separable from attribute distribution of the persons being measured (Bond & Fox, 2015). Hence, using Rasch measurements in describing the item and person measures would enhance rigorous analysis with great value by achieving the assumption of linearity in measures. Thus, RMA generates linear measures for persons and items and placed them on the same equidistant scale. The *Winsteps* statistical package was used in this study because it uses the RMA, and reports person measures and item difficulties on the same linear scale, thereby allowing for direct comparison (Linacre, 2014). In establishing the validity of the measures, RMA generates statistical figures which are interpreted using the INFIT and OUTFIT statistics. Bond and Fox (2015) explained that INFIT statistics help in evaluating how right or wrong an answer to a certain item by a respondent might be whereas the OUFIT statistics shed lights those items which are distant from the ability level of a respondent. The item measures and person measures in which there are INFIT and OUTFIT statistical values with the acceptable range of -2 and +2 are considered good and hence, establishing validity of the measures (Boone *et al*., 2014). In that case, the items are observed to be jointly measuring a single construct. Thus, the validity of the measures obtained in this study was established within this statistical framework. The reliability of measures was established by calculating the inter-rater statistical values which were compared to Cronbach's alpha coefficients (Bond & Fox, 2015).

Nonparametric Wilcoxon Paired Signed Rank test

There was the need to statistically establish whether the PSTs experienced a shift or not in their conceptual understanding of the TSPCK components. As a result, the pre-and post-TSPCK tests were compared to be able establish if there was any shift. It is understood that, in order to

accurately compare the pre-test scores to the post-tests for a possible shift, the scales must first be equated (Wright, 1996). A method of equating tests when Rasch Model Analysis is employed is to anchor by using a fixed based procedure (Boone *et al*., 2014). Thus, the pre-TSPCK data served as the fixed based test to be anchored and then used in equating the scale of post-TSPCK data obtained. The measures from the pre-and post-TSPCK data were thereafter analysed and compared using the nonparametric Wilcoxon Paired Signed Rank test (Whitley & Ball, 2002). The pre and post-TSPCK Rasch Person measures were considered the set of paired data on which the magnitude of difference was to be established by this Wilcoxon test analysis. Analysing for the magnitude of difference in Wilcoxon test focuses on the order of differences in the set of paired data but not the actual value of these differences. As a result, Wilcoxon test does not follow the normal distribution of data like other paired t-tests. It is regarded as the non-parametric equivalent of the paired t-test in which the main distributional assumption of data does not follow the normal data distribution. By analysing for the magnitude of difference, the fact remains that the Rasch person measures compared were naturally linked to and emerging from the same PSTs who wrote the same test twice on a single construct of TSPCK. Thus, Wilcoxon test was considered appropriate in this study for establishing whether there was or not a significant difference between pre and post-TSPCK data based on the nature of the data and the fact that, small sample (*N=17*) was used. The comparison done assisted in establishing whether there was or not any significant difference between the participant PSTs' understanding of TSPCK knowledge components prior to and following the intervention.

The Figure 3.9 below summarises the data analyses of the overall data collected during the stage of learning to reason about and planning to teach the topic of organic chemistry.

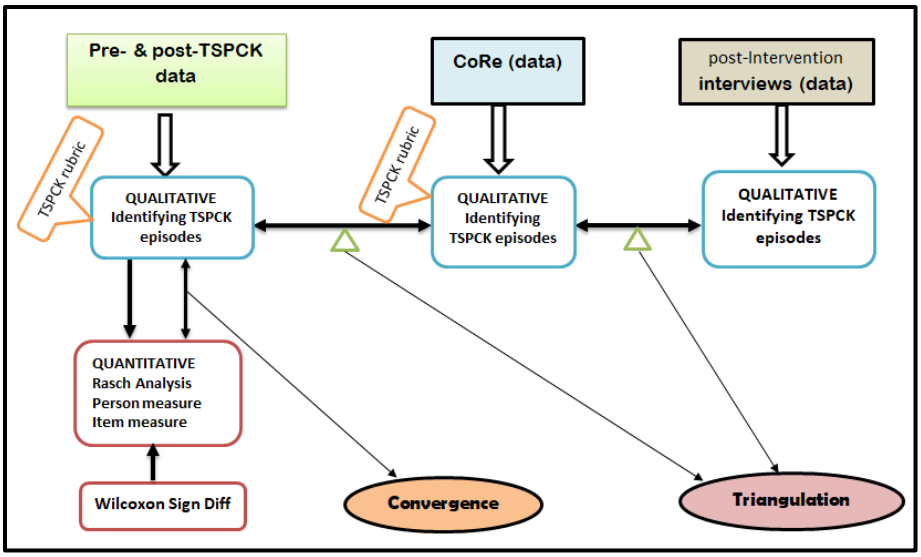


Figure 3.9: Analysis of data for describing PSTs' planned TSPCK

As shown in the Figure 3.9 above, while the numerical data obtained from the analysis of completed TSPCK tool provided patterns that described the quality of TSPCK qualitatively, further analysis also allowed the determination of PSTs' performances per TSPCK component quantitatively. The conversation of scores quantitative data also confirmed the observed qualitative patterns and thus, assisted in statistically establishing the reliability and validity of the measures. This instance of crossing from qualitative measure to quantitative measure represents the first point of convergence in this study. The next section below provides discussions on the analysis of data collected during the actual classroom teaching.

3.6.2 Analysis of classroom teaching, lesson plans and interviews

In this study, the analysis of data collected for the actual classroom on organic chemistry helped in answering the second research question formulated as - *How does the competence to pedagogically transform content knowledge of organic chemistry that pre-service teachers learned during the intervention influence the quality of TSPCK seen in their actual classroom teachings of organic chemistry*? There were steps taken in analysing the PSTs' teachings. Firstly, the video-recordings were transcribed verbatim making it easier to double check and replay the video severally in order to explicitly examine the PSTs' teaching. Then, the in-depth qualitative analysis of ePCK (Park & Chen, 2012; Park & Suh, 2019) was employed in analysing the lessons by applying TSPCK construct as the lens. In the analysis, both the transcripts and video-recordings were thoroughly and repeatedly reviewed in order to identify teaching

segments where the PSTs interactive used TSPCK components in making the content understandable to the learners. Such teaching segments in which two or more TSPCK components have been interactively used by the PSTs are said to have demonstrated 'TSPCK episodes' (Mavhunga, 2018) similar to Park and Chen's (2012) PCK episodes. Also, the quality of teachers' eTSPCK describes the extent of understanding of the interactive use of TSPCK components in explaining the content of a specific topic to the learners (Mavhunga, 2019). Based on this understanding, the identified TSPCK episodes in the 4 PSTs' lessons were graded by using a validated eTSPCK rubric (Miheso, 2018) adopted in this study. The eTSPCK rubric is attached as Appendix XI. An extract of the eTSPCK rubric is provided in the Figure 3.9 below.

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	• Evidence of three 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 Or

Figure 3.10: An extract of the enacted TSPCK rubric (Miheso, 2018)

As shown in the Figure 3.10 above, the eTSPCK rubric was employed to capture and portray different quality of TSPCK episodes identified in the PSTs' lessons enabling the development of a pictorial display of a teacher profile of TSPCK episodes. The TSPCK profiles enable comparisons across the PSTs' lessons with regards to the quality, quantity and distribution of TSPCK episodes identified and the sequence in which these TSPCK episodes emerged in the lessons. For ease of describing TSPCK components interacting in the identified TSPCK episodes, abbreviations have been used similar to how it was done in Chapter 5. These included: LP for 'Learner Prior Knowledge'; CS for 'Curricular saliency'; WD for 'What is difficult to teach or understand'; RP for 'Representations'; and CT for 'Conceptual teaching strategies'. The TSPCK interaction represented by LP-CS/RP for instance, denotes standalone use of LP linked to, as indicated by dash (-), the interactive use of CS and RP, as indicated by forward slash (/) describing interwoven of knowledge components (Mavhunga, 2018). The rubric enabled the

categorization of various TSPCK episodes where there are two TSPCK components interactively used (e.g. LP/CS), the episodes have been categorised as simple TSPCK episodes (Miheso, 2018). In the cases of three TSPCK components interacting (e.g. CS/LP/WD) or two TSPCK components with one component repeated interactively used (e.g. CS/LP/CS), the episodes have been categorised as proficient TSPCK episodes (Miheso, 2018). The teaching segments with more than three TSPCK components (LP/CS/WD/RP) or three components with one repeated (e.g. LP/CS/RP/CS) have been referred to as the sophisticated TSPCK episodes (Miheso, 2018). The cases of one TSPCK component repeated twice or more in a TSPCK episode implies additional depth to the teacher explanations. Visually, TSPCK maps (Mavhunga, 2018) have been used to show the teacher task from which the TSPCK episodes emerged and overlapping circles used to indicate TSPCK components found to be interlinking and inseparable. Unlike in other similar TSPCK studies where TSPCK maps only depict nature of interactions among TSPCK components with the associated teacher task (e.g. Mavhunga, 2018; Miheso, 2018); the TSPCK maps drawn in this study additionally highlighted the learners' role in the PSTs' explanations from which TSPCK episodes emerged. The method of connecting what the learners say in relation to what the teacher says has been argued to open an important field in PCK research that investigates the link between teacher PCK and learners' achievement (Cross & Lepareur, 2015). Thus, highlighting the learners' role in the PSTs' explanations was necessary in this study as the 'drop-in' build-up to the analysis of the relationship between eTSPCK and learner outcomes.

The inductive analysis of lesson plans and lesson-interviews as complementary data was conducted as content supporting the identified TSPCK episodes and pedagogical strategies employed by the PSTs. In conducting the post-lesson interviews, the PSTs were engaged in stimulated video recall sessions where their video-recordings of their lessons were re-played in their presence in other to discuss aspects relating to the identified TSPCK episodes. There were three of us in the TSPCK research team that worked on the above analysis process. We first worked independently with the data and then together. The first time we met after analysing the lessons blindly, we got the inter-rater consistency of 0.73 in terms of identified TSPCK components and TSPCK episodes in the PSTs' lessons. We thereafter held extensive discussions to resolve the inconsistencies by reaching a level of agreement. We repeated the same procedures until we have thoroughly re-examined the lesson video-recordings and finally got the

Cohen Kappa inter-rater reliability of 0.92 (see Appendix XXVI) which was considered acceptable. The data triangulation (use of video-recordings of lessons, lesson plans and interviews) and methodological triangulation (comparison of the results of in-depth qualitative analysis between two researchers) were both ensured in order to enhance trustworthiness of the findings (Merriam & Tisdell, 2016).

3.6.3 Analysis of the eTSPCK-learner outcomes link

As earlier stated, learner outcomes were measured in this study as both the learner achievement and the learners' views about the PSTs' teachings. For the purpose of analysing the eTSPCK-learner outcomes link, there were three different analyses conducted. The first analysis focused on establishing the learner achievement. The second analysis targeted establishing the correlation between eTSPCK and learner achievement. The third analysis examined the learners' views about factors which possibly promoted or hindered their understanding of concepts covered by the PSTs. Each of these analyses is discussed below.

Analysis of learner achievement

The first achievement test focused on functional groups and IUPAC naming of organic compounds while the second achievement test comprised the concepts of physical properties and structures of organic compounds. The first test was conducted with Ruth's and Hope's learners while the second test was conducted with Rose's and Mark's learners. The completed first and second completed achievement tests were marked using the appropriate marking memorandum of correct answers (see Appendix VII and VIII) by awarding 0 and 1 mark to the wrong and correct answers respectively. A sample of learners' written responses in the pre-and post-test is attached with the marking memo as Appendix VII. The marks were peer validated with the assistance of two other experienced and knowledgeable teachers of chemistry who joined me in marking the learners' test scripts. On the raw scores from the raters, the Kappa inter-rater consistency of 0.87 was obtained (see Appendix XXXII) which acceptably described correctness and consistency of the marking done (Mcmillan & Schumacher, 2014). The raw scores were then quantitatively analysed using Rasch Model Analysis (RMA) which transforms raw scores (ordinal data) into interval measures placed on a linear equidistant scale (Bond & Fox, 2015). Unlike the raw data commonly associated with the greatest margin of error at either end of the

scale, RMA generates more accurate probabilistic measures that take into consideration both the person ability and the item difficulty of the tool used (Boone *et al*., 2014). In determining the validity of the measures, RMA generates fit statistics, the INFIT ZSTD and OUT.ZSTD statistical values. The item measures and person measures in which fit statistical values are within the acceptable range of -2 and +2 are considered good and hence, establishing validity of the measures (Boone *et al*., 2014) . Thus, the validity of the measures obtained in this study was established within this statistical framework. RMA also generates item and person reliability where person reliability most importantly, could be compared to the more traditional reliability indices in classical test theory (e.g. Cronbach's alpha of 0.70) such that, person reliability which is closer to 1 indicate a more internally consistent measure (Boone et al., 2014). In this study, the REAL reliability estimate is used in reporting both the item and person reliability since it is considered a more conservative estimate unlike the MODEL reliability which gives the upper limit of the consistency (Boone *et al*., 2014). Moreover, for the purpose of testing for any significant difference between learner performance in the pre-test and post-test, the Rasch measures were anchored. It is essential to highlight that Rasch analysis normally generates its own common scale for item and person measures (Boone et al. 2014) such as in the individual case of learners' pre-test and post-test in this study. Hence, unless the scales are first equated, it is considered inaccurate to directly compare person responses in one test (e.g. pre-test) to the other test (e.g. post-test) (Wright, 1996). One way of equating a test in the Rasch Model Analysis is to use a fixed base procedure which is also regarded as anchoring (Morrison & Fitzpatrick, 1992). The anchoring involves calibrating the base test which is done by fixing the Rasch measures of the items in the base test (e.g. pre-test) and then using that to anchor the new test (post-test) (Morrison & Fitzpatrick, 1992). In this study, this process was ensured by considering the learners' pre-achievement tests as the base test and then fixing its Item Rasch measures to equate the scale of the post-achievement tests. This produced the 'stacked data' (Wright, 1996) which consists of the new Rasch Person measures for an accurate comparison of learner performances in the pre-and post-test. Then, the stacked person data were statistically analysed using Wilcoxon Paired Signed-rank test (WPST) for non-parametric data to establish whether there was or not a significant difference between learner performance in the pre-and post-test. The WPST represents a non-parametric test which is equivalent to the paired *t*-test (Mcmillan & Schumacher, 2014). Unlike the paired *t*-test, the main distributional assumption in

the WPST is that data does not follow a normal distribution (Mcmillan & Schumacher, 2014). In order words, Wilcoxon signed-rank test avoids the assumption of normal distribution by testing for the rank order of differences in the paired data rather than the actual statistical estimate of the differences in the data. Thus, the test is considered appropriate in this study because of its non-parametric technique considering the small sample of the participant learners.

Analysis of correlation between eTSPCK and learner achievement

The correlation analysis attempted to provide an insight about the nature of any relationship between the PSTs' eTSPCK and learner achievement in organic chemistry in addressing the TSPCK-learner outcomes link. It was ensured that, only the test items in the learners' achievement tests which were covered by the PSTs during teachings were considered for this analysis. All other test items which were not covered by the PSTs were excluded from this analysis. This represented a noticeable level of refinement of data ensured in an attempt to most importantly sift out the TSPCK episodes and minimize the noise of other factors which influence classroom instruction and learner achievement. The focus was also to analyse only for the eTSPCK episodes as defined in isolation to other types of teacher knowledge and classroom factors. For the correlation analysis, the scores generated from the PSTs' TSPCK episodes using the rubric were put onto the Rasch Analysis Model for a conversion from raw data to linear measures with minimal margin errors (Bond and Fox 2015). Then, using the Statistical Package for the Social Sciences (SPSS) software (Aldrich, 2018), the Rasch measures representing TSPCK episodes and Rasch Person measures from the analysis of learners' achievement tests were further analyzed. The analysis for done independently for achievement test versus each PST's overall TSPCK episodes. By convention, the statistical correlation analysis for establishing a relationship between two variables is only conventionally defined for paired observations, but not for unpaired observations consisting of two variables with different sizes (Greasley, 2007). However, there is the understanding that, in the cases of unpaired observations (variables), samples could be randomly selected strategically in order to satisfy the underlying principle of pairing variables in a correlation analysis (Lorenz *et al*., 2018; McMillan & Schumacher, 2014). Therefore, the correlation analysis in this study was done in batches to in order to satisfy the underlying principle of pairing these two set of variables. In order to avoid bias involved in such random sampling as Lorenz et al. (2018) cautioned, it was ensured that, all

the data in the first batch, which were not included in the strategic random selection, were considered as part of the second batch for the correlation analysis. The correlation analysis helped in estimating the Pearson's product-moment correlation coefficient (*r*) in each case of achievement test versus each PST's overall TSPCK episodes. The correlation coefficient (*r*) is widely used in research as an index of relationship describing both the strength and direction of the correlation between variables being investigated (McMillan & Schumacher, 2014). While the strength of correlation describes the magnitude of the association between the variables, the direction refers to whether the association is positive or negative (McMillan & Schumacher, 2014). The guideline used for interpreting the strength and magnitude of a correlation coefficient as stated by Hinkle, Wiersma and Jurs, (2003) is presented in the Table 3.8 below.

Table 3.8: Guideline for interpreting the size of correlation coefficient (Hinkle *et al*., 2003)

Range of *r*	Interpretation	Range of *r*	Interpretation
0.90 to 1.00	Very high positive correlation	-0.90 to -1.00	Very high negative correlation
0.70 to 0.90	High positive correlation	-0.70 to -0.70	High negative correlation
0.50 to 0.70	Moderate positive correlation	-0.50 to -0.70	Moderate negative correlation
0.30 to 0.50	Low positive correlation	-0.30 to -0.50	Low negative correlation
0.00 to 0.30	Negligible correlation	-0.00 to -0.30	Negligible correlation

A correlation coefficient of zero implies there is no linear relationship between two continuous variables (McMillan & Schumacher, 2014). The closer a correlation coefficient is to -1 or +1, the stronger the linear relationship between the variables. In other words, if a correlation coefficient is positive, the variables are directly associated such that as the value of one variable increases, the value of the other variable too tends to increase (Greasley, 2007). For a correlation coefficient with a negative value, the variables are inversely associated such that as the value of one variable increases, the value of the other variable tends to decrease (Greasley, 2007).

Furthermore, there was a qualitative examination of learners' performances on each test item versus the corresponding explanations provided by each PST. In doing this, the number of learners who responded correctly on a given test item in the pre-test was compared with the number of learners who responded correctly on the same test item in the post-test. On the same test item, the specific explanations provided by a particular PST were identified and the category of TSPCK episode emerging from such explanations was highlighted. The rationale for matching the learners' conceptual performances to the specific PSTs' explanations (TSPCK episodes) was based on the fact, the in-depth qualitative analysis of PCK and hence, TSPCK in

the actual classroom context, draws principally on examining the quality of explanations provided by the teachers (Park & Chen, 2012; Park & Suh, 2019). In the qualitative term, identifying the specific TSPCK episodes which matched the test items in the achievement tests worked towards sifting out TSPCK in an attempt to minimize the effect of other factors which influence classroom instruction and learner achievement. Most importantly, the qualitative analysis brought to view in qualitative terms, the weakness or strength of component interactions in TSPCK episodes that showed the strength of the correlation between the PSTs' eTSPCK and learner achievement.

In the entire processes of leading to correlation analysis described above, two of our TSPCK researchers joined me in confirming the overall TSPCK episodes, strategic random selection of variables for the analysis and identifying specific TSPCK episodes that matched the test items in relation to the learner performances. The three of us first worked independently with the data and then we worked together. The first time we met on comparing our results, we got the inter-rater consistency of 0.61. We thereafter held extensive discussions to resolve the inconsistencies by reaching a level of agreement. We repeated the same procedures until we have thoroughly re-examined the data for the correlation analysis. Then, we eventually got inter-rater consistency of 0.96 (see Appendix XLII) which was considered acceptable. Both the quantiative and qualitative analyzes done pointed to the benefit of use of a mixed methods research design for holistically examining complexity of TSPCK-learner outcomes link in this study. It assisted in gaining insights into how and by what extent the eTSPCK relates to the learner achievement in the topic of organic chemistry.

Analysis of learners' views

The learners' written responses to the question items, which asked them about the views, were analysed by performing content analysis. The content analysis involves forming categories of responses based on the keywords generated from the participant responses (Krippendorff, 2018). The keywords were identified in the learners' written responses in order to capture aspects of the PSTs' explanations that promoted or hindered learners' understanding of the concepts and what should have been done to enhance learners' understanding. Then, there was an inter-rater reliability check on the categories formed by myself and the two other experienced teachers who

assisted earlier with the content validation. In the cases where there were discrepancies in identifying a suitable category for the response, a discussion was held among the raters to reach a consensus. For the peer validated learners' written responses and the categories formed, an inter-rater reliability agreement was calculated at a Cohen Kappa value of 0.82, which was considered substantial (See Appendix XLIII).

3.7 Convergence of qualitative and quantitative data

Using a mixed methods research design in this study enabled in-depth exploration of the TSPCK-learner outcomes link by following the development of TSPCK in PSTs through the cPCK-pPCK-ePCK trajectory while learning to teach the topic of organic chemistry. As result, each point of convergence of the qualitative and quantitative methods was considered important. The first point of convergence occurred in the learning to reason and planning stage when the qualitative TSPCK data were converted into quantitative TSPCK data. The second point of convergence was noticed when qualitatively identified TSPCK episodes were converted into quantitative data in order to calculate the correlation between the PSTs' eTSPCK and learners' conceptual performances. The section below explains the validity and trustworthiness of the measures in this study.

3.8 Validity and Trustworthiness

The discussions in the previous sections above highlighted the different types of data collected and methods of analysis. In each case, ways of ensuring trustworthiness in qualitative data and validity in quantitative data have been systematically alluded to. In this section, all the strategies of ensuring validity and trustworthiness are pulled together in a coherent summarized manner. The strategies are discussed below for each of the mixed methods research components. Mixed-methods design as used in this study, considered very paramount, the quality of the data collected and the findings obtained in answering the research questions. Due to that fact that, both qualitative and quantitative research approaches were combined in the process of collecting and analysing data, the overall quality of findings depends on each of the strands (Creswell, 2012). This goes with the argument by (Teddlie & Tashakkori, 2009) that the quality of information data and overall results in mixed-methods research is linked to the credibility and

validity of the strands combined. The discussions on the quality of findings as it affects individual qualitative and quantitative strand are presented in the sub-sections below.

Qualitative strand

Qualitative researchers have techniques by which they establish the genuineness and trustworthiness of a research study. Lincoln and Guba (1985), while explaining rigor as a way of building trust in qualitative research, identify certain components that describe trustworthiness in the research. The components include credibility, dependability and transferability. In that line of thought, Suter (2011) posit that the most important criterion for judging the quality of qualitative study is its credibility. Sharing the same view, Merriam and Tisdell (2016) refer to the internal validity (otherwise known as 'credibility') as the definite strength of qualitative research. In enhancing the credibility of a qualitative research, triangulation is frequently used which entails employing more than one source of data all of which must converge to addressing an issue (Suter, 2011). In their view, Merriam and Tisdell (2016, p. 244) describe triangulation as "the best-known strategy to shore up the internal validity of a study". Likewise, Patton (2015, p. 674) is of the argument "triangulation, in whatever form, increases credibility and quality by countering the concern (or accusation) that a study's findings are simply an artefact of a single method". Thus, triangulation was employed in this study in both the planning stage and classroom stage. In the planning stage, data were collected using the pre- and post-TSPCK tool, CoRe tool and post-intervention interviews. The results of the analysis of each data were triangulated in order to holistically describe the quality of PSTs' planned TSPCK demonstrated in the context of learning to reason and planning. Moreover, different sources of data including the video-recorded lessons, lesson plans, pre-and post-intervention interviews were all employed in unfolding the quality of PSTs' eTSPCK. Also, the findings from the analyses of PSTs' eTSPCK, learner achievement in the tests and learners' views were all triangulated in order to describe the influence of PSTs' eTSPCK on learner outcomes. In other words, the different sources of data employed in this study contributed to addressing the identified gap in the literature and providing answers to the research questions guiding this study. Furthermore, Miles and Huberman (1994) highlight the 'audit trail' as a way of ensuring consistency and reliability in research. This, as stated by the authors, is made up evidence of information gathered during data collection which eventually describes decisions made in analysing data and the conclusions

drawn. In this study, the quality of findings and conclusion drawn were strengthened by involving two other TSPCK knowledgeable and experienced researchers for confirmation of the observed trends. The verification of analysed data was done and inter-agreement reliability was ensured. Teddlie and Tashakkori (2009) referred to this as 'member checks' and indicated such is essential to enhance credibility of interpretations. Full descriptions were provided on the stages of data collection, the tools used, the methods involved, decisions made during analysis and interpretation of results. Efforts were also made to ensure the reliability and validity of the measures generated as discussed in the section below.

Quantitative strand

The process of strengthening validity in quantitative research encompasses: the accuracy of measures by virtual of the instrument employed for the process; and establishing with evidence if such an instrument has measured the targeted thing for which it was designed (McMillan & Schumacher, 2014). While discussing reliability, Tavakol and Dennick (2011) refer to the consistency in obtaining similar findings when the same tool is administered on several occasions to the same participants under similar circumstance. It was ensured that all the tools adopted in this study were reliable and valid as used in the previous studies with similar contexts and participants. All the quantitative data obtained in this study were analysed using Rasch Analysis Model. Rasch measurements have the advantage of measuring accurately the person ability and item difficulty which both help in establishing the validity and reliability of the measures. In this regard, Boone et al. (2014) argue that, valid measures are evident when in Rasch Analysis, all items jointly work to measure a single construct and the level of difficulty of the items is determined. Such valid measures become evident when the examined item difficulty indices and person ability indices generated by the Rasch Analysis Model are within the acceptable range of the statistical indices of +2 and -2 (Boone *et al*., 2014). Thus, the validity of the measures obtained in this study was established within this statistical framework. In ensuring the accuracy of the data collected, independent raters were involved in marking all responses to the administered tools and the Cohen Kappa inter-rater reliability was calculated in each case.

3.9 Ethical issue

All the processes of data collection in this study began with ethical considerations regarding ethics approval as an important part of research studies. Punch (2009) points out that empirical research in education inevitably carries ethical issues, because it involves collecting data about people and from people. Based on that, this research process kicked off by obtaining ethics approval (see Appendix XII) from the Ethics Committee in the South African University where this study was conducted. The approval was also obtained from the Gauteng Department of Education (GDE) for permission to conduct this study with the learners in a South African high school (see Appendix XIII). Thereafter, consent forms (see Appendix XIV) were given to the PSTs to indicate their willingness to participant in this study. The forms explain the purpose of this research, its benefits, the confidentiality and anonymity of the data collected. The consents of the physical science methodology course coordinator (see Appendix XV), and course lecturer (see Appendix XVI), the school principals (see Appendix XVII), physical science teachers (see XVIII), participant the high school learners of the selected schools (see Appendix XIX) and parents of the participant learners (see Appendix XX) were sought concerning participations in this study. It was indicated in the consent form that the participant PSTs and high school learners were free to withdraw at any stage without any negative effect on them. The convenience of the sampling participants and their voluntary participations were taken into consideration in this study. All ethics rules and regulations were strictly adhered to in this study.

CHAPTER 4

4. DISCUSSIONS OF TSPCK CONSTRUCT WITH THE PRE-SERVICE TEACHERS

The previous chapter discussed the research methodology guiding the exploration of PSTs' TSPCK-learner outcomes link in Organic Chemistry. The current chapter presents explicit discussions of the intervention conducted with the PSTs focusing on collective TSPCK. This chapter closes by explaining the use of Content Representations (CoRe) tool for pulling together the content-specific knowledge components discussed during the intervention and then, the PSTs' evaluation of the benefits of the intervention.

4.1 Introduction

The history of introduction of the degree of Bachelor of Education in sciences at Wits University is dated back to 2003 with the programme located in the school of Education, Faculty of Humanities. Since its introduction, the degree programme has served as the initial teacher training programme for the PSTs to teach science subjects (physical sciences and life sciences) in high schools. It is basically meant to equip the PSTs with the content and pedagogical knowledge for teaching their specialized science subjects. In conducting the degree programme, the Wits School of Education adopted an integrated strategy where classes are split between pedagogical methodology courses and subject content courses (Mavhunga & Rollnick, 2017). During the training, the PSTs are also exposed to teaching experience where they are posted to high schools in South Africa to teach both their major and sub-major subjects (Rusznyak, 2008). The teaching experience was previously programmed to happen over three weeks twice in every academic session for the four years of degree study. Beginning in 2017, the teaching experience has been rescheduled to happen at the beginning of second semester (between July and August) over six weeks once in every academic session throughout the four years of degree study. The particular aspect of interest in this study was the methodology course where PSTs are normally taught about pedagogical strategies for teaching core science topics after which they are posted to schools for teaching experience. The current chapter presents explicit discussions about the intervention activities, the procedures followed in presenting content to the PSTs and how the PSTs responded during each discussion.

4.2 Rationale for conducting an intervention

As alluded to in Chapter 3, the intervention for this study was located in a physical science methodology course. The methodology course is traditionally known to consist of learning activities and instructional procedures employed by teachers and the underlying principles for the design of such learning activities (Lancaster & Bain, 2019). For this study, the 3rd year of methodology course was chosen because the PSTs learned the content of a physical science topic (organic chemistry) in parallel to their methodology course in the same topic. Content knowledge encompasses a teacher's conceptual understanding of the structures of his or her domain (Kind & Chan, 2019). Recent research studies (e.g. Deng, 2018; Neumann, Kind, & Harms, 2019) in science teacher education emphasize the content-based knowledge for making teaching effective. So, one major role of science teacher education is to promote the PSTs' content-based knowledge which consists of sound content knowledge and well-formed PCK (Evens *et al*., 2018). In this study, the conceptualisation of the PSTs' content knowledge of organic chemistry concepts was essentially characterised for their development of TSPCK needed for teaching organic chemistry. TSPCK is basically the knowledge needed by teachers to pedagogically transform content knowledge of a specific topic in order to make the concepts understandable to learners (Mavhunga, 2016). Therefore, learning about TSPCK concurrently with content knowledge of a specific topic enhances the pedagogical understanding and skills for effective teaching of the topic.

At the South African university where this study was conducted, lectures on both the content and methodology courses normally commence in mid-February and end in the first week of April every academic session. By tradition, the methodology course curriculum consists of learning outcomes that should be achieved by the end of the first semester course and those that should be achieved by the end of the academic session. At the end of the first semester course, the PSTs are expected to demonstrate competence to: plan, design and reflect on the appropriate learning strategies and context for the learners; select, use and adjust teaching methods to meeting the context and needs of the learners. Together with those learning outcomes, over an academic session, PSTs are expected to develop the competence to monitor and assess learners' achievement and learning progress in physical sciences; and ability to remain committed teaching profession. Hence, the intervention for this study was suitably conducted in the first

semester in conjunction with the stated learning outcomes for the methodology course. The content used during the intervention centres on pedagogically transforming the content knowledge of organic chemistry through the five content-specific knowledge components of TSPCK explicitly discussed understand the theoretical framework in Chapter 2. In other words, the intervention focused on engaging the PSTs in explicit discussions about the construct of TSPCK used for developing pedagogical reasoning about and guiding the actual teaching of organic chemistry concepts. It is understood that, pedagogical thoughts, which assist in planning a lesson, precedes the actual teaching of the lesson. Shulman (1987) referred to the thought as pedagogical reasoning and considered it as important as the actual teaching itself. In this line of thought, Nilsson and Loughran (2012) indicated that teachers are known to develop pedagogical reasoning through planning for teaching, interactions with learners and reflection on instructional practices. More so, through the results of some research studies, researchers generally view PSTs as having limited or no PCK because they lack experiences of classroom instructional practices (Evens *et al*., 2015; Lancaster & Bain, 2019).

Consequently, some research studies offered PSTs educational (methodology) courses on PCK (Lancaster & Bain, 2019; Nilsson & Loughran, 2012). Such studies found out that, using useful tools, the participant PSTs improved on their PCK. At the institution where this study was conducted, the use of TSPCK construct began with Mavhunga and Rollnick (2013) where the broad PCK was placed at a topic specific level to explicitly discuss the pedagogical transformation of content knowledge of chemical equilibrium with a group of PSTs. The entire discussions have been referred to as an intervention. The discussions centred on understanding the elements of pedagogical transformation of content knowledge of a specific topic. The authors used a validated TSPCK tool to capture the participants' pedagogical thoughts before and immediately after the discussions. They found out that, following the intervention, the participants improved on their TSPCK by demonstrating the understanding of learner prior knowledge, curricular saliency and what is difficult to teach in formulating responses. Further studies have been conducted with an intervention on the physical science topic of electrochemistry (Rollnick & Mavhunga, 2014), particulate nature of matter (Pitjeng-Mosabala & Rollnick, 2018), electric circuits (Mavhunga *et al*., 2016) and so on. The authors all reported an improvement in the participants' planned TSPCK demonstrated following the intervention. There were recommendations for the implementation of TSPCK construct in teacher education

programmes in order to develop the PSTs' PCK in core science topics. Thus, it was an important starting point in this study to first conduct an intervention with the participant PSTs on the knowledge required for teaching the physical science topic of organic chemistry. While the entire intervention activities were no longer new, the process and its findings were important as they served as the baseline in this study for carefully interpreting the findings emerging from the exploration of TSPCK-learner outcomes link with the participant PSTs in the topic of organic chemistry.

4.3 The design of the intervention

The intervention was planned for sequential discussions over a period of six weeks systematized into overall 12 sessions of 50 minutes each. Each week was designed to have three sessions organized into one period at the beginning of the week and a double period at the end of the week respectively. The single period was used for the introduction of a specific component of TSPCK and a double period was for discussing the understanding of how such component could be applied in transforming CK of organic chemistry. While the focus was on one TSPCK component at a time, the quality of explanations encouraged spontaneous occurrence of other knowledge components of TSPCK. There was recognition of the component occurring irrespective of whether it has once been fully discussed in the previous session or it was to be discussed in the next session. The attention of the PSTs was called to such moments of natural interaction of TSPCK components. The first period each week, which was planned to introduce a component of TSPCK comprised of teacher-learner centred discussions in which the participants were divided into smaller groups to deliberate on the TSPCK component in question. Such group deliberations lasted for about 15minutes after which the entire class shared ideas and the course lecturer consolidated the whole deliberations. These instances of consolidation focused on how discussions on a certain component of TSPCK has incorporated emergence spontaneous of other components and consequently influenced the quality of explanations based on a concept in a topic. The aspects of content knowledge that were focussed on during the intervention included: carbon unique nature, IUPAC naming of organic compounds, functional groups, physical properties of organic compounds and isomerism.

4.3.1 The sessions on Introducing TSPCK construct

The first session focussed on introducing the intervention as Topic-Specific PCK based and seeking the consent of the class of PSTs regarding participation in this study. The process of seeking the participants' consent and administering CK and TSPCK has been explicitly discussed in the previous chapter, Chapter 3. After the whole class consented to voluntarily participate in this study, then the discussions focused on the TSPCK construct as consisting of five content-specific knowledge components for transforming the content knowledge of a specific topic (e.g. organic chemistry). The emphasis was that, TSPCK is the knowledge that assists teachers when planning to teach and when actually teaching a specific topic in order to enhance learners' understanding. The participant PSTs were made to understand that, unlike the broad PCK, TSPCK places PCK at a topic specific level for effective teaching. They were also encouraged to think about teaching other physical science topics by engaging the understanding of the interactive use of content-specific knowledge components which the TSPCK construct focuses on. The five content-specific knowledge components of TSPCK discussed were: learner prior knowledge including misconceptions; curricular saliency; what is potentially difficult for learners to understand; representations; and conceptual teaching strategies.

4.3.2 The sessions on Learner Prior Knowledge

The sessions on learner prior knowledge primarily focussed on identifying the commonly researched misconceptions, importance of teacher knowledge of such misconceptions and the impact on learners' understanding. The discussions emerged sequentially as follows:

(i) What is Learner Prior Knowledge (LP)

To start with, learner prior knowledge (LP) has been described as the "knowledge, skills, or ability that students bring to the learning process" (Jonassen & Grabowski, 1993, p. 416) relating to the current topic or concept. In other words, LP was discussed with the participant PSTs as the entire learners' conceptions, which already existed before learners were introduced to new ideas. This was also referred to the as the learners' preconceptions relating to the current topic or concept. The participant PSTs were made to understand that, in science teaching and learning, learners' preconceptions which support scientific views are regarded as correct conceptions while the contrary ones are referred to as the misconceptions. The attention of the

PSTs was drawn to the fact that, LP as an important component of TSPCK construct describes teacher knowledge of what learners' conceptions including misconceptions are relating to a given topic. This was followed by the discussions on why teacher knowledge of learners' preconceptions is important in teaching and learning.

(ii) Why is teachers' understanding of Learner Prior Knowledge important?

During the intervention, the learners' prior knowledge relating to the current topic or concept was considered one major factor that contributes to learning of the topic or concept (Ladachart & Ladachart, 2019). Likewise, Can and Boz (2011, 2016) argued that constructing new knowledge without adequate link to the learners' prior knowledge produces no meaningful learning and understanding. In order to further explain LP as one important factor in learning, the theory of learning was briefly reviewed with the participant PSTs according to the constructivism view. Learners develop their understanding of topics: from their own individual experiences; by interacting with the environment using their senses to gather information; thinking about and mentally interpreting incoming information through prior (existing) knowledge (Arends & Castle, 1991; Richmond, 2013). Two important points were emphasized during the lecture. First, teachers should be conscious of the fact that learners dwell on their prior knowledge (experiences) to expand on the concepts being introduced to them. Second, learning is an active and engaging process and so, there should be meaningful teacher-learner interactions and the environment for learning to occur. The questioning techniques were discussed as the common tools for investigating learner prior knowledge. For example, Mthethwa-kunene et al. (2015) investigated the PCK of a group of science teachers in Genetics. The teachers were observed to have indicated questioning technique for probing learners' existing knowledge about genetics-related topics they have previously learned (Mthethwa-kunene *et al*., 2015). This was reported to have assisted the observed teachers to identify misconceptions in the learners' responses and connect learners' understanding of the previous concepts to the current topic in order to ensure learning took place. The participant PSTs were reminded that LP as an important component of TSPCK construct represents teacher knowledge of learners' conceptions including misconceptions relating to a given topic. The misconceptions were referred to as the learners' incorrect existing conceptions about the current topic in question. The teacher knowledge of misconceptions enhances their PCK in line with the argument that "as teachers developed better

understanding of students' misconceptions, their PCK became more sophisticated" (Park & Oliver, 2008, p. 275).

(iii) Investigating the PSTs' understanding of the reactivity of alkanes and alkenes

The PSTs were presented with the idea of comparing the reactivity of alkanes and alkenes. They were given 5minutes to discuss in pairs and then asked to explain which of the two classes of hydrocarbons would be more reactive. Given below is the audio transcript of PSTs Jean and Mark.

> ***Jean**: Alkanes would be more reactive than alkenes, alkanes have got only single covalent carbon-carbon covalent bonds but alkenes have got at least a double carbon-carbon covalent bond in addition to other single carbon-carbon covalent bonds, making alkenes to be stronger and more reactive than alkanes.*
>
> ***Mark**: I believe alkenes would be more reactive with alkanes because they've got both the single and double carbon-carbon covalent bonds, that contributions to organic reactions neh.*

When other PSTs were asked, 9 PSTs agreed with Jean's response, 2 PSTs supported Mark, 4 PSTs did not give any response. It was then assumed that, most of the PSTs had the misconception that alkanes would be more reactive than alkenes because alkanes have single covalent bonds which be can easily attacked than a double carbon-carbon covalent bond in alkenes.

(iv) Addressing the misconception associated with the reactivity of alkanes and alkenes

This misconception centres on the assumption that because alkanes have single carbon-carbon covalent bonds, they should be more reactive than alkenes with double carbon-carbon covalent bonds. The correct knowledge for learners to know is that the double bond between carbon atoms in alkenes describes weak pi bond and thus, alkenes are found to be more reactive compared to alkanes. In order to address this misconception, two important points were emphasised to the PSTs to make the concept understandable to the learners. First, the pi bond is weak in alkenes making the double bond to be prone to the electrophilic attack. This could be explained by using a symbolic structure of ethene for example as shown in the Figure 4.1 below

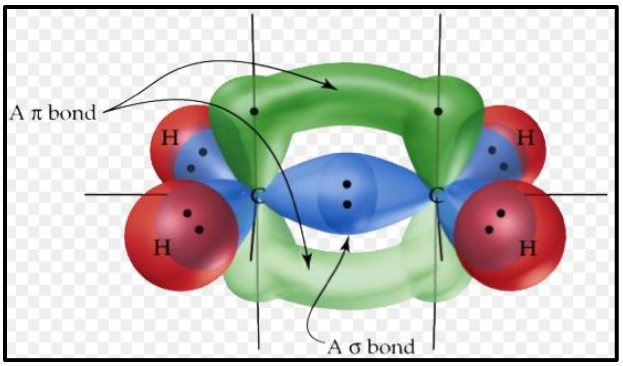


Figure 4.1: Pi and Sigma bonds in alkenes

The carbon-carbon double (C=C) is made up of a sigma (ϭ) bond and a pi (π) bond. The sigma bond consists of electrons occupying space that is of small volume, they are found half-way between and with strong attractions to the two nuclei. The pi bond consists of electrons which could be seen be further away from the two nuclei and so, the attractions are weak. While a sigma bond is strong, a pi bond is weak making it very easy to be attacked by electrophilic reagents. Second, the reactivity of alkenes is linked to only the cleavage of the pi bond present in the double bond. By energy measure, less energy is required by the cleavage of the pi bond in alkenes (double bond) whereas more energy is required by the cleavage of a single C-C bond in alkanes.

Task for the pre-service teachers: The PSTs were asked to discuss the remaining two misconceptions in their groups and then design a teaching segment on how to address the misconceptions. There were presentations by the PSTs which revealed their understanding of the key concepts in addressing each misconception.

In discussing this misconception, the PSTs were encouraged to emphasize key concepts and use representations where necessary to enhance understanding. These sessions on closed by acknowledging the significance of identifying and knowing misconceptions when thinking about teaching organic chemistry.

4.3.3 The sessions on curricular saliency

The discussions on curricular saliency targeted developing knowledge for analysing and organizing the concepts in a given topic for the purposes of planning and teaching the topic effectively. The aim of the discussions centred on: identifying pre-concepts; Big Ideas;

subordinate concepts; sequencing of concepts; and the importance for teaching the topic. The steps highlighted below were taken in explaining curricular saliency to the PSTs.

(i) What is curricular saliency?

Curricular saliency describes the position of a given topic in the curriculum and reasons for teaching the topic (Rollnick et al. 2008). As contained in the Curriculum and Assessment Policy Statement (CAPS) for Physical sciences, organic chemistry (organic molecules) is a physical science topic that learners learn in Grade 12, Term 1. Also, curricular saliency encompasses the pre-concepts, Big Ideas, subordinate concepts, sequencing concepts and importance of teaching the topic. It was specified to the PSTs that the pre-concepts represent important chemical concepts that must have been covered in chemistry before they can teach a particular topic. They were made to understand that, for learners to adequately learn newly introduced concepts, they must develop the ability to link such concepts to the previous acquired knowledge and the concepts must be returned to some other time for emphasis and adding-on more advanced elements according to the cumulative learning theory (Maton, 2009; Muklis, Abidin, & Pamungkas, 2018). They were asked to think about concepts that are closely related to organic chemistry that learners must have learnt before introducing organic chemistry to them. Their responses included: elements, compounds, atoms, molecular formulae of compounds. The reason they gave for mentioning those concepts was that, the concepts are come across when dealing with organic compounds and learners must have understood them properly before teaching organic chemistry. However, they were told about most important pre-concepts like chemical bonding (e.g. covalent bonding) which learners must have been taught to avoid learner difficulty on catenation property of carbon. Under chemical bonding, their attention was also drawn to hydrogen bonds which some organic compounds (like ethanol) contain to be soluble in water. This was followed by discussions on the Big Ideas and subordinate concepts.

(ii) Identifying and formulating Big Ideas:

The session began with a facilitated discussion on what pre-concepts are for teaching organic chemistry. The PSTs correctly mentioned with reasons, chemistry concepts as follows:

> Atoe*: Atoms, atomic properties of elements particularly those that are involved in organic compounds like carbon, hydrogen, oxygen.*

Mark*: Intermolecular forces are important because they affect physical properties like boiling point and melting point.*

Tefo*: Chemical bonding like hydrogen bonding, covalent bondings are part of learners would come across in organic chemistry.*

The pre-concepts were described as the concepts that learners must have learned and understood the new knowledge can build. The responses above showed that, the PSTs understood what pre-concepts mean. This was followed by discussions on identifying Big Ideas. The PSTs shared their thoughts with the class about the Big Ideas.

Rose: Hydrocarbons…they consist of only carbon and hydrogen

Tato: Alkanes….they represent the simplest class of hydrocarbons

Peta: Alcohols…they consist of hydroxyl groups

Ruth: Organic reactions like substitution, elimination and so on.

The PSTs were probed about the possible Big Ideas in organic chemistry. They mentioned concepts such as hydrocarbons, alkanes, alkynes, alkynes and alcohols. From the PSTs' responses, it was obvious that they did not have the understanding of what Big Ideas are and how to formulate them. Big Ideas were explained to the participant PSTs as containing the key concepts in a topic necessary for developing learners' understanding of the topic. It was specified that a Big Idea is a statement that briefly describes core knowledge in a topic in which there are other smaller concepts viewed as important for developing learners' understanding of the topic (Loughran *et al*., 2012). Other smaller concepts in the topic were referred to as the subordinate concepts. They were told that definitions, sub-headings (like Alcohols, Alkanes, and Hydrocarbons) do not constitute Big Ideas. The typical examples of key concepts explicitly discussed included: IUPAC naming of organic compounds; functional groups of organic compounds; and organic reactions. To make 'IUPAC naming of organic compound a Big Idea, it was put in a statement form as follows: Organic compounds are named according to the IUPAC system. The naming of alkanes was mentioned as an example of a subordinate concept. Afterwards, the PSTs were presented with other key concepts identified in this study according to the literature namely: carbon unique nature; functional groups; reactions of organic

compounds; physical properties and structures of organic compounds (Davidowitz & Potgieter, 2016; Davidowitz & Vokwana, 2014). They were asked to think about using the key concepts to formulate Big Ideas.

Step III: Introduction to Content Representations (CoRe): The PSTs were introduced to CoRe as a pedagogical tool for structuring and organizing concepts in a topic in preparation for teaching. It was used to capture PSTs' pedagogical transformation thoughts on different aspects of organic chemistry discussed during lectures. They were presented with completed CoRe on another physical science topic extracted from the book by Loughran et al. (2006). Then, they were divided into Tutorial groups to complete the CoRe prompt on curricular saliency and learners' misconceptions. They were instructed to use the extract of the completed CoRe as a guide.

4.3.4 The sessions on what is difficult to teach or understand

The discussions on what is difficult were meant to make the PSTs think of specific difficult concepts in organic chemistry relating to learners' prior knowledge (misconceptions). They were also to develop the ability to link the reasons to specific gate keeping concepts that when not fully understood add to the difficulty of the concepts regarded as difficult.

Step I: Learning difficulties in chemistry generally: At both the high school and tertiary levels, chemistry is generally considered difficult to teach and learn (Treagust *et al*., 2000). One of the reasons for the difficulty is that some scientific views of the chemistry concepts which are in most cases contradictory to the intuitive and learners' everyday perspectives. Consequently, learners develop misunderstandings when they place correct instructional explanations of the concepts within the framework of prior instructional conceptions (Treagust *et al*., 2000). Another reason is that chemistry topics are known to be difficult because they relate to the structures of matter consisting of abstract concepts (Sirhan, 2007). Meanwhile, the abstract concepts are underpinning concepts to learn and sufficiently grasped by the learners because without them further chemistry or science concepts and their theories cannot be easily understood (Ayas & Demirbaş, 1997; Nicoll, 2001). The difficulties in learning chemistry in relation to its abstract nature then requires learners to be equipped with a high-level skill so they could apply the knowledge appropriately when necessary (Zoller, 1990).

Step II: Learning difficulties in Organic chemistry: In the previous research studies that focussed on organic chemistry, a few concepts highlighted to be difficult included: representations (including drawing) of organic molecules (Johnstone, 2006); properties of organic compounds (Anderson & Bodner, 2008); isomerism (Taagepera & Noori, 2000); classifying organic compounds (Domin, Al-Masum, & Mensah, 2008); types of organic reactions (Ferguson & Bodner, 2008) ; and mechanism of organic reactions (Ferguson & Bodner, 2008). With the participant PSTs, the difficulty around thinking about the three-dimensional structures of organic molecules was discussed. Since the abstract nature of chemistry concepts requires thinking in three levels of domains (Johnstone, 1991), to this, the organic chemistry concepts are no exception. These three domains of thinking include the macroscopic level, microscopic level and symbolic level (O'Dwyer & Childs, 2017). This thought of engaging the three levels of representation when thing about concepts have been found to pose a substantial challenge to novices (Bradley & Brand, 1985; Ngozi-Olehi, Duru, Uchegbu, & Amanze, 2018). Ngozi-Olehi et al. (2018) indicated that various difficulties learners encounter in learning organic chemistry involve understanding the three-dimensional nature of organic molecules. The difficulty is associated with the inability to do conversation between two-dimensional representation of molecules as presented in the textbooks and that teachers write on the board and the three-dimensional structures of the same molecules. When the correct understanding of this is not in place, learners fall back to memorizing terminologies and rules associated with molecules pretending the three-dimensional structures of molecules is understood. Organic chemistry concepts are known to be highly demanding cognitively making its learning over-whelming for learners who only operates at the concrete stage of cognitive ability (O'Dwyer & Childs, 2017). For this reason, organic chemistry concepts are taught to learners in their exit grade, Grade 12 in South African schools. The learners' inability to see the vitality and significance of organic chemistry concepts in the high schools and university level also contribute to the difficulty (Katz, 1996)

Step III: Summary of the difficulties: First, there is the widespread belief that chemistry is difficult because teachers ask learners to think about too many abstract entities that they cannot see or touch. Second, for learners thinking about unavailable concrete objects or events may be as challenging as reasoning involving abstract entities. Third, chemistry may not be difficult because of the nature of the things we talk about but because of the high cognitive demand

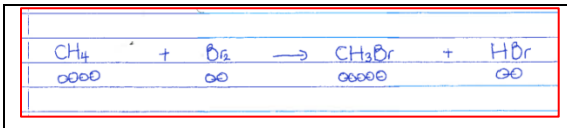
involved in applying the knowledge acquired. These in many cases require learners to make judgments and decisions taking by considering the effect of multiple factors, both concrete and abstract**.** Fourth, learners' misconceptions that interfere with developing correct scientific knowledge should be addressed.

Step IV: Teacher knowledge of what is difficult: First, identifies specific concepts with reasons related to prior knowledge of students or common misconceptions. This entails identifying potential learners' difficulties in a topic that can hider full understanding of the big and subordinate ideas in the topic. ***Second***, provides reasons linking to specific gate keeping concepts that when not fully understood add to the difficulty of a concept regarded as difficult.

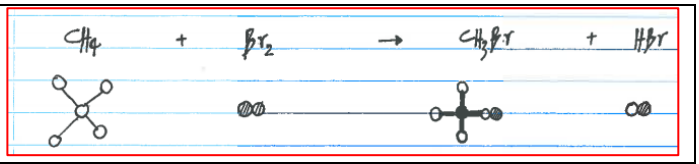
Step V: Task for the pre-service teachers: Completing the CoRe prompts on what you would consider difficult relating to teaching the identified Big Idea.

4.3.5 The sessions of Representations

The sessions on representations introduced the use of three levels (macroscopic, symbolic and sub-microscopic) of representations in explaining concepts as suggested by the research papers (Cheng & Gilbert, 2009) which served as the pre-reading task for the PSTs. The participant PSTs seemed to appreciate the value offered by these three levels of representations but they complained about difficulty in representing concepts at a sub-microscopic. In order to understand their precise kind of difficulty, they were asked to represent the substitution reaction between methane and bromine to produce bromomethane and hydrogen bromide. The extract of pre-service teacher Yola and Hope is given in the Figure 4.2 below.



Yola's sub-microscopic representation

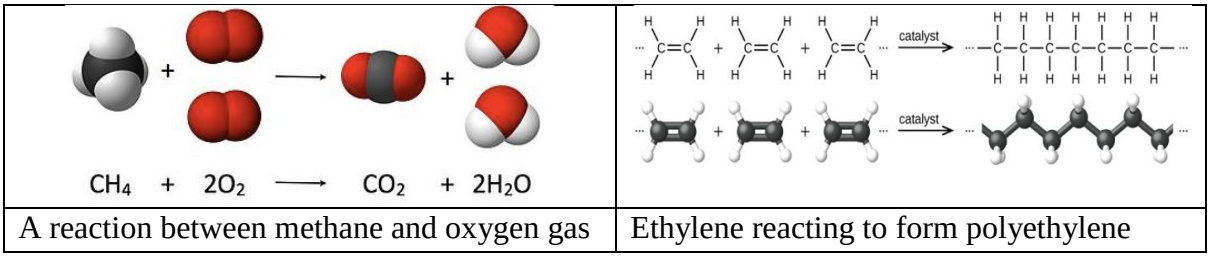


Hope's sub-microscopic representation

Figure 4.2: PSTs' first attempt in representing methane substitution reaction

Yola's representation as given in the Figure 4.3 does not differentiate carbon atoms from hydrogen atoms and bromine atoms, all atoms appeared to be the same. Likewise, Hope's representation does not distinguish atoms of carbon from hydrogen atoms in the molecule of methane and she wrongly represented bromomethane. In order to make the use of different

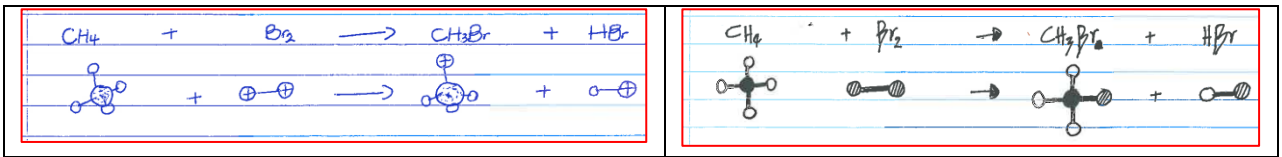
shapes understandable to the PSTs in sub-microscopic representations of chemistry concepts, the Figure 4.3 below was projected for them to see and there were discussions on them. The Figure illustrates the reaction between methane and oxygen gas and also the polymerization of ethylene to form polyethylene. The PSTs were glad to see using different shadings to illustrate the constituents involved as the reactants and products in the reactions as shown in the Figure 4.3 below.



A reaction between methane and oxygen gas	Ethylene reacting to form polyethylene

Figure 4.3: Use of microscopic representations to explain organic chemistry concepts

As shown in the Figure 4.3 above, the PSTs' attention was drawn to the use of colours and shapes in representing different atoms in each molecule. The PSTs were encouraged to try and re-represent the substitution reaction between methane and bromine, using the projected slides as an example. The extract of Yola and Hope's second sub-microscopic representations is given in the Figure 4.4 below.



Yola's sub-microscopic representation	Hope's sub-microscopic representation

Figure 4.4: PSTs' second attempt in representing methane substitution reaction

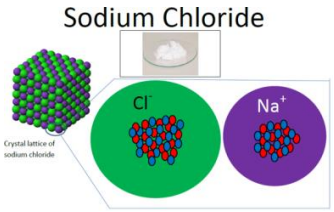
The above sub-microscopic representations showed that the PSTs understood the representations used as the guideline. Then, further explanations were provided on each level of representations and how to combine them in teaching.

Combining three levels of representations in teaching

The ***macroscopic level*** of representation describes what is concrete and observable such as a colorless liquid of salt and water in a glass beaker as shown in the Figure 4.5 (a) below. The ***sub-microscopic level*** describes the molecular and invisible forms of representations such as bonds and atoms that a salt is made up of as in the Figure 4.5 (b) below. The ***symbolic level***

describes all chemical equations, symbols and formulae used for representing atoms and molecules as in the Figure 4.5 (c) below.





NaCl

(a) Macroscopic representation **(b)** Sub-microscopic representation **(c)** Symbolic representation

Figure 4.5: The three levels of representations

In chemistry it is essential to use all three levels of representation. Use of three levels of representation can help learners develop deeper understanding problem-solving skills. The use of representations motivates the interest of learners by engaging them in constructive and critical thinking thereby enhancing learners' understanding of the concepts (Prain & Tytler, 2012).

Task for the pre-service teacher: They were asked to complete the CoRe prompts on representations in their Tutorial groups on their identified Big Ideas.

4.3.6 The sessions on Conceptual teaching strategies (CTS)

The discussions on *conceptual teaching strategies* (CTS) focused on the understanding of integration of TSPCK components in teaching organic chemistry concepts. These involved identifying learner's misconceptions and addressing the misconceptions by providing standardized knowledge with emphasis on what is important for learners using representations in order to previous the occurrence of such misconceptions in teaching organic chemistry concepts considered confusing and difficult. The discussions were guided by two researcher papers namely: Graulich (2015) - The tip of the iceberg in organic chemistry classes: how do students deal with the invisible? And Bussey et al. (2013) - Variation theory: A theory of learning and a useful theoretical framework for chemical education research by. Based on the authors' suggested teaching strategies, the discussions with the participant PSTs on CTS were divided into the categories below.

(i) CTS focusing on increasing the PSTs' awareness of alternative meanings which may be assigned to the scientific terms commonly associated with the teaching and

learning of organic chemistry. An example discussed was the term '*hydroxyl group*' denoted by OH in organic compounds (e.g. CH_3OH) which in inorganic compounds (e.g. NaOH), it is being referred to as the hydroxide ion, OH^-. Another example involved organic compounds (e.g. C_2H_6) referred to as the *carbon-containing compounds* with at least a carbon-hydrogen bond whereas inorganic compounds could also be carbon-containing compounds (e.g. CO_2) but without a carbon-hydrogen bond. The strategies include explaining the meaning of the terms when used and indicating how it differs from similar terms.

(ii) CTS focusing on the understanding of variation theory, a conceptual method of teaching science. These applied to discussing organic concepts side by side because of the similarity that might result in difficulty associated with differentiating and understanding such concepts. An example discussed with the PSTs included the cases of the functional groups of alcohols, phenols and thiols having the structure R-OH, Ar-OH and R-SH respectively. There was also an example of aldehyde and ketone containing carbonyl group discussed with the participant PSTs as shown in the Figure 4.6 below.

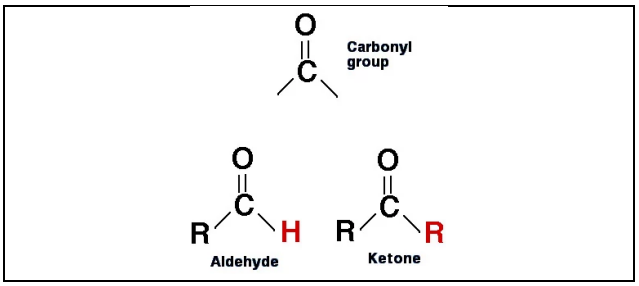


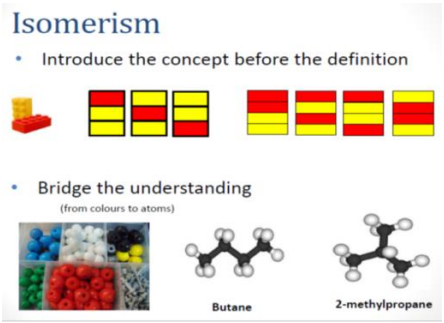
Figure 4.6: Difference and similarity between Aldehydes and Ketones

(iii) CTS focusing on identifying learners' potential misconceptions by asking them about their views related to the current concepts prior to the presentation of the concepts. These also include addressing the misconceptions by providing correct knowledge which emphasizes what is important to understanding with a link to everyday knowledge that builds on their experiences such as the Figure 4.7 below. Organic compounds occur throughout every living thing and in countless products like jelly beans in a plastic container. Jelly beans are composed of sugars, gelatin and starch – all organic compounds. And the plastic container is a combination of polymeric organic compounds.

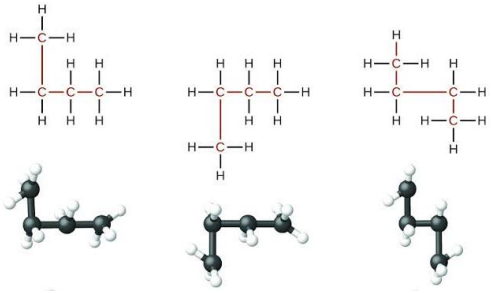


Figure 4.7: Use of familiar examples (macroscopic representations)

The strategies also involve engaging learners in demonstrations (e.g. laboratory experiments) which provide opportunities for observations. These included for example the demonstrations on the reactivity of alkenes versus alkanes, testing to differentiate similar functional groups of aldehydes and ketones. Such demonstrations are described to have a long-term impression confronting misunderstandings regarding organic reactions and functional groups. These included developing learners' understanding of the submicroscopic models used by chemists to describe, explain, and predict the properties of chemical substances and processes. Also, helping learners learn to manipulate the wide variety of symbols used in chemistry to represent and visualize important components of such models. These strategies were encouraged to teach different organic concepts such as isomerism as shown in the Figure 4.8 below.



(a) Macro and sub-micro representations



(b) Symbolic and sub-microscopic representations

Figure 4.8: Three levels of representations for introducing isomerism

The PSTs responses showed how well they received and agreed on the use of the above conceptual teaching strategies in teaching chemistry concepts.

4.3.7 Pulling TSPCK components together as a construct for teaching

The last session of the intervention focused on concluding discussions on the individual component of TSPCK with a reflection and emphasis on the important points raised during each

session. During these discussions, there were explicit links made on the importance of reasoning and planning through the components of TSPCK leading to the pedagogical transformation of organic chemistry concepts. The use of CoRe was also emphasized as the tool for enhancing understanding of the 5 knowledge components of TSPCK.

4.4 Summary

In this chapter as described in the above sections, there were explicit and interactive discussions with the PSTs on the five content-specific knowledge components needed to pedagogically transform the content knowledge of the topic of organic chemistry in order to develop TSPCK for the topic. There were applications of learning through verbal conversations and written responses accompanied with quick feedback that allowed for deep reasoning and better understanding. While the discussions purposely focused on the ability for pedagogical transformation of content knowledge, it accidentally provided the PSTs opportunities to develop their conceptual understanding as the strategies employed challenged them to think about the content of organic chemistry. The evidence of benefits that the PSTs derived from the explicit discussions was seen from their written evaluation on the last week of the intervention as shown in the Figure 4.9 below.

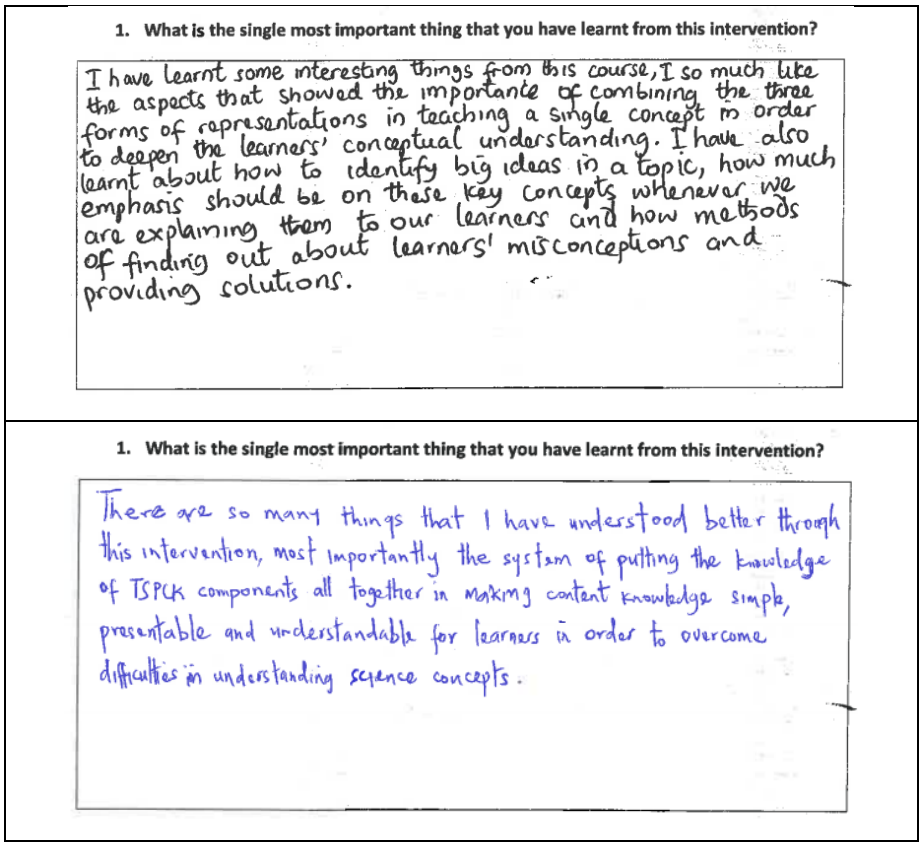


Figure 4.9: Extract from Rose and Hope's written evaluation of the intervention

In a nut shell, the method of pedagogical transformation of content knowledge by thinking through learner prior knowledge, curricular saliency, what is potentially difficult, representations and conceptual teaching strategies was found stimulating for the participant PSTs. The extract of written responses given in the Figure 4.9 above reveals the anticipated impact of the intervention of the explicit discussions. Furthermore, efforts were made in this study to examine the translation of collective TSPCK that the PSTs learnt in this chapter into personal TSPCK demonstrated as planned TSPCK and enacted TSPCK analysed in the next two chapters, Chapter 5 and Chapter 6 respectively. While the purpose of this chapter was to provide insightful descriptions of the intervention activities, a few signals pointing conceptual learning of knowledge components increased interest in the findings emanating from this study. The next chapter provides the analysis of PSTs' personal TSPCK demonstrated as planned TSPCK in the context of learning to reason and planning the topic of organic chemistry.

CHAPTER FIVE

5. ANALYSIS OF PRE-SERVICE TEACHERS' PLANNED TSPCK

The previous chapter provided explicit discussions which exposed the PSTs to the collective TSPCK through the five content-specific knowledge components focusing on the topic of organic chemistry. This chapter presents the analysis the quality of PSTs' planned TSPCK in building a credible base for describing enacted TSPCK, the focus in the next chapter and eventually establishing the TSPCK-learner outcomes link, the overall purpose of the study. The chapter closes with a summary of the findings emerging from the analysis in answering the first research question guiding the study.

5.1 Introduction

The current chapter presents the analysis of the PSTs' personal TSPCK (pTSPCK) as teacher knowledge visible in the context of learning to reason about teaching and planning the topic of organic chemistry. As alluded to in Chapter 2, the Refined Consensus Model (RCM) conceptualizes PCK across its grian sizes sch as TSPCK to include what a teacher knows, what a teacher does and the pedagogical reasoning guiding a teacher's actions in the actual classroom (Carlson & Daehler, 2019). The current chapter tracked the effect of explicit discussions which focused on collective TSPCK as discussed in the previous chapter (Chapter 4) and the PSTs' pTSPCK manifested as planned TSPCK as they formulated written responses to teacher tasks. The chapter attempted to answer the 2nd research question guiding this study stated as: How does an intervention, which focuses on developing competence to pedagogically transform content knowledge of organic chemistry, influence the quality of pre-service teachers' TSPCK in the context of learning to reason and planning? As alluded to in Chapter 2, similar previous studies (e.g. Mavhunga & Rollnick, 2013; Mavhunga *et al*. 2016) conducted explicit TSPCK interventions with in-service and PSTs and they consistently reported an improvement in the participants' planned TSPCK following the interventions. Consequently, any further possible reports of improvement in the participants' planned TSPCK following a similar explicit intervention can no longer be considered a new research finding as it has been established repeatedly in previous studies. Nevertheless, following the same procedures of an explicit intervention was crucial in this study since the target was exploring the TSPCK-learner outcomes

link with a group of PSTs who are generally known to possess fragmented PCK (Aydin *et al.* 2015). Also, establishing the quality of PSTs' planned TSPCK was important as it was hoped to work towards building a credible base for interpreting the PSTs' eTSPCK analysed in the next chapter, Chapter 6. The section below provides a recap of the methodological approaches used in this chapter.

5.2 A recap of methodology used in this chapter

As alluded to in Chapter 3, the sample for this chapter consists of 17 PSTs who were exposed to an explicit TSPCK intervention discussed in the previous chapter, Chapter 4. The sources of data for examining the PSTs' planned TSPCK included: the validated CK and TSPCK tools in organic chemistry (Davidowitz & Vokwana, 2014); Content Representations (CoRe); and stimulated recall interviews. The explicit discussions about the content of the research tools, how the tools were administered with the PSTs, methods of analysis and validating the measures have been provided in the methodology chapter, Chapter 3 (section 3.4.1, section 3.5.1 and section 3.6.1). Using an appropriate rubric, the marking of the PSTs' CK completed tool showed higher scores in the post-test than pre-test (See Appendix XXV). This reflects an improvement in the PSTs' conceptual knowledge of organic chemistry following the intervention. The quantitative analysis of the PSTs' planned TSPCK is presented in the next section below.

5.3 Analysis of Planned TSPCK

5.3.1 Quantitative evidence supporting an improvement in the PSTs' planned TSPCK

Raw scores

As alluded to in Chapter 3, the PSTs' TSPCK tests were scored by using a validated planned TSPCK rubric (see Appendix X) linked to the 5 TSPCK components rated on a 4-criterion scale corresponding to categories 'limited (1)', 'basic (2)', 'developing (3)', and 'exemplary (4)'. The categories reflect differing degree of explanations demonstrating extent of understanding of interactive use of TSPCK components. The PSTs' scores in the pre-and post-TSPCK tests are presented as shown in the Table 5.1 below. For ease of representation, the TSPCK components given in each column are abbreviated as follows: Learner Prior Knowledge 'LP'; Curricular saliency 'CS'; What is potentially difficult for learners to understand 'WD'; Representations

'RP'; and Conceptual teaching strategies 'CT'. Each row provides the scores for each participant pre-service teacher (PST) across the 5 TSPCK components in the pre-test (T_1) and post-test (T_2). It also provides the calculated average pre-test scores (AT_1) and calculated average post-test scores (AT_1) for each PST across all the 5 TSPCK components. The last row gives the proxy average scores for the entire class of participant PSTs per TSPCK component in the pre-test and post-test. The proxy average scores calculated for TSPCK components do not imply that TSPCK is the mathematical sum of its individual knowledge components but rather the interactive use of these knowledge components (Aydin *et al*. 2015). Consequently, the calculated proxy average scores recorded in the Table 5.1 below considered extent of the PSTs' interactive use of the TSPCK components in formulating written responses as the planned TSPCK rubric emphasizes. The proxy average scores indicate the overall effect of the interactive use of TSPCK knowledge components.

Table 5.1: Pre-service teachers' raw scores in the pre-and post-TSPCK tests

PST	**LP**		**CS**		**WD**		**RP**		**CT**		Average scores	
	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	AT_1	AT_2
Semo	2	4	1	3	1	4	1	4	1	4	1	4
Rose	1	3	1	3	1	4	1	4	1	3	1	3
Hope	1	3	1	4	1	3	1	3	1	3	1	3
Jean	1	4	1	3	1	3	2	4	2	3	1	3
Peta	2	4	2	4	1	4	2	4	1	2	2	4
Ruth	1	3	1	4	2	3	1	4	1	3	1	3
Atoe	2	3	1	4	2	3	2	4	1	3	2	3
Mark	2	4	2	4	1	3	2	3	1	3	2	3
Tato	1	4	1	3	1	2	1	2	1	3	1	3
Tefo	1	3	1	4	1	3	2	4	1	2	1	3
Bapa	2	4	2	3	2	3	1	4	2	3	2	3
Debi	1	3	1	3	1	3	1	2	1	3	1	3
Madi	2	3	2	3	1	3	1	4	1	2	1	3
Zasi	2	3	2	4	1	2	2	4	1	2	2	3
Tuli	1	4	2	3	1	2	1	2	1	2	1	3
Tabo	1	2	1	3	1	2	1	3	1	2	1	2
Yola	1	3	1	3	1	3	1	4	1	3	1	3
Average	1	3	1	3	1	3	1	3	1	3	1	3
Proxy Average for pre-TSPCK test across all components (T_1) = 1 (Limited TSPCK)												
Proxy Average for post-TSPCK test across all components (T_2) = 3 (Limited TSPCK)												

PST = Pre-service teacher, LP= Learner Prior Knowledge, CS = Curricular saliency, WD = What is potentially difficult for learners to understand, RP = Representations, CT = Conceptual teaching strategies

*T_1 = Pre-TSPCK test, T_2 = Post-TSPCK test, AT_1 = Average pre-TSPCK test, AT_2 = Average post-TSPCK test

As shown in the Table 5.1 above, the PSTs had higher scores in the post-test (T_2) compared to the pre-test (T_1) to varying degrees across the 5 TSPCK components. The calculated proxy average scores for each TSPCK component revealed a score of '1' in the pre-test and a score of '3' in the post-test. The raw scores have been re-presented graphically as shown in the Figure 5.1 below for each TSPCK component such that the emerging patterns in each case could be visually inspected easily.

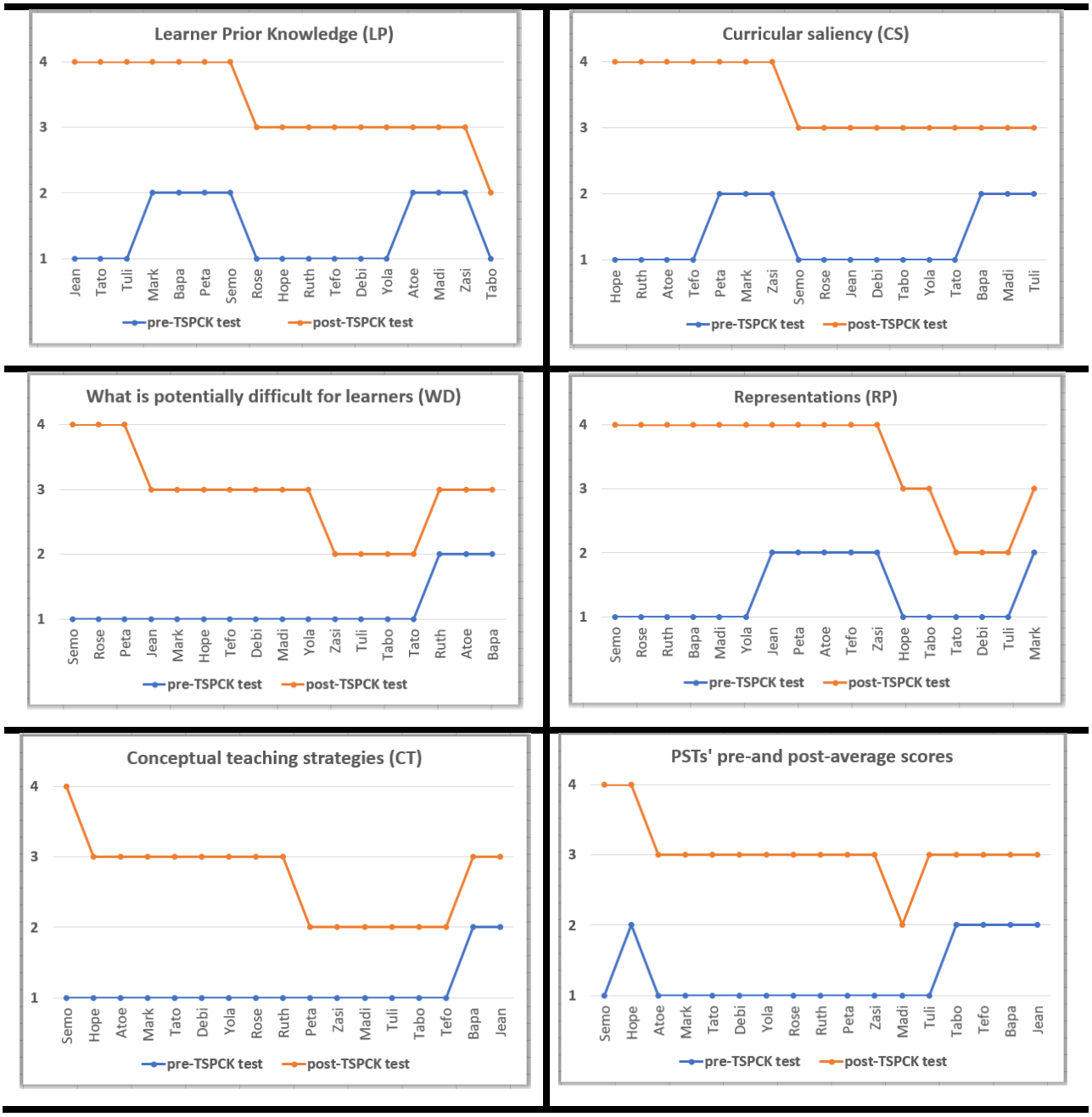


Figure 5.1: Graphs of PSTs' pre-and post-TSPCK scores

Looking across the five graphs on TSPCK components as shown in the Figure 5.1, there are 3 categories of jump when compared the PSTs' pre-test scores to the post-test scores. First, there are cases of three jumps from '1' in the pre-test to '4' in the post-test. Second, there are cases of two jumps from either '2' in the pre-test to '4' in the post-test or '1' in the pre-test to '3' in the post-test. Third, there are cases of one jump from either '1' in the pre-test to '2' in the post-test or '2' in the pre-test to '3' in the post-test. On all the 5 TSPCK components, there are more PSTs with two jumps particularly from '1' in the pre-test to '3' in the post-test compared to the three jumps and one jumps. This could also be observed on the graph of PSTs' pre-and post-average scores with 10 PSTs having their overall scores increased from '1' in the pre-test to '3' in the post-test. The pattern suggests an improvement from the PSTs' limited planned TSPCK ('1') in the pre-test to the developing planned TSPCK ('3') in the post-test following their exposure to the explicit discussions on cTSPCK. Nevertheless, there is the need to further confirm these patterns by a more rigorous statistical quantitative analysis and in-depth qualitative analysis. This is done in the sub-sections below. Meanwhile, the patterns in the above already indicated a synopsis of the possible trend that may emerge from further analysis of data.

Conversion of raw scores into Rasch measures

The PSTs' raw scores given in the Table 5.1 above were statistically analysed using Rasch Model Analysis (RMA). As alluded to in Chapter 3, RMA generates more accurate probabilistic measures of person abilities thereby establishing a rank order of both the test items and participants who took the test (Bond & Fox, 2015). It also generates reliability indices for the items and persons making it possibly to determine the internal consistency of the research tools. Likewise, RMA generates two indices of fit statistics (infit ZSTD and outfit ZSTD) for item measures and person measures. The fit statistics which fall within the range of -2 and +2 are considered conventionally acceptable thereby indicating that both the items and person measures coherently work together to measure a single construct, and thus constitute a valid measure (Boone *et al*., 2014). The Table 5.2 below summarizes the results of the conversion of PSTs' raw scores into Rasch measures. The detailed version of this analysis is attached as Appendix XXII. Each row indicates a pseudonym assigned to the participant PST, pre-TSPCK Rasch measure with the infit and outfit indices, post-TSPCK Rasch measure with the infit and outfit indices. At the bottom of the Table 5.2 below, the calculated mean for Person measures in each

test, person reliability, item reliability and a description of Fit statistics (infit/outfit indices) are provided.

Table 5.2: Rasch Person Measures for the pre-service teachers' pre/post-TSPCK tests (N=17)

Pre-service teacher (PST)	Person Measures for pre-TSPCK test			Person Measures for post-TSPCK test		
	Pre-TSPCK	*Fit statistics*		Post-TSPCK	*Fit statistics*	
	Rasch measure	IN. ZSTD	OUT. ZSTD	Rasch measure	IN. ZSTD	OUT. ZSTD
Madi	-0.55	-0.5	-0.5	5.42	-0.9	-0.8
Ruth	-1.84	0.2	0.2	4.01	-0.8	-0.7
Atoe	-2.58	1.0	1.3	4.01	-0.8	-0.7
Tuli	-0.55	1.2	1.1	3.05	-0.5	-0.2
Jean	-1.15	-1.4	-1.4	3.05	0.1	-0.3
Hope	-0.55	-0.7	-0.7	3.05	-0.6	-0.4
Yola	-1.15	0.9	1.0	3.05	-0.6	-0.4
Semo	-4.37	0.3	0.4	2.39	1.3	1.4
Peta	-1.15	1.0	0.9	2.39	-0.6	-0.6
Mark	-1.84	0.2	0.2	2.39	-0.6	-0.6
Rose	-1.15	-1.4	-1.4	2.39	-0.2	-0.3
Tato	-1.15	-0.2	-0.2	2.39	-0.6	-0.6
Bapa	-2.58	-0.8	-0.9	1.37	0.4	0.3
Zasi	-5.76	0.4	0.4	0.92	0.1	0.4
Debi	-2.58	-0.6	-0.7	0.46	1.0	1.1
Tabo	-1.84	1.7	1.7	-0.02	1.0	1.0
Tefo	-5.76	0.4	0.4	-0.55	0.1	0.1
Rasch MEAN	-2.15			2.34		
Person reliability	0.68			0.88		
Item reliability	0.75			0.91		
Infit/Outfit indices	All INZSTD & OUTZSTD fall within the range of -2 and +2.			All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.		

Note: The order of arrangement of PSTs was based on descending order of Rasch measures in the post-TSPCK test. The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-TSPCK test (UIMEAN=0 and USCALE=1)

As shown in the Table 5.2 above, the all the PSTs had varying negative Rasch measures in the pre-TSPCK test which describe their low performance in the test. However, all the PSTs had varying positive Rasch measures except in the cases of Tefo and Tabo. This describes the PSTs' better performance in the post-TSPCK test compared to the pre-TSPCK test. The higher calculated mean for Post-TSPCK person measures (2.34) than the lower calculated mean for Pre-TSPCK person measures (-2.15) describes an improvement in the PSTs' quality of TSPCK in the pre-test compared to the post-test. The person reliability was 0.68 for the pre-test and 0.88 for the post-test. The higher person reliability in the post-test compared to the pre-test is an

indication that enough items were sufficiently spread along the continuum and enough spread of person ability among the PSTs who responding to the TSPCK tool. In other words, to increase the person reliability value in the pre-test, the person ability should be improved, and this was achieved in the post-test. The item reliabilities for the pre-test and post-test were 0.75 and 0.91 respectively found within the range of 0 and 1 and higher than the Cronbach's alpha coefficient of 0.70. This implies that the items in the TSPCK tool are very replicable, wide spread among the persons, generating very minimal standard errors and uncompromised development of reliable measures. Likewise, the fit statistics (infit and outfit indices) were within the acceptable range of -2 and +2 which seems to suggest good fit of PSTs' responses thereby establishing the validity of the measures. The rank order of the items in the pre-and post-TSPCK test is discussed as follows.

The Rank order for the Item measures

The Rasch item measures which indicate the participant PSTs' level of difficulty on the TSPCK test items (TSPCK components) are attached as Appendix XXIII. The summary of the item rank order is provided in the Table 5.3 below.

Table 5.3: Rank order of Rasch Item measures for the analysis of pre-and post-TSPCK tests

Item measure	Learner Prior Knowledge (LP)	Curricular Saliency (CS)	What is difficult (WD)	Representations (RP)	Conceptual Teaching Strategies (CT)
Pre-TSPCK	1.85	1.29	2.81	0.55	3.71
Post-TSPCK	-1.08	-2.35	0.42	-3.63	2.65
Gain	-2.93	-3.64	-2.39	-4.18	-1.06

Note: *For the analysis, Item measure set to zero and Units per Logit=1 (UNIMEAN=0 and USCALE=1). *Gain=Post-TSPCK item measure minus Pre-TSPCK item measure.

As shown in the Table 5.3 above, the item measures for the PSTs' pre-TSPCK test denote varying degrees of diffculty given that they are all positive statitsically values. It is important to recall that, in interpreting item measures from Rasch analysis, positive values represent very low chances of having a good number of participants who responded correctly on the items. So, in the pre-TSPCK test, the TSPCK component *Conceptual teaching strategies* (CT) emerged as the most difficult followed by *What is difficult* (WD) and then *Learner Prior Knowledge* (LP)

followed by *Curricular saliency* (CS) and *Representations* (RP). It was only on RP that only a fair percentage of PSTs (45% from 0.55 item measure) had the chances of responding correctly.

In the post-TSPCK test, RP emerged the least difficult followed by CS and then LP. However, CT emerged the most difficult followed by WD. The post-item measure of 0.42 for WD means that, about 58% of PSTs had the chances of responded correctly on the item (TSPCK component). It was not suprinsingly that, the TSPCK component 'conceptual teaching strategies' CT still emerged as the most difficult for the participant PSTs. CT required the PSTs to draw on more interactive on the other four TSPCK components while formulating a single written response. Such an understanding requires experiences of classroom teaching of the concepts (or topics) which were lacking in the participant PSTs. While the knowledge component CT remained the most difficult, it should be acknowledged that the post-TSPCK item measure (2.65) was less than the pre-TSPCK item measure (3.71). This seems to imply that even though the participant PSTs found CT difficult, they still conceptually engaged more with the component in the post-test than they did in the pre-test. This is similar to the TSPCK component WD with post-TSPCK item measure (0.42) compared to a high post-TSPCK item measure in the (2.81). The PSTs' difficulty has been particularly reported on this knowledge component in previous studies (e.g. Mavhunga & Rollnick, 2013; Mavhunga *et al*. 2016) due to their lack of teaching experiences and regular interactions with learners. Nevertheless, the calculated *gain* in the Table 5.3 above on the 5 TSPCK components showed that, the PSTs' understanding of each TSPCK component improved following the intervention. The next section below presents the analysis done for a possible significant difference between the PSTs' performances in the post-TSPCK test and pre-TSPCK test.

Comparing Person Rasch measures for significant difference

In order to accurately compare the pre-and post-TSPCK tests for a significant difference, the Rasch Person measures were anchored as explicitly discussed in Chapter 3 (section 3.6.1). The stacked data generated from the anchoring process is provided in the Table 5.4 below (see Appendix XXIV for the original version).

Table 5.4: Stacked data from the Rasch analysis of pre-and post-TSPCK tests

Pre-service teacher	Pre-TSPCK test		Post-TSPCK test	
	Rasch Measure	S. Error	Rasch Measure	S. Error
Madi	-0.55	0.75	4.85	1.90
Ruth	-1.84	0.75	3.42	1.14
Atoe	-2.58	0.75	3.42	1.14
Tuli	-0.55	0.81	2.45	0.86
Jean	-1.15	0.81	2.45	0.86
Hope	-0.55	0.81	2.45	0.86
Yola	-1.15	0.81	2.45	0.86
Semo	-4.37	0.81	1.81	0.75
Peta	-1.15	0.85	1.81	0.75
Mark	-1.84	0.85	1.81	0.75
Rose	-1.15	0.85	1.81	0.75
Tato	-1.15	0.87	1.81	0.75
Bapa	-2.58	0.87	0.86	0.65
Zasi	-5.76	0.87	0.46	0.63
Debi	-2.58	1.13	0.07	0.62
Tabo	-1.84	1.88	-0.30	0.61
Tefo	-5.76	1.88	-0.66	0.60
Mean	**-2.15**	**0.96**	**1.82**	**0.85**

To establish whether there was any significant difference or not, the equated Rasch Person measures were further analysed using the Wilcoxon Paired Signed Rank test (Whitley & Ball, 2002). The rationale for using Wilcoxon Paired Signed Rank test has been provided in Chapter 3 (section 3.6.1). The result of the Wilcoxon test is provided in the Figure 5.2 below.

Pre-Test Person measure	Anchored Post-Test Person measure	Diff= (Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	153
-0,55	4,85	5,4	5,4	14,00	14	n=	17
-1,84	3,42	5,26	5,26	13,00	13	σ{T}	42,2493
-2,58	3,42	6	6	15,00	15	α	0,05
-0,55	2,45	3	3	6,50	6,5	Action(L)	-82,8
-1,15	2,45	3,6	3,6	9,50	9,5	Action(U)	82,8
-0,55	2,45	3	3	6,50	6,5	z	3,6
-1,15	2,45	3,6	3,6	9,50	9,5	Reject Null at 0,05	
-4,37	1,81	6,18	6,18	16,00	16	*p*	0,00029
-1,15	1,81	2,96	2,96	4,00	4		
-1,84	1,81	3,65	3,65	11,00	11		
-1,15	1,81	2,96	2,96	4,00	4		
-1,15	1,81	2,96	2,96	4,00	4		
-2,58	0,86	3,44	3,44	8,00	8		
-5,76	0,46	6,22	6,22	17,00	17		
-2,58	0,07	2,65	2,65	2,00	2		
-1,84	-0,3	1,54	1,54	1,00	1		
-5,76	-0,66	5,1	5,1	12,00	12		

Figure 5.2: Wilcoxon significant test for pre-and post-TSPCK tests

As shown in the Figure 5.2 above, at a significance level (α) of 0.05, the alpha value *p* is given as 0.00029. The value of *p* is much more less than the significance level of 0.05 and that shows there is a significance difference between the PSTs' performance in the pre-TSPCK test and post-TSPCK test. This is of the implication, following the intervention, the quality of PSTs' TSPCK in organic chemistry concepts improved significant. They experienced the greatest improvement on the knowledge components of Representations, Curricular saliency and Learner Prior Knowledge. In spite of the statistical validity of this finding, it could nevertheless be considered limited as it does not practically state what knowledge components were interactively used to describe the quality of TSPCK in written responses. This is most important in this study in adequately describing the quality of PSTs' TSPCK. Hence, it is essential to examine qualitatively what constitutes the improvement of the quality of PSTs' TSPCK. It is hoped that such qualitative examination together with these quantitative reports would give a sound baseline for interpreting TSPCK in the actual classroom and therefore increase the credibility of this study. The discussions in the next section below provide the qualitative evidence from the analysis of TSPCK written responses, post-intervention interviews and completed CoRe by the PSTs.

5.3.2 Qualitative evidence supporting an improvement in the PSTs' planned TSPCK

As observed in the quantitative analysis above, the PSTs generally experienced an improvement from the category of Limited TSPCK in the pre-test to the category of Developing TSPCK in the post-test. However, the analysis did not qualitatively reveal what knowledge components of TSPCK were found interacting and the extent of this interaction among the knowledge components of TSPCK components. It is important to highlight that, pedagogical transformation competence in a planning context comprises the understanding of interactive use of TSPCK components in formulating written responses on a given concept. Therefore, the in-depth qualitative analysis of the PSTs' written explanations in the TSPCK tests are provided below as samples of work that demonstrated improvement from limited TSPCK to developing TSPCK following the intervention. Samples of explanations from the CoRe prompts completed by the PSTs which equally demonstrated understanding of interactive use of TSPCK components are also provided as supporting evidence. Further supporting evidence are drawn from the PSTs' oral responses during the stimulated recall interview in order to understand their struggle and success that accompanied the development of TSPCK. These insights from the written explanations and responses during the interview work towards building a comprehensive understanding of the PSTs' interactive use of content-specific knowledge components learned during the intervention.

(i) Improvement on the TSPCK component Learner Prior Knowledge (LP)

Samples of written explanations from the TSPCK tool

On the TSPCK component LP, the first question item required the PSTs to provide explanations on a learner's choice of alcohols from a list of organic and inorganic compounds that contain oxygen and hydrogen atoms (see Appendix I). The learner in question selected the compounds 1, 2, 4 and 7 as alcohols as provided in the Figure 5.3 below.

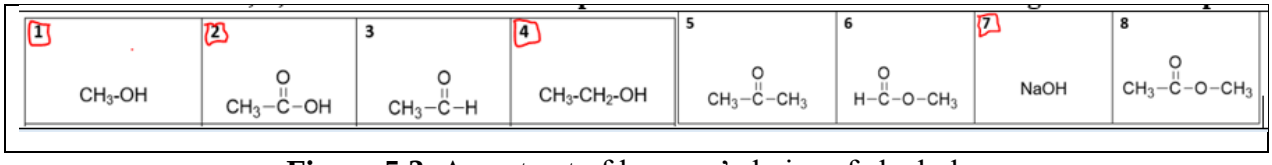


Figure 5.3: An extract of learners' choice of alcohols

As shown in the Figure 5.3 above, the learner in question could be observed to have referred to all compounds containing O and H as alcohols irrespective of whether the compound is organic or inorganic. The extract of Ruth's written responses which demonstrated an improvement from Limited TSPCK in the pre-test to Developing TSPCK in the post-test is provided in the Figure 5.4 below.

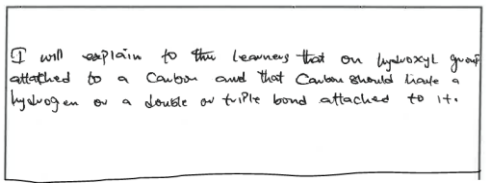
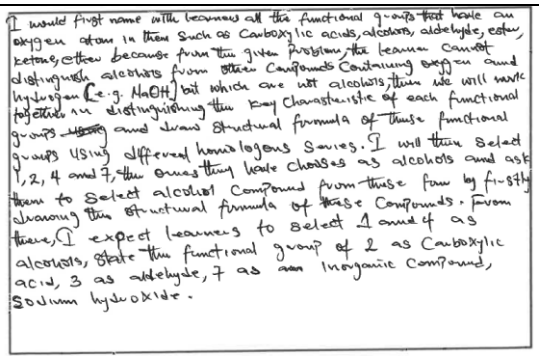
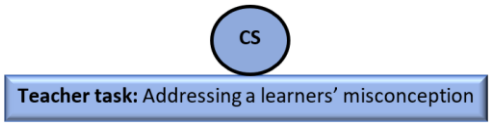
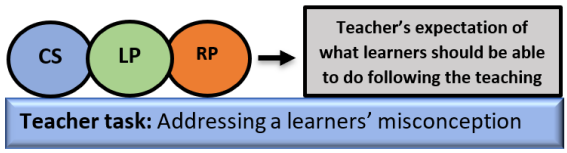
Pre-TSPCK test	Post-TSPCK test
	
I will explain to the learners that an hydroxyl group attached to a carbon and that carbon should have hydrogen or a double or triple bond attached to it.	I would first name with learners all the functional groups that have an oxygen atom in them such as carboxylic acids, alcohols, aldehyde, ester, ketone and ether because from the given problem, the learner cannot distinguish alcohols from other compounds containing oxygen and hydrogen (e.g. NaOH) but which are not alcohols, then we will work together in distinguishing the key characteristic of each functional groups and draw structural formula of these functional groups using different homologous series. I will the select 1, 2, 4 and 7, the ones they have chosen as alcohols and ask them to select alcohol compound from these four by firstly drawing the structural formula of these compounds. From there, I expect learners to select 1 and 4 as alcohols, state the functional group of 2 as carboxylic acid, 3 as aldehyde, 7 as an inorganic compound, sodium hydroxide.
TSPCK map 	**TSPCK Map** 

Figure 5.4: Ruth's written responses on learner prior knowledge (pre/post-TSPCK test)

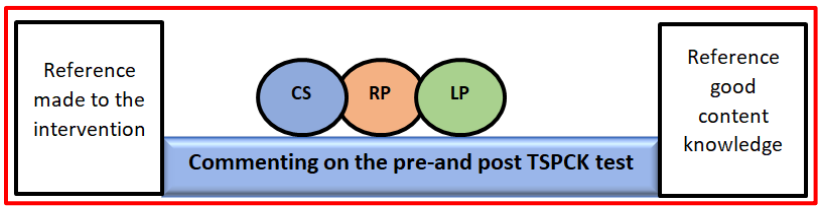
As shown in the Figure 5.4 above, the Ruth's written explanation provided in the pre-test showed her intention to explain the hydroxyl group bonded to a carbon atom in a saturated or unsaturated hydrocarbon. Ruth seemed to understand the place of explaining the hydroxyl group, as an important functional group that the learner needed to understand. Such an understanding is an

element of TSPCK component curricular saliency (**CS**), describing 'functional group' as a key concept. However, Ruth's explanation in the pre-test seemed to be limited to only thinking about a key concept without touching other important aspects that could appropriately address the learner's misconception. The explanation was inadequate due to its in-explicitness in specifically highlighting and addressing the learner's misconception.

In the post-test as shown in the Figure 5.4 above, Ruth indicated her intention to begin by naming with learners all the specific functional groups that have oxygen atom. The IUPAC naming of organic compounds is one of the Big Ideas in organic chemistry explicitly discussed during the intervention (see Chapter 4, section 4.3.3) and such an understanding is an element of TSPCK component curricular saliency '**CS**'. She further stated the reason as follows *"…..because from the given problem, the learner cannot distinguish alcohols from other compounds containing oxygen and hydrogen (e.g. NaOH) but which are not alcohols…*" This statement reflects Ruth's knowledge of the exact learner's misconception emerging from the thought that, all compounds containing oxygen and hydrogen could be considered an alcohol. This understanding is an element of learner prior knowledge (**LP**). Following this was her plan to work with the learners in "*distinguishing the key characteristic of each functional group*" and by drawing "…*structural formula of these functional groups using different homologous series*" This statement further speaks to the Ruth's knowledge of CS and also her understanding of the use of a symbolic level of representation (**RP**) in supporting her explanation as they were encouraged to do during the intervention (see Chapter 4, section 4.3.5). She concluded by stating the expectation that, following her explanations, the learners would be able to correctly identify alcohols from the list of compounds provided. This expectation suggests Ruth's ability to begin to think like a teacher who has the learners' conceptual understanding at heart. Her explanations in the pre-TSPCK test compared to the post-TSPCK test described her developed thoughts about addressing learner's misconception progressing from **CS** in the pre-test to **CS/LP/RP** in the post-test.

Ruth's responses during the stimulated recall interview seemed to reveal the reasoning behind the difference in her written explanations provided in the post-test compared to the pre-test. The extract of her interview responses is provided as follows.

Ruth: I could say I have now understood better how these things of TSPCK work yeah …… my initial thought was it's fine to just point out to the learners that the hydroxyl group should be attached to a carbon atom and end it there, but having learned about TSPCK, by the time I wrote the second test, I understood how such an explanation would make learners understand important aspects like IUPAC naming of compounds especially those that are similar to alcohols and then teaching them about functional groups (**CS**) by drawing structures for them to see what elements **(RP)** are in there…….I also realized it would be necessary for learners to understand how an organic compound differs from an inorganic compound especially those organic compounds that have got OH…….. Learners think the OH in inorganic compounds is the same as the hydroxyl group in organic compound (**LP**) thereby confusing the two. So, I would say the understanding of what and what constitutes TSPCK really helped me in the post-test than in the pre-test where I wrote based on my personal perception, and I could also say one must have good content knowledge to be able to respond correctly, yeah.



While commenting on her pre-and post-test written responses, Ruth linked the improvement observed in her post-test to what she learnt about knowledge components during the intervention. Her statements further revealed the understanding of what aspects (e.g. IUPAC naming and identifying functional groups) are important to explain to the learners with the use of symbolic representations. This understanding is an element of curricular saliency (**CS**) and symbolic level of representation (**RP**) as given in the extract below. She also referred to learners have the thought that the OH (hydroxide ion) in inorganic compounds was the same as the OH (hydroxyl group) in organic compounds. This suggests her understanding of a learner's misconception, an element of Learner Prior Knowledge (**LP**). She linked the improvement in her conceptual understanding to what constitutes TSPCK as discussed during the intervention (see Chapter 4) and also, to the strength of content knowledge which was observed to have improved as well following the intervention (see Appendix XXV). Her statements during the stimulated recall interview appeared to reveal her understanding of the interactive use of TSPCK components (**CS/RP/LP**) seen from her written work in the post-test in relation to what she learnt during the

intervention. This reflects an improvement in the Ruth's pedagogical transformation competence focusing on organic chemistry.

Samples of written explanations from the CoRe prompts

A similar level of pedagogical transformation competence was observed as Ruth completed a CoRes prompt relating to the formulated Big Idea stated as "*All members of a homologous series have the same functional group*" in her tutorial group with other student-teachers during the intervention. The prompt required the participant PSTs to identify typical learners' misconceptions relating to the Big Idea they have identified. An extract of the identified misconceptions relating to this Big Idea as indicated by PSTs in the Ruth's group is provided in the Figure 5.5 below.

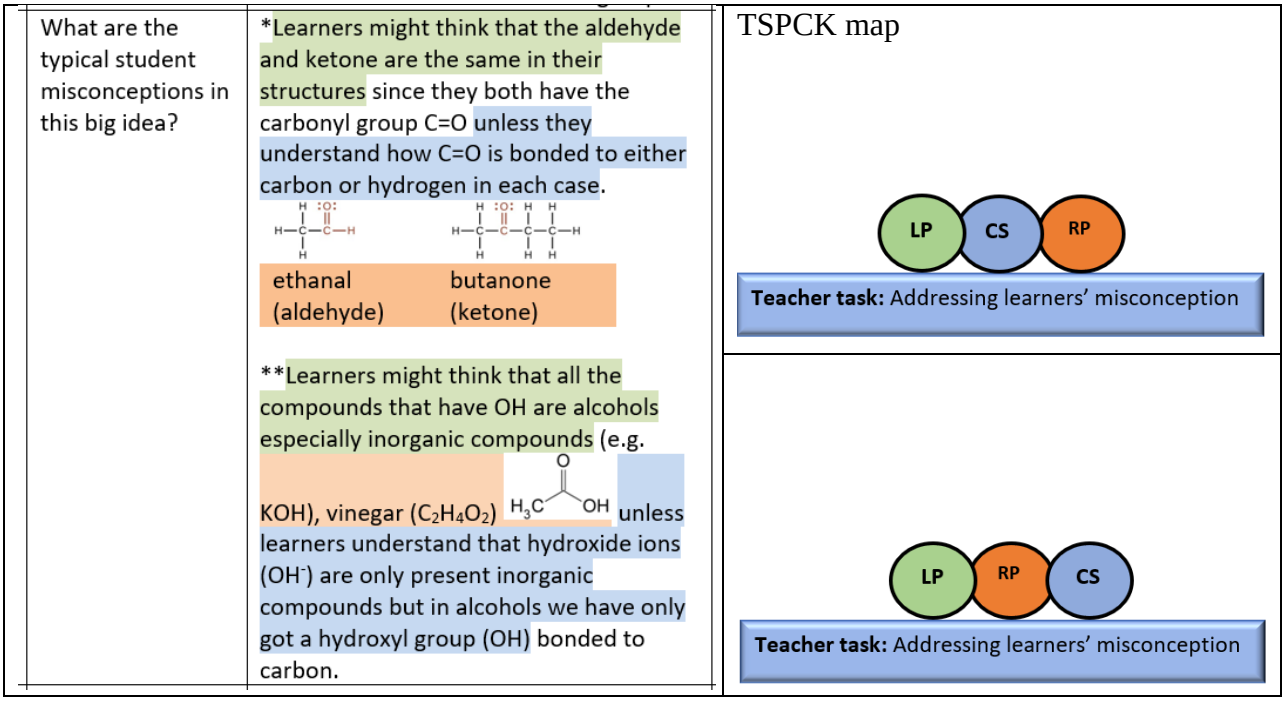


Figure 5.5: Identifying misconceptions relating to the identified Big Idea (Ruth's group)

As shown in the Figure 5.5 above, the group of PSTs identified learners' possible assumption relating to taking aldehyde functional group for ketone functional group since they both have carbonyl group bonded to other atoms. This is an element of Learner Prior Knowledge (**LP**). The next statement that "*unless they (learners) understand how C=O is bonded to either carbon or hydrogen in each case*" describes an important aspect of how carbonyl group is bonded in other to differentiate aldehyde functional group from ketone functional group. This is an element

of curricular saliency (**CS**). The group of PSTs further showed the structural representations of aldehyde and ketone with carbonyl group indicated in each case in support of their explanation. This is a form of symbolic level of representation **(RP)**.

Also, the Ruth's group of PSTs referred to another learners' misconception regarding all compounds that have the symbol OH as alcohols not considering whether the compounds are organic or inorganic compounds (**LP**). This was accompanied with the use of structural and symbolic formula (**RP**) of potassium hydroxide as an inorganic compound and vinegar as an organic compound. An important pointed out for learners to understand was identifying hydroxide ions as only associated with inorganic compounds and hydroxyl groups as found in organic compounds (alcohols). This is an element of curricular saliency (**CS**), the important aspect that must be emphasized in order to enhance the learners' conceptual understanding.

In the cases of the two typical misconceptions described, the Ruth's group of PSTs seemed to have interactively used content-specific knowledge components in identifying and addressing the possible learners' misconceptions. It is important to highlight that, pplanning lessons around learners' common misconceptions relating to the identified Big Ideas may be challenging for PSTs because experience of teaching lies at the center of this aspect of teachers' PCK. Nevertheless, the explicit discussions held during the intervention seemed to have assisted such critical thinking in the participant PSTs.

Specifically, the extract of the explanations provided by Ruth's group in addressing the identified misconceptions are given in the Figure 5.6 below.

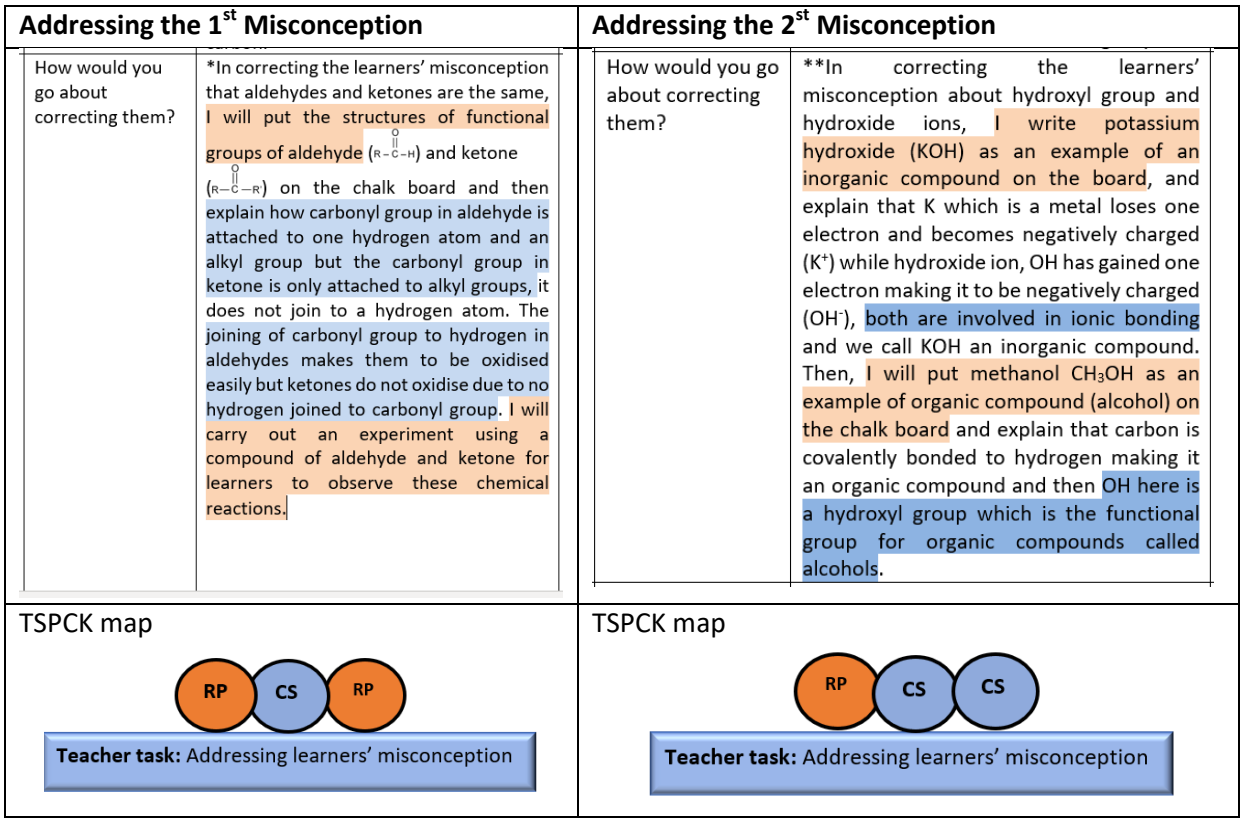


Figure 5.6: Addressing misconceptions relating the identified Big Idea (Ruth's group)

In addressing the learners' misconception relating to aldehydes and ketones, Ruth's group indicated the intention to explain what constitutes the aldehyde functional group and ketone functional using their structures. This describes their knowledge of the use of symbolic representation **(RP)** in explaining individual atoms found in the functional groups. The group further explain carrying out an experiment to describe how the hydrogen attached to carbonyl group makes aldehydes to be easily oxidized thereby describing oxidation reaction which distinguishes aldehydes from ketones. This describes the PSTs' knowledge of using macroscopic representation (**RP**) to teach oxidation (organic reaction) which is important for learners to know, an element of teacher knowledge of curricular saliency **(CS)**. The PSTs' explanation demonstrated their understanding of learners' misconception (LP), curricular saliency (**CS**) and symbolic with macroscopic representations (RP repeated) as shown by the TSPCK map above. In an effort to address the second misconception, Ruth's group indicated the intention to explain the ionic bonding between potassium and hydroxide ion in order to make learners understand that the compound is an inorganic compound involving the gain/loss of electrons. The concept of ionic bonding is considered an important concept in this regard. The

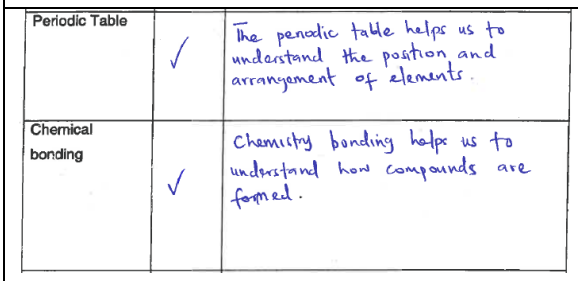
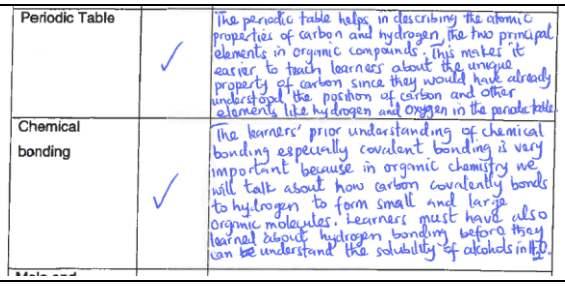
group further explained the plan to use methanol as an example of organic compound in which carbon is covalently bonded to hydrogen and hydroxyl functional group categories the compound as an alcohol. The concept of hydroxyl functional group is considered important in this regarding in classifying the compound as an alcohol.

Thus, a critical examination of Ruth's written responses in the post-TSPCK test and her comments made during the stimulated recall interview seemed to reflect the same quality of written and oral explanations drawing on the understanding of interactive use of multiple TSPCK components as also observed on the CoRe prompts completed by the PSTs in the Ruth's tutorial group.

(ii) Improvement on the TSPCK component Curricular saliency

Samples of written explanations from the TSPCK tool

Under the category of CS, there are five question items focussing on: identifying most pre-concepts important for organic chemistry; identifying three Big Ideas from a list of concepts; sequencing selected Big Ideas with reasons; drawing a concept map of the Big Ideas and subordinate concepts; and stating why learning about organic chemistry is important. The extract of Hope's written responses is presented here in as a typical example of PSTs' improvement from Limited TSPCK in the pre-test to Developing TSPCK in the post-test on the TSPCK component CS. Given a list of 10 concepts in chemistry (see Appendix I), the 1st item asked PSTs to choose 4 most important concepts (pre-concepts) that must have been covered before teaching organic chemistry and provide reasons for their choices. Hope showed good knowledge of pre-concepts in both the pre-test and post-test by choosing atom, periodic table, chemical bonding and intermolecular forces. However, there seems to be a difference in the reasons Hope provided in the pre-test compared to the post-test. The extract of the reasons Hope provided to justify his choices is given in the Figure 5.7 below.

<table>
<tr><th>Pre-TSPCK test</th><th>Post-TSPCK test</th></tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Period Table: The period table helps us to understand the position and arrangement of elements.

Chemical bonding: Chemical bonding helps us to understand how compounds are formed.</td>
<td>Period Table: The periodic table helps in describing the atomic properties of carbon and hydrogen, the two principal elements in organic compounds. <u>(CS)</u>. This makes it easier to teach learners about the unique property of carbon (<u>WD)</u> since they would have already understood the position of carbon and other elements like hydrogen, and oxygen in the periodic table.

Chemical bonding: The learners' prior understanding of chemical bonding especially covalent bonding (<u>LP</u>) is very important because in organic chemistry we will talk about how carbon covalently bonds to hydrogen to form small and large organic molecules. Learners must have also learned about hydrogen bonding before they understand the solubility of alcohols in H_2O. (<u>CS</u>)

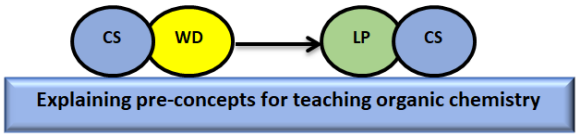

</td>
</tr>
</table>

Figure 5.7: Hope's written responses on pre-concepts for teaching organic chemistry (pre/post-TSPCK test)

As shown in the Figure 5.7 above, in the pre-test, Hope selected 'periodic table' as an immediate concept with the reason broadly linked to the position and arrangement of elements without specifically stating aspects of organic chemistry. However, while writing on the same 'periodic table' in the post-test as an immediate concept, She specifically indicated "…*atomic properties*' *of carbon and hydrogen, the two principal elements in organic compounds*…." as knowledge about the periodic table which learners should have in place before introducing them to organic chemistry. This is an element of curricular saliency (**CS**), teacher knowledge of important aspects. She further stated that, the understanding of atomic properties of carbon and hydrogen would make it "*easier to teach learners about the unique property of carbon*….." This statement reflects Hope's knowledge of what might be easier or difficult to teach, an element of the TSPCK component "what is difficult" (**WD**).

Likewise, while writing on the selected chemical bonding in the pre-test, Hope referred to the knowledge of formation of compounds to justify 'chemical bonding' as an immediate concept for organic chemistry. This shows a good understanding of the general concept in chemistry. However, she appeared to have provided a deeper explanation with better insight in the post-test. She seemed to be more specific by referring to the "*learners' prior understanding of chemical bonding especially covalent bonding is very important….*" While learners are required to have the knowledge of chemical bonding in place before learning about organic chemistry, highlighting 'covalent bonding' gives a sense of a carbon atom covalently bonded to another carbon atoms and atoms of hydrogen mostly importantly, and then, atoms of other elements. This is one important aspect of organic chemistry when dealing with the unique nature of carbon, an element of TSPCK component curricular saliency **CS**. This statement also reveals the understanding of possible learner prior knowledge (**LP**). Making a link conceptually between concepts could also be observed in her statement "*Learners must have also learned about hydrogen bonding before they understand the solubility of alcohols in H_2O"* Overall, Hope seemed to have demonstrated the understanding of interactive use of TSPCK components CS, WD and LP in justifying why periodic table and chemical bonding were considered pre-concepts for teaching organic chemistry.

Furthermore, from a given list of organic chemistry concepts, the 2nd item on the TSPCK component CS required the PSTs to select what they would consider 3 Big Ideas. The extract of Hope's selection in the pre-and post-TSPCK test is provided in the Figure 5.8 below.

Pre-TSPCK test

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.	✓

Post-TSPCK test

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.	

Figure 5.8: Hope's selection of Big Ideas (pre/post-TSPCK test)

In the pre-test, Hope's selection of Big Ideas included: carbon has a unique nature; alkanes have unique properties; empirical formulae tell us how many atoms of each kind are present in compounds. The only Big Idea among the concepts she selected was "*carbon has a unique nature*". This is a central concept under which learners learn about the atomic properties of carbon, why carbon becomes the building block in organic chemistry. Such an understanding is important to prepare learners for why carbon forms both small and large organic molecules, the catenation property. The remaining two concepts of properties of alkanes and empirical formula that Hope selected in the pre-test are subordinate concepts. However, in the post-test, Hope seemed to have improved in her understanding of what Big Ideas are as she selected: carbon has a unique nature; there are several major types of reactions for organic materials; functional groups in organic chemistry tell us about the different types of compounds. The Big concepts in these statements are: catenation property of carbon, organic reactions and functional groups.

The 3rd item on CS asked the PSTs to sequence with reasons, their chosen 3 Big Ideas. The extract of Hope's written responses in the pre-and post-test is provided in the Figure 5.9 below.

<table>
<tr><th>Pre-TSPCK test</th><th>Post-TSPCK test</th></tr>
<tr>
<td>
3. Using the three selected concepts from 2 above, give the sequence you would teach them and your reasons for doing so
<table>
<tr><th>Concepts</th><th>Reasons</th></tr>
<tr><td>Carbon has a unique nature</td><td>Carbon forms bonds with other elements.</td></tr>
<tr><td>Alkanes have unique properties.</td><td>Alkanes are the first group of hydrocarbons.</td></tr>
<tr><td>Empirical formulae tell us how many atoms of each kind are present in compounds</td><td>They are used for representing organic molecules.</td></tr>
</table>
</td>
<td>
3. Using the three selected concepts from 2 above, give the sequence you would teach them and your reasons for doing so
<table>
<tr><th>Concepts</th><th>Reasons</th></tr>
<tr><td>Carbon has a unique nature.</td><td>Carbon is the building block of organic chemistry. As a result, the understanding of carbon nature is the basic knowledge in organic chemistry.</td></tr>
<tr><td>Functional groups in organic chemistry tell us about the different types of carbons</td><td>Learners need to know about functional groups because they are used to classify organic compounds into various homologous series and they are also useful in IUPAC naming of compounds.</td></tr>
<tr><td>There are several major types of reactions for organic materials</td><td>After describing functional groups of each homologous series, then it would be good to discuss reactions that each homologous series undergoes because they are related to functional groups.</td></tr>
</table>
</td>
</tr>
<tr>
<td>Carbon has a unique nature: Carbon forms bonds with other elements.

Alkanes have unique properties: Alkanes are the first group of hydrocarbons.

Empirical formulae tell us how many atoms of each kind are presen in compounds: They are used for representing organic molecules.</td>
<td>Carbon has a unique nature: Carbon is the building block of organic chemistry. As a result, the understanding of carbon nature is the basic knowledge in organic chemistry.

Functional groups in organic chemistry tell us about the different types of compounds: Learners need to know about functional groups because they are used to classify organic compounds into various homologous series and they are also useful in IUPAC naming of compounds.

There are several major types of reactions for organic materials: After describing functional groups of each homologous series, then it would be good to discuss reactions that each homologous series undergoes because they are related to functional groups.</td>
</tr>
</table>

Figure 5.9: Hope's sequencing of identified Big Ideas (pre/post-TSPCK test)

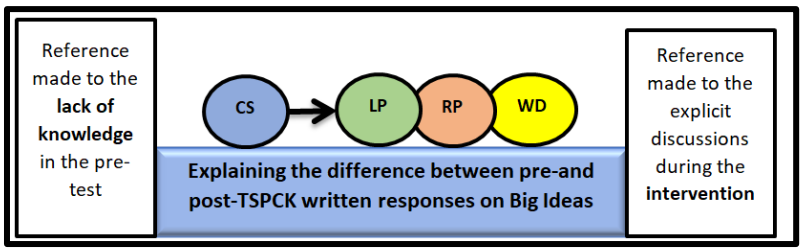
In the pre-test, Hope placed the carbon's nature as the first concept on which the knowledge of alkanes' properties should build. These concepts are conceptually arranged because carbon's nature exposes learners to the carbon's ability to bond with other elements and in alkanes, learners specific learn about organic compounds in which only single carbon-carbon covalent bond exists between carbon atoms and atoms of hydrogen. However, teaching 'empirical formula' after 'alkanes' does not follow a good conceptual order because learners' understanding of empirical formula should have been a prior knowledge for the number of atoms in the molecules of alkanes.

Hope's responses in the post-test revealed an improved understanding. She put carbon's nature as the first concept on which knowledge of functional groups should build and then the knowledge of organic reactions. This is a conceptual arrangement of concepts reflecting an improvement in her understanding of curricular saliency (**CS**). Also, her reasons for this

conceptual arrangement of concepts revealed her knowledge of specific important aspects that are affected by the concepts in question. She referred to carbon unique nature as the basic knowledge that learners must first be taught in organic chemistry. She related functional groups to the classification of organic compounds into individual homologous series and used for IUPAC naming. She also associated several reactions of organic compounds with the functional groups which learners must have previously learned. Following the intervention, Hope seemed to have improved by establishing a conceptual link among concepts.

During the post-intervention interview conducted with Hope, she explained the reasoning behind the difference observed in her pre-test written work and post-test written on Big Ideas. The extract of her explanations is provided as follows.

> **Hope**:…. yes, there's a difference between my answers in pre-test compared to the post-test…well, I would say it was very hard to identify Big Ideas among many other important concepts, I couldn't just figure out what exactly they are so I really struggled in the first test, my answer was based on my personal views about what general concepts are commonly taught in organic chemistry, I only started thinking about Big Ideas as key concepts in a statement form that should be first identified and then emphasized to the learners when dealing with a topic, you know we did that during our method course**…(CS)….**I now see the importance of making connections among concepts, linking them to what learners have previously learned in order to iron out any misconceptions that learners might be having **(LP)** and also representing them in a visual way **(RP)**, that assists in overcoming any difficulty associated with abstract nature of these concepts **(WD)** neh, so I would say I have now improved in my thinking about teaching strategies for this topic due to various discussions we had during our lectures…….



As shown in the extract of Hope's comments above, she linked the weakness of her written responses in the pre-test to the lack of knowledge about what Big Ideas are. She indicated that, following the lectures (explicit intervention), she developed the ability to think about "*Big Ideas as key concepts in a statement form that should be first identified and then emphasized to the learners when dealing with a topic*" This statement revealed the positive impact of the

intervention on improving Hope's ability to identify key concepts and think about emphasizing such whenever she has the opportunity to teach. This is an element of teacher knowledge of the TSPCK component curricular saliency (**CS**). Also, she highlighted making connections among concepts with the purpose of identifying any learners' misconceptions relating to the concept. This is an element of TSPCK component learner prior knowledge **(LP)**. She equally talked about visual representation of concepts in addressing possible areas of difficulty. The statement reflects her knowledge of TSPCK component 'representation' **(RP)** at a macroscopic level and also, 'what is potentially difficult for learners to understand' **(WD)**. She linked this ability to conceptually about teaching a specific topic to the explicit discussions held during the intervention.

Her improved understanding of the connection between Big Ideas and subordinate concepts seemed to manifest as she responded on the 4th item which asked them to draw a concept map based on the concepts they selected. The extract of concept maps in the pre-and post-TSPCK tests are given in the Figure 5.10 below.

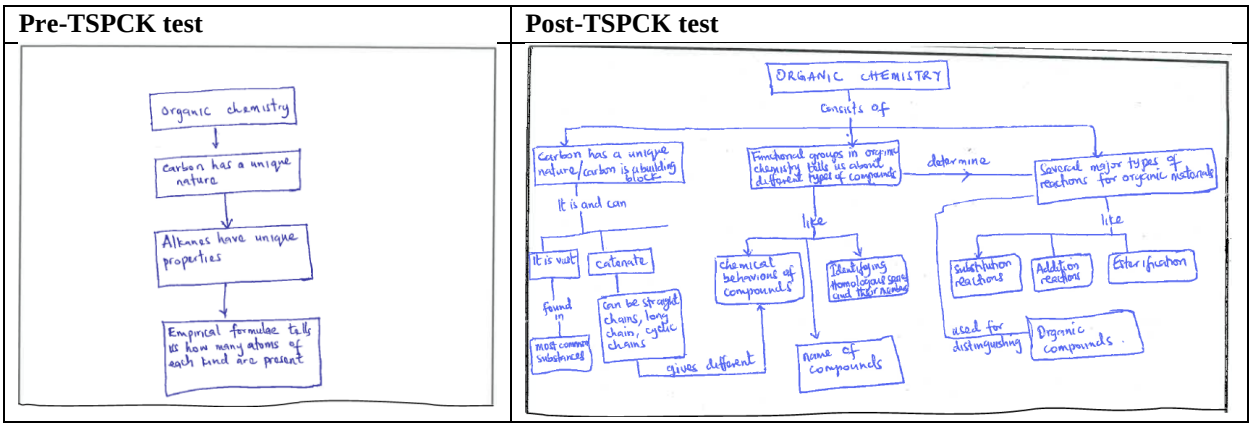


Figure 5.10: Hope's concept map on the selected Big Ideas (pre/post-TSPCK test)

As shown in the Figure 5.10 above, in the pre-test, Hope showed how her identified Big Ideas (a mixed of key concept and subordinate concepts) were related. Since there were linking words, the chart could only reveal how one concept leads to the other.

However, in the post-test as shown in the Figure 5.10 above, Hope clearly indicated her identified three Big concepts (carbon nature, functional groups and organic reactions) with their subordinate concepts (e.g. chemical reactivity of carbon, homologous series, substitution reaction). What seemed to have made Hope's written concept map better in the post-test than in

the pre-test was that, she now understood what Big Ideas were, their subordinate concepts and making connections among them using linking words.

The 5th item on the TSPCK component, curricular saliency asked the PSTs to explain why it is important to learn about organic chemistry in terms of the conceptual progression, application to the outside world and motivation or interest. The extract of Hope's written work in the pre-and post-TSPCK tests is provided in the Figure 5.11 below.

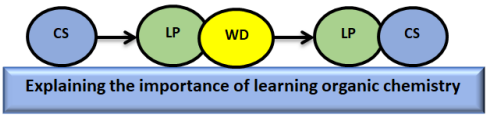
Pre-TSPCK test	Post-TSPCK test
5. Why is it important for students to learn about organic chemistry? Identify reasons related to: i. Conceptual progression i.e. development of concepts Organic chemistry consists of different concepts. Organic chemistry consists of different concepts	5. Why is it important for students to learn about organic chemistry? Identify reasons related to: i. Conceptual progression i.e. development of concepts Scientific concepts are connected and do not exist in isolation with each other. Organic chemistry explores other concepts such as chemical reactions, atomic properties of elements, intermolecular forces, chemical bonding. As a result, the development and understanding of organic chemistry is deepened with the use of other concepts in relation to it and by learning about organic chemistry, learners get to understand other concepts like covalent bonding and chemical reactions better. Scientific concepts are connected and do not exist in isolation with each other. Organic chemistry explores other concepts such as chemical reactions, atomic properties of elements, intermolecular forces, chemical bonding. As a result, the development and understanding of organic chemistry is deepened with the use of other concepts in relation to it and by learning about organic chemistry, learners get to understand other concepts like covalent bonding and chemical reactions better.
ii. Application to outside world There are so many things that learners are exposed to made up of organic compounds. There are so many things that learners are exposed to made up of organic compounds.	ii. Application to outside world Organic chemistry is vast and is almost everything that students are familiarisal with. It exists in food, medicine, plastics. As a result, learners get to note that organic chemistry is relevant to their everyday world and thus a deep understanding of the concept of organic chemistry is deeped since the teacher is able to move from abstract explanations to concrete explanations using organic chemistry substances found in everyday life. Organic chemistry is vast and is almost everything that students are familiarised with. It exists in food, medicine, plastics. As a result, learners get to note that organic chemistry is relevant to their everyday world and thus a deep understanding of the concept of organic chemistry is deeped since the teacher is able to move from abstract explanations to concrete explanations (**WD**) using organc chemistry substances found in everuday life.
iii. Motivation or Interest Organic chemistry is very interesting. Organic chemistry is very interesting.	iii. Motivation or Interest Since learners are made aware that organic chemistry is part of their lives through giving examples such as plastics being polymers and nail polish being a ketone and some foods being esters. Learners are motivated to learn more about organic chemistry and industrial chemistry beyond high school level and they develop interest in understanding how those substances are made and also learners gain an interest of the concepts since examples given resolutes with their lives. Since learners are made aware that organic chemistry is part of their lives through giving examples such as plastics being polymers and nail polish (**LP**) being a ketone and some foods being esters. Learners are motivated to learn more about organic chemistry and industrial chemistry beyond high school level and **(CS)** they develop interest in understanding how these substances are made and also learners gain an interest of the concepts since examples given resolutes with their lives. 

Figure 5.11: Hope's explanations on the importance of teaching organic chemistry (pre/post-TSPCK test)

While writing on the conceptual progression as an aspect of the importance of teaching organic chemistry, Hope's explanation in the pre-test, as shown in the Figure 5.10 above, was limited to considering organic chemistry as consisting of different concepts without stating the specific concepts. However, in the post-test, she explicitly indicated how organic chemistry builds on and connects to other concepts in general chemistry giving specific examples (e.g. chemical reactions, intermolecular forces). What seemed to make Hope's explanation better in the post-test than in the pre-test was the understanding of specific concepts and their connection to the knowledge of organic chemistry. This is an improvement on her teacher knowledge of curricular saliency **(CS)**.

While writing about the application of organic chemistry to outside world in the pre-test, Hope indicated that, learners are exposed to so many things in organic chemistry without explicitly stating what precisely she was referring to. However, in the post-test, she talked about the presence of organic compounds in some of the substances that learners are familiar with. This statement reflects her understanding of an aspect of learner prior knowledge (**LP**) that should be connected to the teaching and learning of organic chemistry. She also pointed out the place of teachers drawing on such learner prior knowledge to move from abstract to concrete explanations. This statement reflects her understanding of a possible difficulty (**WD**) associated with learning organic chemistry at an abstract level without connecting to the concrete aspects to enhancing learning.

While writing on the motivation aspect of the importance of learning about organic chemistry in the pre-test as shown in the Figure 5.11 above, Hope's explanation broadly referred to organic chemistry as interesting. However, in the post-test, she seemed to demonstrate the understanding of learner prior knowledge as she referred to dwelling on aspects of organic chemistry which learners are well familiar with on daily basis (**LP**). She also indicated learners developing interest in high study of organic and industrial chemistry. This describes the knowledge of possible post-concepts, an element of curricular saliency (**CS**). Thus, following the intervention, the overall improvement observed in the Hope's post-TSPCK test written responses could be seen to have a clear link to her understanding of interactive use of TSPCK components in formulating explanations to teacher tasks.

Samples of written explanations from the CoRe prompts

Likewise, there are CoRe prompts targeting the PSTs' knowledge of curricular saliency. The first CoRe prompt required the PSTs to identify a Big Idea on the topic of organic chemistry and then state what they would like learners to know about the idea. The extract of the written responses provided by Hope's group is given in the Figure 5.12 below.

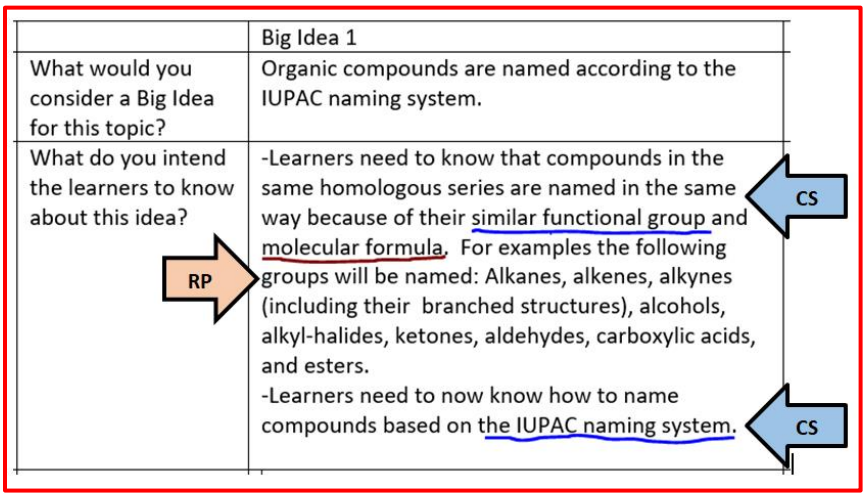


Figure 5.12: Identification of a Big idea (Hope's group)

As shown in the Figure 5.12 above, Hope's group identified the IUPAC naming of organic compounds as the Big Idea on which they completed the CoRe prompts. While responding to what they would intend learners to know about the Big Idea, they stated the similar functional group and molecular formula among organic compounds in the same homologous series as the reason for learners to understand why such compounds are named in the same way. The reference made to the 'functional group' reflects the PSTs' knowledge of a Big Idea, an element of curricular saliency (**CS**). The thought of relating IUPAC nomenclature to the molecular formula also signals the PSTs' understanding of a symbolic form of representations (**RP**). Then, the Hope's group moved on to stating the importance of teaching learners about the Big Idea. The extract of their written response is provided in the Figure 5.13 below.

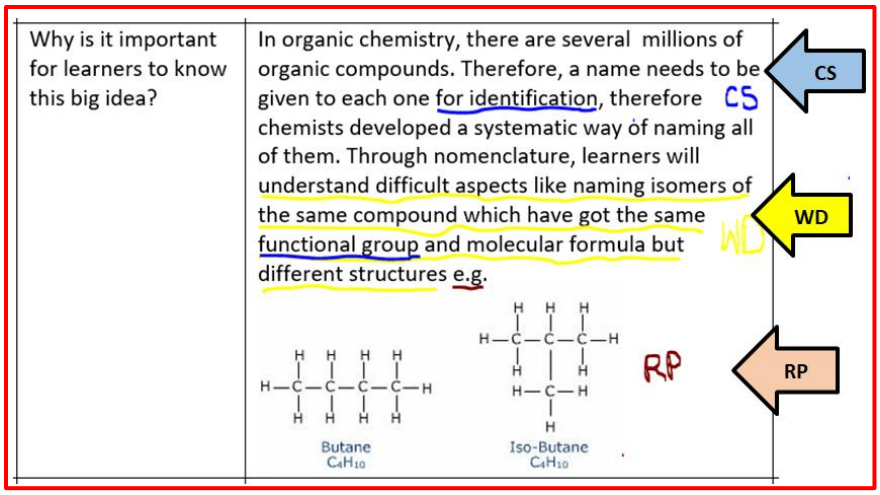


Figure 5.13: Explaining the important of teaching a big idea (Hope's group)

As shown in the Figure 5.13, Hope's group stated identification purposes as one of the reasons for teaching learners about the IUPAC nomenclature of organic compounds. The PSTs in this group also demonstrated the knowledge of possible aspects of learning difficulty (**WD**) associated with the Big Idea by referring to the naming of isomers which have the same functional group and molecular formula but different structures. They supported their explanations with the structures of butane and its isomer. The group further demonstrated the knowledge of the use of symbolic representations (**RP**) as they practically gave the structures of butane and isobutane to support the explanation provided.

Furthermore, Hope's group responded on the concepts that must be taught before teaching IUPAC nomenclature of organic compounds. The extract of their explanations is provided as shown in the Figure 5.14 below.

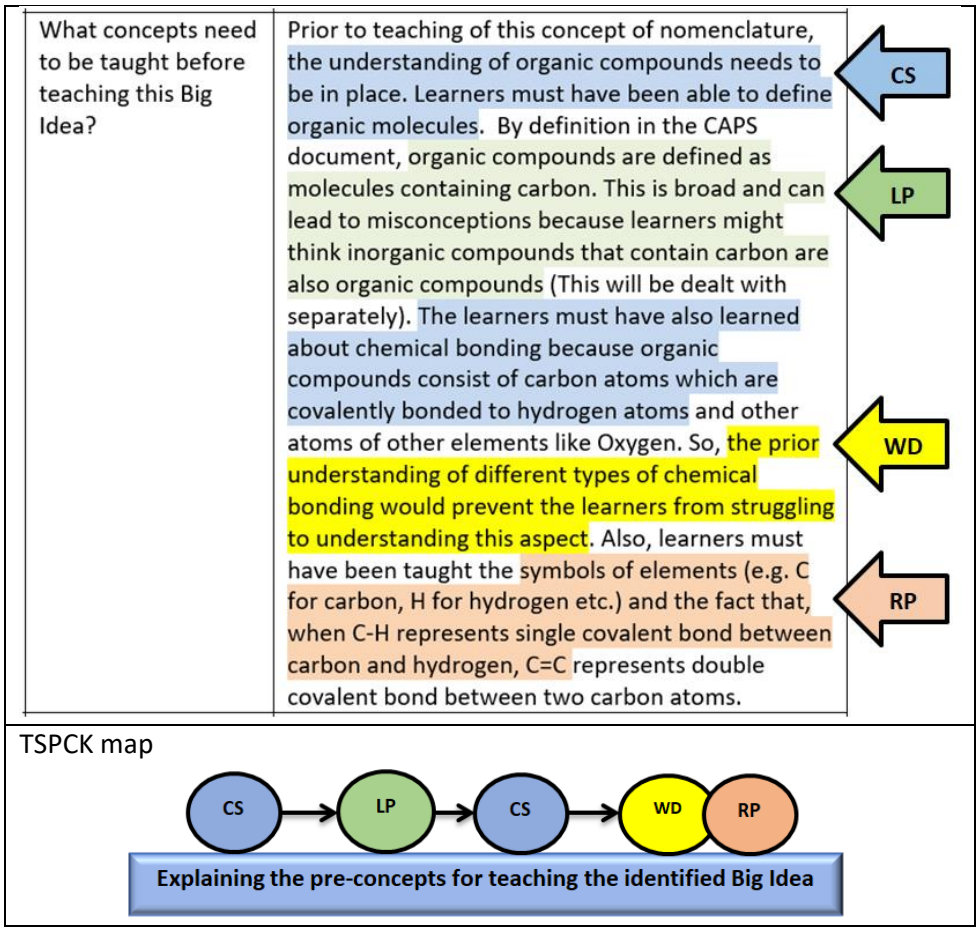


Figure 5.14: Explaining pre-concepts relating to the identified Big Idea (Hope's group)

As shown in the Figure 5.14 above, Hope's group of PSTs started by indicating that, learners must have understood what organic compounds are before introducing them to IUPAC nomenclature. This reflects the PSTs' knowledge an immediate pre-concept necessary for teaching the current topic (concept) and this is an element of curricular saliency **(CS)**. The group of PSTs further demonstrated an understanding of a possible learners' misconception **(LP)** in their statement "*By definition in the CAPS documents, organic compounds are defined as molecules containing carbon. This is broad and can lead to misconceptions because learners might think inorganic compounds that contain carbon are also organic compounds*" Following this statement was the reference made to the concept of chemical bonding as an immediate concept which learners must have in place before teaching them IUAPC nomenclature of organic compounds. They indicated that, the prior understanding of "*different types of chemical bonding would prevent the learners from struggling to understand….*" This statement appeared to describe the PSTs' knowledge of possible area of difficulty and what might be responsible for

such difficult. This is an element of the TSPCK component 'what is difficult to teach or understand' **(WD)**. The group concluded by showing the place of using symbolic representations **(RP)** in teaching the identified Big Idea.

Thus, a critical examination of Hope's written responses in the post-TSPCK test and her comments made during the stimulated recall interview seemed to reflect the same quality of written and oral explanations drawing on the understanding of interactive use of multiple TSPCK components as also observed on the CoRe prompts completed by the PSTs in the Hope's tutorial group.

(iii) Improvement on the TSPCK component Representations (RP)

Samples of written explanations from the TSPCK tool (Rose)

On the PSTs' knowledge of representations, provided below are the extracts of Rose's written explanations which showed an improvement from limited TSPCK in the pre-test to developing TSPCK in the post-test. Given the list of 5 different ways of representing an organic molecule (pentane) in teaching, the first item asked the PSTs to choose the representation (s) they would find most useful for teaching among other representations (see Appendix I) . The extract of Rose's written responses is given as shown in the Figure 5.15 below.

Pre-test	Post-test
1. There are many ways of representing a molecule with molecular formulae C_5H_{12}, (pentane). Representations for C_5H_{12} are shown in 'b' below. a) Which representations do you find the most useful? 1, 3	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? 1, 2, 5

Figure 5.15: Rose's choices of most useful forms of representations (pre/post-TSPCK test)

As shown in the Figure 5.15 above, Rose's choice of representation 1 and 3 considered only the symbolic level of representing organic molecules. However, her choice of representation 1, 2 and 5 in the post-test considered the symbolic, sub-microscopic and combination of macroscopic with sub-microscopic levels of representations respectively. This showed an improvement in the use of multiple representations while thinking about teaching a given concept as the PSTs were encouraged during the intervention (see Chapter 4, section 4.3.5).

The second question item on the TSPCK component 'representation' asked the PSTs to describe the use of the listed forms of representations. The extract of Rose's written responses in the pre- and post-test is given in the Figure 5.16 below.

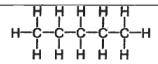
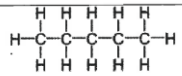
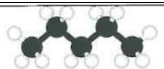
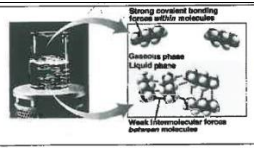
<table>
<tr><th>Pre-test</th><th>Post-test</th></tr>
<tr><td>b) Complete the table and describe when you would use each of these representations in your teaching.
Representation | Use in teaching
1  | For showing learners the number of carbon atoms bonded to hydrogen atoms.
For showing learners the number of carbon atoms bonded to hydrogen atoms.</td><td>b) Complete the table and describe why you would use each of these representations in your teaching.
Representation | Use in teaching
1  | When explaining saturated hydrocarbons to show the structure of single covalent bonds between carbon and hydrogen atoms and also for explaining reactions (like substitution reaction) and isomerism of saturated hydrocarbons
When explaining saturated hydrocarbons to show the structure of single covalent bonds between carbon and hydrogen atoms <u>(RP)</u> and also for explaining reactions (like substitution reaction) and isomerism of saturated hydrocarbons. <u>(CS)</u></td></tr>
<tr><td>3 CH_3-CH_2-CH_2-CH_2-CH_3 | For showing learners the condensed arrangement of carbon and hydrogen.
For showing learners the condensed arrangement of carbon and hydrogen.</td><td>2  | When explaining the arrangement of carbon atoms and hydrogen atoms at a sub-microscopic level difficult to see because it is abstract and also for example the 3-D nature of saturated hydrocarbons
When explaining the arrangement of carbon atoms and hydrogen atoms at a sub-microscopic level difficult to see because it is abstract and also for example the 3-D nature of saturated hydrocarbons.</td></tr>
<tr><td></td><td>5  | When explaining physical properties of organic compounds by starting from the visible state of a substance (like H_2O in a cup) that is easy to recognize and then showing sub-microscopic arrangement of how atoms are bonded with each other and also the strength of intermolecular forces which are difficult to see because they are abstract.
When explaining physical properties of organic compounds by starting from the visible state of a substance (like H_2O in a cup) that is easy to recognize and then showing sub-microscopic arrangement of how atoms are bonded with each other and also the strength of intermolecular forces which are difficult to see because they are abstract. (<u>WD</u>)</td></tr>
</table>

Figure 5.16: Rose's selection of representations with reasons provided (pre/post-TSPCK test)

As shown in the Figure 5.16 above, in the pre-test, Rose stated the use of representation 1 in showing the number of carbon and hydrogen atoms found in a given organic molecule. She also referred to the use of representation 2 in showing the condensed arrangement of carbon and hydrogen in a given organic molecule. The explanations considered using the representations to explain the number and arrangement of atoms in the molecule. While the explanations provided in the pre-test were not so expatiated as they referred to the broad use of the identified representations, the explanations provided in the post-test seemed to be more elaborate and talking to specific aspects of organic chemistry thereby suggesting a clear insight. For example,

while responding in the post-test on the representation 1, Rose referred to the use of the representation in explaining the concepts of organic reactions and isomerism of saturated hydrocarbons which could be considered specific to organic chemistry. Isomerism and organic reactions are important aspects in the study of organic chemistry and thus, the ability to specifically highlight these aspects describe Rose's knowledge of curricular saliency (**CS**) following the intervention. On the representation 2, she mentioned using the representation to explain the arrangement atoms of carbon and hydrogen at a symbolic level considered difficult to see. This suggests her understanding of sub-microscopic level as the level of representation (**RP)** which the diagram depicts, the arrangement of atoms as the specific important aspect that the representation could be used to explain (CS) and the abstract nature which makes such aspect difficult either to teach or understand **(WD)**. On the representation 5, she referred to the use of representation as a way of moving from macroscopic level easy for learners to recognize to sub-microscopic level in explaining arrangement of atoms and strength of intermolecular forces, concepts difficult to see. This further suggests Rose's understanding of two levels of representations (RP), important concepts (CS) with reference made to what is difficult **(WD)**.

The third question item asked the PSTs to describe how they would use the representations selected as the most useful in teaching the difference in the boiling points of butane (-0.5^0C) and pentane (36^0C). The extract of Rose's written explanations in the pre-and post-test is given in the Figure 5.17 below.

Pre-TSPCK test	Post-TSPCK test
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)? I will use rep 1 and 3 to explain how butane and pentane differ in terms of carbon chain length and boiling points. I will use rep 1 and 3 to explain how butane and pentane differ in terms of carbon chain length and boiling points.	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)? I will first refer to the glass of water in rep 5 to remind learners of liquid state, one of the three states of which they should have learned in Grade 10. Then I will make learners understand that at room temperature, butane is a gas and pentane is a liquid. And then, I will use rep 1 to show learners the structures of butane and pentane, with pentane having a longer carbon chain than butane. Thus, the longer carbon chain, the heavier the compound and the stronger the intermolecular forces shown in rep 5 meaning that more energy is required to break bond of pentane as compared to the bonds of butane, as a result, the boiling point of pentane (which is a liquid) is higher than the boiling point of butane (which is a gas). Macroscopic 'RP' LP I will first refer to the glass of water in rep 5 to remind learners of liquid state, one of the three states of matter which they should have learned in Grade 10. Then I will make learners understand that at room temperature, butane is a gas and pentane is a liquid. And then, I will use rep 1 to show learners the structures of butane and pentane, with pentane having a longer carbon chain than butane. Thus, the longer carbon chain, the heavier the compound and the stronger the intermolecular forces shown in rep 5 meaning that more energy is required to break bond of pentane as compared to the bonds of butane as a result, the boiling of petane (which is a lquid) is higher than the boiling point of butane (which is a gas). CS Symbolic 'RP' CS RP LP CS RP CS Explaining Boiling points of organic compounds using representations

Figure 5.17: Rose's explanations on boiling points of butane and pentane using representations

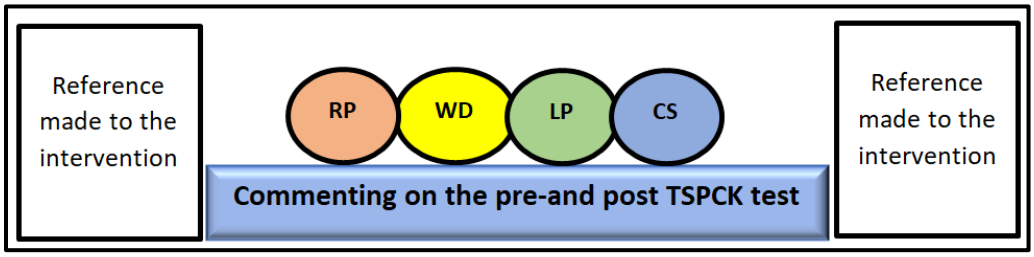
As shown in the Figure 5.17 above, in the pre-test, Rose indicated her intention to use rep 1 and 3 in explaining the difference between butane and pentane focusing on their chain length and boiling points. Both representations focused on the symbolic level of representation and the explanations provided more not so elaborate regarding how these were going to be used.

However, in the post-test, Rose indicated her intention to use of the representation 5, showing the glass of water, to remind learners of the liquid states of matter, the concept she assumed they should have learned in Grade 10. This is an understanding of a macroscopic representation (**RP**) linked to learner prior knowledge (**LP**). She further indicated that she "*will make learners understand that at room temperature, butane is a gas and pentane is a liquid*" This is an element of the TSPCK component curricular saliency (CS) talking to the state of matter, the physical

property of organic compounds. She also referred to the use of a symbolic representation in specifically explaining how atoms of carbon and hydrogen are structured butane and pentane causing one to be having longer chain length than the other. This is an understanding of the use of a symbolic representation (**RP**). Another important aspect pointed out in her explanation was how the higher strength of intermolecular forces present in an organic molecule would require more energy in breaking the bond thereby raising the temperature and then, the boiling point as in the case of pentane. This is more elaborate and it reflects the understanding of a key concept like the relationship between 'boiling point' and 'intermolecular forces', an element of curricular saliency (**CS**).

During the stimulated recall interview, Rose explained the reasoning behind the difference in her pre-test written responses compared to the post-test written responses. The extract of comments is provided as follows:

> **Rose**: I think my understanding about the use of representations improved after the lectures…yeah I now understand the importance of explaining a concept to learners from the concrete aspect to the abstract aspect, like starting from macroscopic representation and then move on to use of structures and symbolic before presenting the sub-microscopic (**RP**) for them to understand most of these abstract concepts which normally appear very difficult to conceptualize, (**WD**) and I also got to realize that, such strategy would help learners to construct meaning by drawing from their daily experiences, those instances they are familiar with, those are related to the content **(LP**) being presented to them, so thinking about representing concepts at the three levels also helps in making connections among the concepts and so, learners get to appreciate the importance of understanding one concept it is related to another concept (**CS)** so I would say this understanding really helped me in the second test unlike in the first test I only thought of the use of structures.



The Rose's response as provided above reveals the positive impact of the explicit intervention on her understanding of the use of representations as revealed in her statement that "…*my understanding about the use of representations improved after the lectures*…" She also indicated moving from one level of representation to another in making learners understand concepts which are potentially difficult because they are abstract. This signals her understanding of

representations **(RP)** and what is potentially difficult for learners to understand (**WD**). She further stated how she got to know that, combining levels of representations makes learners connect to their daily experiences associated with the content being presented to them in the classroom teaching. This is an element of Learner Prior Knowledge (**LP**). She concluded by referring to how the thought of three levels of representations assists in making connections among concepts in order to deepen learners' conceptual understanding. This is an element of curricular saliency (**CS**). She linked the positive change to the pedagogical competence learned during the intervention.

Samples of written explanations from the CoRe prompts

An aspect of CoRe prompts required the PSTs to describe with reasons, the representations they would use in teaching their identified Big Idea. Rose's group stated "*Organic compounds have predictable chemical and physical properties determined by their respective functional groups (and structure)*" as their identified Big Idea. The extract of the written responses provided by this group of PSTs is provided in the Figure 5.18 below.

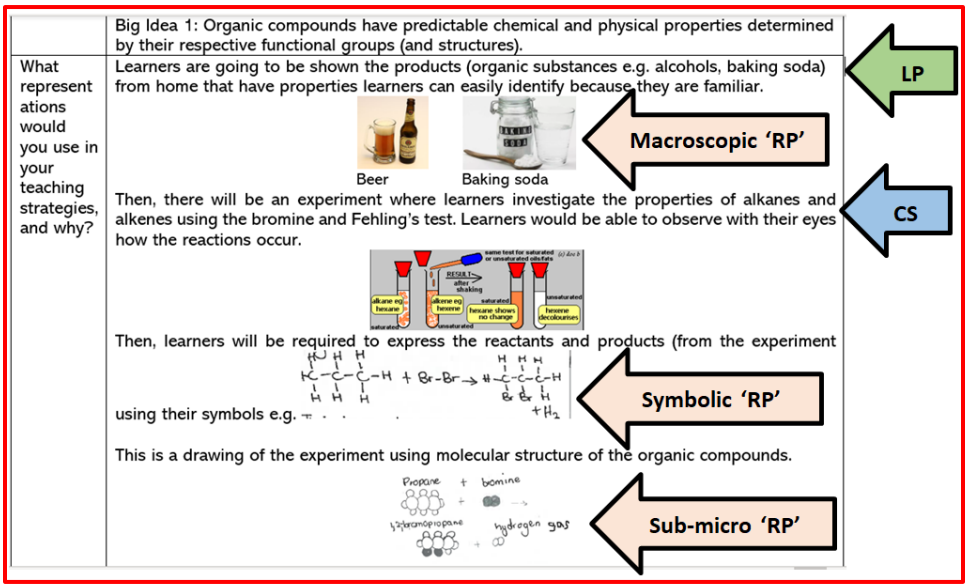


Figure 5.18: Representations for teaching a Big Idea (Rose's group)

As shown in the Figure 5.18 above, Rose's group indicated showing the learners organic substances (like alcohols and baking soda) which are familiar and commonly available in homes and learners' environment. This is an element of a macroscopic level of representations (**RP**) and Learner Prior Knowledge (**LP**). The group further stated engaging learners in a laboratory

experiment where they would be able to observe organic reactions focusing on the properties of alkanes and alkenes. In the teaching and learning of organic chemistry, organic reactions are considered one of the Big Ideas, making the knowledge an element of curricular saliency (**CS**). This further describes the PSTs' knowledge of the use of use of macroscopic representations in teaching a concept considered very important for learners to know. Rose's group also included the use of symbols and sub-microscopic ways of representing the chemical reactions as they occur in the laboratory experiment conducted. While this group of PSTs could be observed to have demonstrated the three levels of representations used in teaching chemistry concepts, they also linked this knowledge to what is important for learners to understand and learner prior knowledge using familiar examples.

5.4 The link between intervention discussions and improvements in the quality of PSTs' TSPCK following the intervention

(i) Learner Prior Knowledge (LP)

The pre-TSPCK test scores on LP as shown in the Table 5.2 and Figure 5.1 revealed that, PSTs had difficulty in either identifying or addressing the learners' misconception relating to what hydroxyl group signifies as required by the test. Consequently, 10 and 7 PSTs demonstrated Limited TSPCK and Basic TSPCK respectively. This was similar to what was experienced with the PSTs prior to the explicit discussions on LP. As alluded to in Chapter 4, section 4.3.2, during the intervention, 9 PSTs had the misconception that alkanes would be more reactive than alkenes because alkanes have carbon-carbon single covalent bonds which get easily attached than a carbon-carbon double covalent bond in alkenes. 4 PSTs were quiet about this while only 2 PSTs had the correct understanding that alkenes are more reactive than alkanes. In an attempt to bridge this gap, the PSTs they were made to understand the misconception and they were provided with the correct knowledge by explaining important concepts involved using a structural representation as shown in Chapter 4, Figure 4.1. However, in the analysis of post-TSPCK test as shown in the Table 5.2 and Figure 5.1 above, 7 PSTs could identify the misconception, provide standardized knowledge and confront the identified misconception by drawing on three or more other TSPCK components thereby demonstrating the *Exemplary category of TSPCK* ('4'). Nine (9) PSTs could identify the misconception, provide the standardized knowledge and re-phrase the explanation by drawing on two other TSPCK components thereby demonstrating *Developing category TSPCK* ('3') such as the case of Ruth

whose written work was provided as a typical example. Ruth's post-TSPCK written explanations on LP revealed her understanding of the interactive use of multiple TSPCK components drawing on the knowledge of important concepts that must be emphasized in teaching, learners' possible misconception relating to such concepts and use of symbolic representations. This pedagogical transformation competence drawing on the interactive use of multiple TSPCK components was equally observed on the CoRe prompts completed by the PSTs in the Ruth's group (see Figure 5.5 and 5.6).

(ii) Curricular saliency (CS)

The pre-TSPCK test scores on CS as shown in the Table 5.2 and Figure 5.1 revealed that, majority of the PSTs (11) had Limited TSPCK ('1') while the remaining 6 PSTs had Basic TSPCK ('2'). Although the PSTs in the two categories of TSPCK had a good understanding of the pre-concepts for organic chemistry, they were unable to identify 3 Big Ideas with subordinate concepts, arrange them in a logical sequence with conceptual reasons for the arrangement and why the knowledge of organic chemistry is important for learners. Hope's written responses provided in the Figure 5.7 to 5.11 above showed a typical example of this limited understanding. As alluded to in Chapter 4, section 4.3.3 (ii), during the intervention session on CS, the PSTs showed a good understanding of what pre-concepts are but they wrongly referred to subordinate concepts like hydrocarbons, alkanes, and alcohols as Big Ideas. As a result, the discussions provided made them to understand that, Big Ideas comprise of phrases or clauses which describe key concepts (e.g. organic reactions, functional groups in organic chemistry) in a topic necessary for developing learners' understanding of the topic. The importance of showing the link between Big Ideas and subordinate concepts were also discussed with the PSTs. Following that, the analysis of PSTs' post-TSPCK test (see Table 5.2 and Figure 5.1) revealed that, 10 PSTs had Developing TSPCK ('3') while the remaining 7 PSTs had Exemplary TSPCK ('4'). These two levels of TSPCK reflect good understanding of Big Ideas, subordinate concepts, logical sequence and explanations drawing on two or more other TSPCK components. A typical example was the extract of Hope's written responses shown in the Figure 5.7 to 5.11 where in addition to the knowledge of CS, she also engaged the understanding of LP, WD and RP. Similar to the PSTs' written responses in the post-TSPCK test, the PSTs in the Hope's tutorial group gave written responses that equally demonstrated understanding of the interactive use multiple TSPCK components in their completed CoRe prompted (see Figure 5.12, 5.13 and 5.14). These included

the knowledge of important concepts that must be emphasized in teaching, learners' possible misconceptions, areas of learning difficulty relating to the concept and use of representations

(iii) Representations

The pre-TSPCK test scores on RP as shown in the Table 5.2 and Figure 5.1 revealed that, eleven (11) PSTs demonstrated Limited TSPCK and the rest six (6) PSTs had Basic TSPCK as seen from their written responses. For example, in the test as presented in the Figure 5.16, Rose only thought of symbolic representations as the strategy for teaching in her written explanations. Likewise, during the intervention session on RP (see Chapter 4, Figure 4.3), the PSTs expressed difficulty in representing chemistry concepts at the sub-microscopic level. Consequently, the explanations for clarifications with examples were provided to address the PSTs' difficulty on representing concepts at sub-microscopic levels. Following that, the PSTs showed a good understanding of the how to represent the substitution reaction of methane with bromine. There were also discussions on the examples and importance of combining the three levels of representations in teaching. Furthermore, the post-TSPCK scores on RP as shown in the Table 5.2 and Figure 5.1 revealed that, eleven (11) PSTs demonstrated Exemplary TSPCK while the remaining six (6) PSTs demonstrated Developing TSPCK. This shows the PSTs' improved understanding of combining two or three levels of representations with other TSPCK components in explaining organic chemistry concepts. A typical example was the extract of Rose's written work provided in the Figure 5.16 above where she showed the understanding of three levels of representations interactively used with Learner Prior Knowledge (LP) and Curricular saliency (CS). This pedagogical transformation competence was also observed as the PSTs in Rose's group completed CoRe prompt (see Figure 5.18) where they described the organic chemistry concepts that they would use each level of representation to explain.

5.5 Summary

The analysis of data presented in this chapter revealed two important key findings. First, the PSTs' understanding on each content-specific knowledge component improved significantly from a lower category (Limited TSPCK) to a higher category (Developing TSPCK) following the intervention. Second, the analysis suggests a successful application of the pedagogical transformation competence learnt by the PSTs during the intervention in providing explanations

of the same quality in the completed post-TSPCK tool and complementary Content representations (CoRe) tool. The quality of planned TSPCK demonstrated by the PSTs following the intervention seemed to have been principally informed by the understanding of the interactive use of multiple TSPCK components in formulating written responses to teacher tasks. This understanding drew on the knowledge important aspects of organic chemistry that must be emphasised in teaching, learners' possible misconceptions, what is potentially difficult to teach or understand and the use of representations. These findings are consistent with the reports from previous studies (e.g. Mavhunga & Rollnick, 2013; Mavhunga, 2016) on the PSTs' planned TSPCK following an explicit discussion that focused on collective TSPCK in the specific core physical science core topics. As earlier indicated, these findings work towards creating a credible baseline from which the TSPCK-learner outcomes link in organic chemistry could be carefully interpreted with the same participant PSTs. The next chapter presents the analysis of the PSTs' classroom teaching in organic chemistry by focusing on the quality of enacted TSPCK (eTSPCK) demonstrated.

CHAPTER SIX

6. ANALYSIS OF PRE-SERVICE TEACHERS' ENACTED TSPCK

The analysis in the previous chapter focused on the PSTs' planned TSPCK as seen through their written work on organic chemistry, following an exposure to an intervention based on collective TSPCK. This chapter presents the analysis of PSTs' enacted TSPCK as seen through their actual classroom teaching of organic chemistry concepts. Both the findings from this chapter and the previous chapter work towards building a holistic picture of the PSTs' personal TSPCK acquired from the explicit intervention as seen from both planning and enactment. The link between these versions of TSPCK is important in examining the correlation between PSTs' eTSPCK and learner achievement, the main purpose of this study.

6.1 Introduction - Situating enacted TSPCK as ePCK

The purpose of this chapter is to examine the PSTs' enacted TSPCK (eTSPCK) as the teacher knowledge visible in classroom teaching. It is a continuation of the analysis of TSPCK of a group of PSTs who were exposed to the explicit intervention described in Chapter 4 and subsequently showed a gain in planned TSPCK in organic chemistry as presented in the previous chapter, Chapter 5. As argued in Chapter 2, PCK and in association TSPCK is not conceptualized as only a cognitive construct which exists in the heads of teachers but as a dynamic construct describing complex processes requiring application of knowledge which teachers engaged in the actual classroom teaching (Shulman, 2015). With respect to that, the Refined Consensus Model (RCM) encompasses the conceptualization that PCK across its grain sizes such as TSPCK, includes what a teacher knows, what a teacher does and the pedagogical reasoning guiding a teacher's actions in the actual classroom (Carlson & Daehler, 2019). The model highlights a developmental trajectory of teacher professional knowledge consisting of three distinct realms. It identifies collective PCK (cPCK) as the first realm where in-service and PSTs get to know about a shared professional understanding about PCK (Mavhunga, 2019). Personalizing the individual understanding of cPCK, teachers portray personal PCK (pPCK) which manifests in the planning context and also enacted PCK (ePCK) demonstrated in the context of actual classroom teaching. Thus, cPCK, pPCK and ePCK represent the three distinct realms that must be explored in order to sufficiently describe the nature of teachers' PCK leading

to their development of professional knowledge for teaching (Chan & Hume, 2019). As alluded to in Chapter 4, focusing on the topic of organic chemistry, the participant PSTs learned about the collective TSPCK (cTSPCK) which they individually personalized and manifested as the planned TSPCK measured and portrayed in organic chemistry in the previous chapter, Chapter 5. This chapter presents the examination of the PSTs' personal TSPCK manifested as the enacted TSPCK (eTSPCK) in the classroom teaching of organic chemistry. It is understood in this study that, PCK is complex and tacit in nature thereby making it very difficult to capture and portray (Henze & Van Driel, 2015) particularly in the actual classroom teaching due to the dynamic nature of teaching and learners processes. Thus, attempts were made in this chapter to capture and portray the PSTs' eTSPCK as much as possible by applying approaches similar to those employed in the previous related PCK studies. It is acknowledged in this chapter that, absolute justice might not have been done in portraying the entire complex nature of TSPCK in practice as some other important aspects might have been missed out. Therefore, this chapter is presented in three parts. The first part comprises a recap of the methodological approaches used in this chapter. The second part provides a sample of analysis out of the four cases analyses examined in order to capture and portray the PSTs' eTSPCK in the lessons delivered. This was followed by pictorial representations used in an attempt to present the overview of the results of the analysis. The third part includes the presentation of the key findings from the analysis. This chapter closed with the summary of the analysis and findings. Both the findings from the previous chapter and this chapter are envisaged to expand the existing understanding in the literature about how theory (knowledge) influences practice (actions), in responding to the known theory-practice dissonance. The findings were also hoped to work towards creating a credible base for describing whether there exists or not any relationship between PSTs' TSPCK and learner outcomes, the focus in the next chapter.

6.2 A recap of methodology used in this chapter

This chapter presents the analysis of lessons delivered by a subset of 4 PSTs (Ruth, Hope, Rose and Mark) from the cohort of 17 participant PSTs who delivered two lessons each to a total of 88 physical sciences learners at a township school in South Africa. While Ruth's and Hope's lessons focused on functional groups and IUPAC nomenclature of organic compounds, Rose and Mark delivered lessons on physical properties and structures of organic compounds. The pre-and

post-lesson interviews were conducted with each of the PST and their lessons were video-recorded. The video-recordings were first transcribed verbatim and then, the in-depth qualitative analysis of ePCK (Park & Chen, 2012; Park & Suh, 2019) was employed in identifying TSPCK episodes emerging from the lessons. Using the eTSPCK rubric, the emerging TSPCK episodes from the PSTs' lessons were categorised as in the level of simple, proficient and sophisticated TSPCK. The detailed discussions on the participant PSTs' content knowledge, lessons delivered and their duration, school grade and number of participant learners in each, methods of data collection, analysis and establishing reliability and trustworthiness are all explicitly discussed in Chapter 3 (section 3.3.2, section 3.4.2 and section 3.6.2). The sample analysis of lessons is presented in the next section below.

6.3 Sample analysis for capturing and portraying complexity of TSPCK in the classroom

The analysis of data as explained in Chapter 3 (section 3.6.2) was done independently for each of the 4 PSTs as a standalone mini case study. Due to the difficulty in capturing and portraying the complexity of teachers' ePCK and hence, eTSPCK as alluded to in Chapter 2, a step by step method was followed in the in-depth qualitative analysis of TSPCK episodes in each lesson. As a result of the volume of the analyses done, only the detailed analysis of Ruth's lesson first lesson is presented herein as a sample while the detailed analysis of her lesson 2 together with the Hope's, Rose's and Mark's lessons are attached as Appendix XXVII, Appendix XXVIII, Appendix XXIX and Appendix XXX respectively. Ruth was observed to have displayed high quantity of her TSPCK episodes in the proficient and sophisticated categories. Her TSPCK episodes also seemed to reflect a variety of interactions among the TSPCK components that fall across the spread of the TSPCK rubric. In this section, the analysis of Ruth's teaching is first presented as an overview of her teaching drawing from her lesson plan and responses during the pre-lesson interview. Following this was the presentation of her lesson sequence and identification of TSPCK episodes in the lessons. Then, Ruth's responses during the stimulated recall interview were provided to understand the reasons for her instructional decisions.

Detailed analysis of Ruth's lessons on functional groups and IUPAC nomenclature

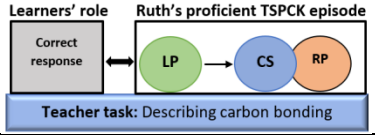
Lesson overview

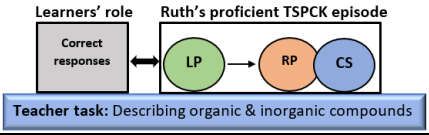
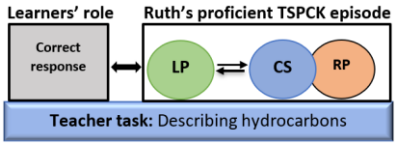
Ruth's lessons focussed on the functional groups and IUPAC nomenclature of organic compounds. Similar to the learning outcomes highlighted in her lesson plan (see Appendix XXXI), she stated during the pre-lesson interview her intention to ensuring "*learners understand what constitutes the functional group for each homologous series"* and "*learners understand the IUPAC rules for naming organic compounds*". She further explained that the learners' ability to identify functional groups would help them in distinguishing between organic molecules based on their homologous series. She added that, learners' understanding of IUPAC rules would help them in correctly naming organic compounds whenever they come across them. The Ruth's intentions could be observed to revolve around teaching learners the required knowledge and significance of learners' ability to apply the acquired knowledge where necessary. While talking about her envisaged learners' misconceptions relating to the concepts, Ruth stated learners' common assumption that all compounds of carbon are organic compounds. She also referred to learners' confusion relating to the symbolic representation of hydroxide ion and hydroxyl group in distinguishing between alcohols and inorganic compounds like sodium hydroxide. In addressing the misconceptions, she indicated the use of questioning in first eliciting learner prior knowledge and structural representations of organic molecules in explaining concepts. The sequence of her lesson presentations and content covered with the identification of TSPCK episodes are described below.

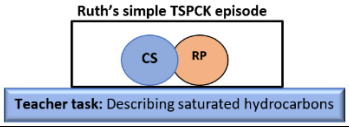
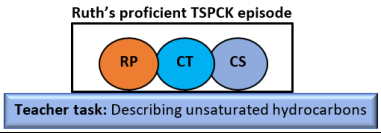
Lesson sequence and the identification of TSPCK episodes

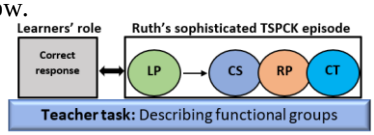
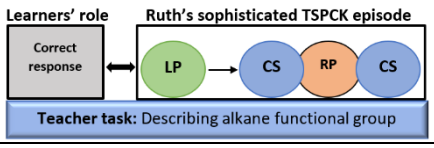
The detailed analysis of Ruth's lessons is presented in the Table 6.1 below. The first column provides extract of the Ruth's interactions with learners in sequence per time in minutes. The second column provides a brief comment on the teaching event and presents the in-depth qualitative analysis highlighting the TSPCK episode visually represented using a TSPCK map.

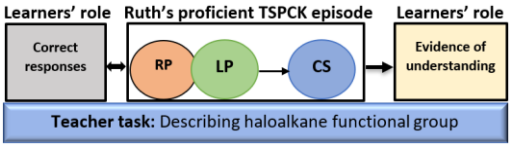
Table 6.1: Analysis of Ruth's lessons on functional groups and IUPAC nomenclature

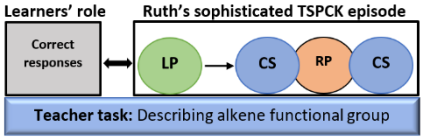
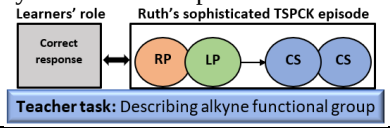
Lesson 1	
Extracts of Ruth's teaching in sequence	Comments/Qualitative in-depth analysis
0-2min: Describing carbon's ability to form bonds **Ruth**: Great! Now, from what you have learnt in organic chemistry, what is it or what is that special character or a property that carbon has that makes us to be able to study carbon compounds? *There was no response from learners* **Ruth**: Ok, they say that carbon has the ability to catenate, what does that mean? SF2: it's the ability of carbon form bonds. **Ruth**: You got it! So, carbon forms bonds just like other elements to attain stability right **(LP)** however, carbon is special in that it forms covalent bonds among its own atoms, atoms of other elements much more than any elements such that we have small and very large organic molecules **(CS)** let's see an example (*she put the chemical formula and structure of chloropropane on the board*), here we can see one carbon bonded to another carbon and to another carbon,**(RP)** at the same time, carbon is bonded to these hydrogen atoms and chlorine atom so as carbon can form small molecules like this, you can all see this right?	**Comment**: The extract here was part of the Ruth's lesson introduction focusing on carbon bonding. **In-depth Qualitative Analysis**: **Ruth's role:** In an attempt to understand learners' existing knowledge, Ruth asked learners about the carbon's unique property. **Learners' role:** Learner SF2 correctly referred to carbon catenation as its ability to form bonds which Ruth then knew it was knowledge that learners have in place (LP). **Ruth's role:** Expatiating on SF2's response, Ruth emphasized carbon forming covalent bonds its own atoms and atoms of other elements to form small and large organic molecules, an aspect important for learners to understand (CS). She also used the structure of chloropropane as well as the chemical formula to make learners understand carbon's bonding to its own atoms and atoms of other elements. This is a use of representation at a symbolic level to promote learner understanding (RP). Ruth's interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 
2-4min: Describing organic and inorganic compounds **Ruth**: So, now we have organic chemistry, one important branch of chemistry where we talk about organic compounds, now refresh your mind Grade 12, what can you say about organic compounds? **SM2**: compounds of carbon **Ruth**: Compounds of carbon, any other opinion? **SM3**: Organic compounds are made up of carbon and hydrogen **Ruth**: Aright, he said organic compounds are compounds of carbon, there's something you must know here, it's not all compounds of carbon that are organic compounds, **(LP)** take for instance CO_2, it's a compound of carbon (*Ruth drew the structure of carbon dioxide as shown below*) **(RP)** here, carbon is covalently bonded to oxygen, electrons are shared among them note that, but since carbon is not covalently bonded to hydrogen, it is not an organic compound, **(CS)** meanwhile the other guy said organic compounds consist of carbon and hydrogen right, very well here is an example (*Ruth drew the structure of methane on the board*) carbon covalently bonded to four hydrogens, so this compound is organic, we can as well have other compounds which are organic but they consist of	**Comment**: The extract here was the continuation of the lesson introduction, focusing on establishing learners' existing knowledge about what organic and inorganic compounds are. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners what they could say about organic compounds by recalling what they previously learnt. **Learners' role:** Through their responses, learner SM2 and SM3 revealed general correct understanding of organic compounds which they are bringing into the discussion (LP). **Ruth's role:** Expatiating on SM2's response, Ruth in her statement cautioned learners about assuming that all compounds of carbon are organic compounds. This is an understanding of a possible misconception (LP). Showing her understanding of the use of a symbolic representation, she supported her explanation using carbon dioxide and its structure as an example (RP). She also expatiated on learner SM3's response by using methane and its structure as an example of carbon covalently bonded

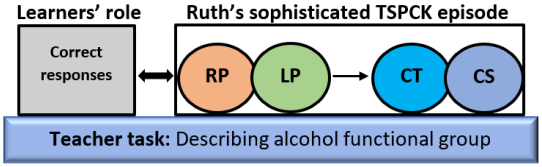
other elements in addition to carbon and hydrogen, an example is here (*Ruth referred to the structure of chloropropane already drawn on the board*), so, in organic compounds carbon is covalently bonded to hydrogen, very compulsory, is that ok?	to hydrogen. Ruth's interactive use of TSPCK components (LP-RP/CS) at a proficient level of TSPCK episode in connection to learners' correct responses is given by the TSPCK map below. 
4-6min: Describing Hydrocarbons **Ruth**: So let's discuss saturated and unsaturated hydrocarbon as a class of organic compound. What do you think we mean by hydrocarbons? SM3: compounds of carbon and hydrogen **Ruth**: Who has got something to add? There was no response from the learners **Ruth**: Indeed, in hydrocarbons we've got carbon and hydrogen atoms even in all organic compounds **(LP)** but one thing about hydrocarbons is that they consist of only carbon and hydrogen atoms covalent bonded, please take note of that guys, other organic compounds may contain carbon, hydrogen and other elements except hydrocarbons **(CS)** the simplest hydrocarbon is methane, our CH_4 shown here (she pointed at the structure of methane on the board) **(RP)** . Then, we all know fuels right, natural gases and even gasoline, those are common examples of mixtures in our environment containing hydrocarbons we will look at them later, are you following? Ss: yes	**Comment**: The discussion here focused on describing hydrocarbons serving as a foundation for later discussions on the functional group for alkanes, alkenes and alkynes. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe hydrocarbons before providing her own explanation. **Learners' role:** Through his response, learner SM3 showed a good understanding to an extent by describing hydrocarbons described as the compounds of carbon and hydrogen (LP). **Ruth's role:** Commenting on SM2's response, Ruth considered important for learners to know, the inclusion of the word 'only' to SM2's description of hydrocarbons, thereby adding value by locating where emphasis is to be placed in the established learner prior knowledge about carbon and hydrogen and also linked that to classifying hydrocarbons as the simplest of all organic compounds thereby demonstrating an understanding of curricular saliency (CS). She supported her explanation with giving methane as an example explained using its structure thereby demonstrating her understanding of the use of a symbolic representation (RP). She also gave familiar examples of hydrocarbons in order to situate her explanation in the learners' context which further talks to the Ruth's understanding of learner prior knowledge (LP). Ruth's interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 
6-7min: Describing saturated hydrocarbons **Ruth**: So, when we talk about saturated hydrocarbons we're referring to the hydrocarbons which have got only single covalent bonds between carbon atoms and hydrogen atoms **(CS)**, let's take for instance propane here (*she pointed at the structure of propane on the bond*), here is carbon bonded to	**Comment**: The discussion here focused on describing what saturated hydrocarbons are in relation to the previous discussion on hydrocarbons. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth described saturated hydrocarbons as consisting of only single covalent bonds between

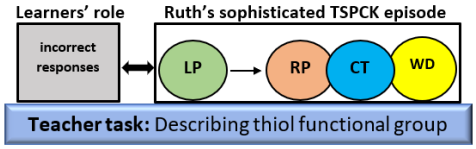
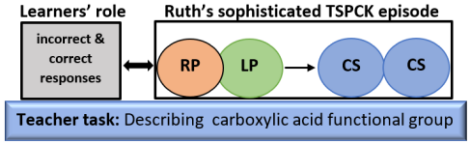
another carbon, **(RP)** and then these carbons are bonded to hydrogen atoms right, so to these carbon atoms (*she pointed at the last carbon to the right hand side and the first to the left hand side*), we have maximum of three hydrogen atoms completely bonded to each end-carbon, you see but to this middle carbon atom, we have two hydrogen atoms bonded to it, so the carbon forming 4 bonds is catered for right? **Ss**:…..(yes)……	atoms of carbon emphasised as the important aspect for learners to know at this point (**CS**). She supported her explanation with reference made to the structure of propane drawn on the board in explaining this (**RP**). **Learners' role**: None Ruth's interactive use of TSPCK components (CS/RP) at a simple level of TSPCK episode is given by the TSPCK map below. 
7-8min: Describing unsaturated hydrocarbons **Ruth**: And then, in unsaturated hydrocarbons, that is where we have either a double or triple bond between carbon atoms just like in here (she drew the structure of ethene on the board), here we've got two carbon atoms bonded to four hydrogen atoms, and you see a double covalent bond between carbon atoms? **(RP)** and another type of unsaturated neh that's similar to this one (*she pointed to the structure of ethene on the chalk board*) is having at least one triple covalent bonds between carbon atoms **(CT)** like (*she drew the structure of ethyne on the board*), now there is something about this, this tells us that, in a single bond, there are two pairs of electrons which are shared and in a double bond, there are four pair of electrons which are shared, and then a triple bond, there are six pair of electrons which are shared, so you've got to understand what those bonds actual mean, (**CS**) are we together? **Ss**:…..(yes)…….	**Comment**: The discussion here focused on describing unsaturated hydrocarbons in relation to the previous discussions on hydrocarbons. **In-depth Qualitative Analysis**: **Ruth's role:** Using the structures of ethene and ethyne, Ruth described unsaturated hydrocarbons with at least a double covalent bond or triple covalent bond between atoms of carbon. She most importantly explained a single covalent bond representing two pairs of electrons. She demonstrated the understanding of conceptual teaching strategies (CT) interactively used with representations (RP) as she explained the similarity and difference between ethene and ethyne with emphasis on the type of carbon-carbon covalent bond (CS). **Learners' role**: None The Ruth's interactive use of TSPCK components (RP/CT/CS) at a proficient level of episode is given by the TSPCK map below. 
8-10min: Describing functional groups **Ruth**: Now, we come to talk about functional groups yeah, what is a functional group? SF3: A group of atoms in organic chemistry Ruth: Any other opinion? (***There was no response***) **Ruth**: Right, chemists commonly use the term functional groups with organic compounds, (**LP**) they are referred to as the central atoms in a molecule, but they most importantly give organic molecules their reaction characteristics, here we've got the homologous series, **(CS)** with a particular functional group which is common to all the members, so functional group is what makes an organic compound which belongs to a given homologous series different from another organic compound that belongs to a different homologous series let's say this (*she drew the structure of ethane*) **(RP)**, it's ethane and then (*she drew the structure of ethene on the board*), ethene right and	**Comment**: The discussion here focused on describing what functional groups represent in the study of organic compounds. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe functional groups as a starting point preceding her explanations. **Learners' role:** Learner SF3 correctly referred to functional group as a group of atoms in organic chemistry but without stating their uniqueness (LP). **Ruth's role:** Ruth expatiated on SF3's response by linking the organic reactions undergo by homologous to their functional groups thereby demonstrating the most important element of what learners should know, an aspect of curricular saliency (CS). She used structural representations of ethane and ethene (RP) to further explain how

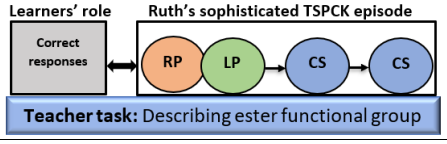
then **(CT)** (*she drew the structure of ethyne on the board*), they both have carbon and hydrogen atoms but different functional groups, am I right? Ss: yes	functional groups differentiate one homologous series from the other, an element of conceptual teaching strategies (CT). Ruth's interactive use of TSPCK components (LP-CS/RP/CT) a level of episode in connection to a learner's correct response is given by the TSPCK map below. 
10-11min: Describing Alkane functional group **Ruth**: Now, from our discussions, how would you describe alkanes and their functional group, that's two in one, yes? **SF2**: Alkanes are saturated hydrocarbons and they've got single covalent bonds between carbon atoms **Ruth**: That's brilliant! We have explained saturated hydrocarbons as having single covalent bonds between carbon atoms and carbon atoms are covalently bonded to hydrogen atoms (**LP**) as well so now each time we come across alkane homologous series neh, all the members are identified by single covalent bonds between carbon atoms in their molecules, please always remember that, (**CS**) so we represent the alkane functional group as (*she put wrote C-C on the chalk board*), **(RP)** with this functional group, if one member undergoes let's say substitution reaction, all other members too will undergo the same organic reaction **(CS)**, yeah that's for alkanes, any question before we move on? *There was no response from learners.*	**Comment**: The discussion here focused on describing the alkane functional group. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to first describe alkanes and their functional groups as a starting point preceding her explanations. **Learners' role:** Learner SF2's response showed a good understanding of alkanes as saturated hydrocarbons with single covalent bonds between carbon atoms (LP). **Ruth's role:** Ruth expatiated on SF2' response by indicating the alkane functional group characterized by a single carbon-carbon bond, is used for identifying organic compounds in the alkane homologous series thereby demonstrating the understanding of what learners should know, an aspect of curricular saliency (CS). She supported her explanation with the structure of alkane functional group drawn on the board thereby describing her knowledge of the use of a symbolic representation (RP). She further referred to the common organic reactions like substitution reaction that all members of alkanes undergo due to their common functional group. This describes Ruth's understanding of additional aspect of what learners needed to know about alkane functional group ahead of a specific discussion on organic compounds reactions, an aspect which will serve as a prior knowledge to the discussion on organic reactions, this is also a demonstration of an element of curricular saliency (CS) of a different kind that brings additional depth, other than emphasis of most important aspects, lit is about laying a group with prior concepts for a near future discussion. Ruth's interactive use of TSPCK components (LP-CS/RP/CS) at a sophisticated level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 

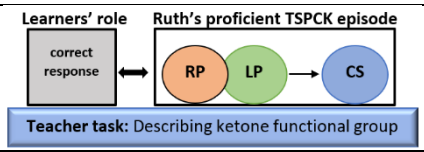
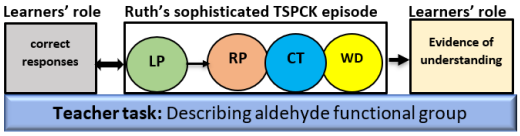
11-13min: Describing Haloalkane functional group **Ruth**: Let's see a similar group here (*She drew the structure of bromobutane*), **(RP)** who can tell us what this Br represent? **SM10**: Bromine **Ruth**: It's bromine, an element from which group? **SM10**: 7 **Ruth**: And what do you call those elements? Yes? **SF7**: They are halogens **Ruth**: So, Other examples include? **Ss**: Chlorine, Fluorine, Iodine, Bromine **Ruth**: Brilliant, so whenever we talk about halogenated compounds, those are compounds that contain the atoms of those elements you just mentioned **(LP)**. Now, so here (*she pointed at the structure of bromobutane*) is similar group to alkanes, we refer to them as haloalkanes, just like saying halogenalkanes, but it's correct to say haloalkanes, they are special homologous series of saturated hydrocarbons, which has got single carbon to carbon covalent bonds and then one more halogens, **(CS)** note here they are saturated class of hydrocarbons, we represent the functional group as (*she wrote R-X on the board*), here, our alkyl R is bonded to halogen X. Any question? **SF8**: Ma'am can one haloalkane have two halogens like Flourine and Chlorine in one molecule? **Ruth**: Here is a question for you guys, who is gonna help? SM2: yes, as long as they are halogens **Ruth**: Exactly, when we see it like that, it is still gonna be a haloalkane, it doesn't change the homologous series. Any other question? **Ss**….(No response from learners)	**Comment**: The discussion here focused on describing the haloalkane functional group. **In-depth Qualitative Analysis**: **Ruth's role:** Using the structure of bromobutane drawn on the board (**RP**), Ruth asked learners to know if they could recognize bromine in the structure. **Learners' role:** The Learners' responses showed understanding of Bromine, their group in the periodic table, their common name and other elements in the group (**LP**). **Ruth's role:** As an important aspect for learners to know, Ruth expatiated on the learners' correct responses to describe haloalkanes and their functional group with R-X as a symbolic representation. **Learners' role**: Learner SM2 responded in agreement to SF8's question asking if a haloalkane could have two halogens in the same organic molecule. This suggests SM2's understanding of Ruth's explanations. Ruth's interactive use of TSPCK components (RP/LP-CS) at a proficient level of TSPCK episode in connection to the learners' correct responses and reflecting learners' understanding of the explanations provided by Ruth is given by the TSPCK map below. 
13-15min: Describing Alkene functional group **Ruth**: Now, how about alkenes and their functional group guys? Who's gonna tell us something? **SM11**: They are unsaturated hydrocarbons **Ruth**: Yes, how can we recognize them? **SM8**: They have got double bond **Ruth**: Yeah, alkenes are unsaturated hydrocarbons as we earlier discussed, **(LP)** that's right. We've got to have at least a double covalent bond between carbon atoms in alkenes, so we use it to represent the functional group for all the members in the alkenes homologous series **(CS)** we represent functional group for alkenes by simply writing (*she put C=C on the chalk board*) on the board, so we find that, in all organic compounds that belong to the alkene homologous series neh **(RP)**. Something interesting to know about alkenes is that, if they react with hydrogen gas (*she put the equation of ethene and hydrogen gas on the board*), the hydrogen gas are added across the double bond and then, it becomes an ethane, we call that reaction halogenation of alkenes, all members of alkenes undergo it (**CS**) because they've got the same functional group, any question? *There was no response from learners.*	**Comment**: The discussion here focused on describing the alkene functional group where Ruth engaged learners in questioning before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe alkenes and their functional groups in order to first establish their existing understanding. **Learners' role:** Learner SM11 and SM8's responses showed good understanding of alkenes as unsaturated hydrocarbons with a double covalent bond between carbon atoms (**LP**). **Ruth's role:** Ruth expatiated on the learners' correct responses by re-emphasizing a double covalent bond between carbon atoms, an important aspect (**CS**) and using a symbolic representation of its functional group (**RP**). Another important aspect pointed out in her explanation was the halogenation reaction of alkenes to become alkanes (**CS**). Ruth's interactive use of TSPCK components (LP-CS/RP/CS) at a sophisticated level of TSPCK episode in connection to learners' correct responses

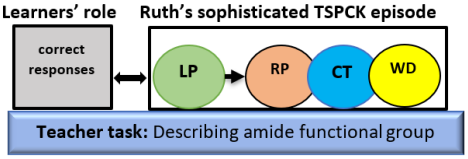
	is given by the TSPCK map below. 
15-16min: Describing Alkyne functional group **Ruth**: So, how about alkynes guys? SM5: They are also unsaturated hydrocarbons because they have got a triple bond between carbon atoms. **Ruth**: Yes, in the case of alkynes, a triple covalent bond is present between the two carbons **(LP)** as we can see here (*she referred to the structure of ethyne on the board*), we have the number of hydrogens reduced to two because of the triple bond neh. **(RP).** Now, when it comes to the functional group, all organic compounds in the alkyne homologous series have got their own functional group which we can find in molecules which makes them to be different from other organic compounds **(CS)** (*she put the structure of the functional group on the board*) of alkynes is given as this and this means that, there are six bonding electrons between these two carbons so, we identify all members of alkynes with this triple bond between two carbon atoms, so now, because alkynes have their the same functional group in their molecule, they undergo similar organic reaction like addition reaction, they first form alkenes and then further reaction leads to the formation of alkane, (**CS**) you see, so functional groups make you think different when you come across organic compounds right? Ss: yes	**Comment**: The discussion here focused on describing the alkyne functional group where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe alkynes in order to first establish their existing understanding thereby. **Learners' role:** Learner SM5 showed a good understanding by describing alkynes as unsaturated hydrocarbons with at least a triple covalent bond between carbon atoms (**LP**). **Ruth's role:** In her explanation, Ruth re-emphasized the triple covalent bond between carbon atoms as the first important aspect for learners to note thereby describing her knowledge of an aspect of curricular saliency (**CS**). She simultaneously used the structure of ethyne drawn on the board to identify the alkyne functional group a symbolic representation of the functional group (**RP**). She further related the functional group to similarity in the organic reactions that all members of alkyne homologous series undergo thereby showing another important aspect for learners to understand about the alkyne functional group (CS). Ruth's interactive use of TSPCK components (RP/LP-CS/CS) at a sophisticated level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 
16-18min: Describing Alcohol functional group **Ruth**: We've come to the next functional group (*she faced the chalk board and wrote R-OH*), **(RP)** so now which functional group are we talking about here guys looking at this? What class of organic compounds does this represent? **SM1**: hydroxyl group **Ruth**: Is it? **Ss**…(Learners echoed yes)…. **Ruth:** So what class of organic compounds does it represent? **SF2**: Alcohols **Ruth**: Very good, you said this OH here? **SF2**: Hydroxyl group **Ruth**: Hydroxyl group, that's good, so here we're talking about the hydroxyl group OH, our oxygen is covalently bonded to hydrogen, so you don't think it's the same as the hydroxide group **(LP)** which we normally represent as OH^- for	**Comment**: The discussion here focused on describing the alcohol functional group where Ruth asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Using the structure of alcohol functional group drawn on the board (RP), Ruth asked learners to mention the functional group indicated and class of organic compounds represented in order to first establish learner prior knowledge. **Learners' role:** Learner SM1 and SF2 showed a good understanding as they correctly identified OH as the hydroxyl group and alcohol functional group as represented (LP). **Ruth's role:** Ruth confirmed the learners' existing

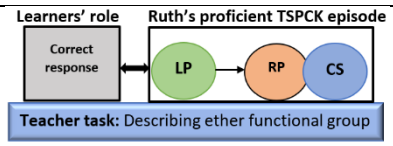
instance in NaOH, it's an hydroxide ion in inorganic compounds but in organic compounds, it's an hydroxyl group so you don't confuse the two, OH here it's the functional group of all alcohols, it's for members in the alcohol homologous series (**CT**) here is ethanol (***she drew the structure***), as you can see, it consists of five carbons single covalent bonds bonded to hydrogens to represent our alkyl R, now our R is bonded to OH group so we do represent all alcohols by R-OH to show the functional group and because all members in the alcohol homologous series have got same OH, they all undergo reactions like oxidation, esterification and so on, one important thing for you note, **(CS)** you see when alcohols are oxidized, they produce other organic compounds like ketones, carboxylic acids, that's not the focus for today, just take note of that.	knowledge of hydroxyl group for alcohols. She further cautioned learners not to confuse the hydroxyl OH in alcohols with the hydroxide ion (OH^-) in inorganic compounds because of their similarity in representations. This logic of describing the difference and similarity of hydroxide group and hydroxide ion seemed to describe Ruth's knowledge of a conceptual teaching strategy (CT) used in science teaching. In addition to emphasizing the hydroxyl functional group for alcohols, she further referred to the types of organic reactions (e.g. oxidation, esterification) that all members of alcohols undergo because they all contained the hydroxyl functional group. This appeared to describe her knowledge of a Big Idea in organic chemistry, an element of curricular saliency (CS). Ruth's interactive use of TSPCK components RP/LP-CT/CS at a sophisticated level of TSPCK episode in connection to the learners' correct responses is given by the TSPCK map below. 
18-20min: Describing Thiols functional group **Ruth**: So, now there's a group of organic compounds which are very similar to alcohols when you look at their name, who can tell us? SM12: Aldehyde **Ruth**: How? SM13: Alkanols Ss: (Laugh!!!) **Ruth**: Eish guys, aldehyde are organic compounds with a specific functional group but they aren't in any way thiols and alkanols are also known as alcohols, **(LP)** ok. Another similar group of organic compounds is called Thiols (*she wrote the name on the board*), we can see that the name is similar to alcohols right? Ss: yes **Ruth**: Yeah, Thiols have got their functional group here is it (*she wrote R-SH on the chalk board*), here is our SH, **(RP)** sulfhydryl group, bonded to an alkyl group, R just like we've got CH_3SH, its name is methanethiol we can also see that, the functional group for our alcohol here (*she pointed at the R-OH on the chalk board*) is somehow similar to this thiol right? Ss: yes **Ruth**: So now you've got to understand that in alcohol, we have got our hydroxyl group OH bonded to a carbon atom but in thiol functional group, we can see that oxygen atom in OH has been replaced by Sulphur S **(CT)** so because of how similar thiols are to alcohols, it may be difficult to remember it's hydryl in Thiols but in alcohols, it's hydroxyl, so you've got to be careful to avoid mistakes, you see the difference?	**Comment**: The discussion here focused on explaining the Thiols functional group where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to mention any similar organic compounds to alcohols already discussed with them in an attempt to investigate their prior knowledge of Thiols. **Learners' role:** In their responses to Ruth's question, Learner SM12 and SM13 wrongly referred to aldehyde and alkanols respectively as the similar organic compounds to alcohols they could think of (LP). **Ruth's role:** Ruth commented on the learners' responses by indicating alcohols are the same as alkanols and writing Thiols on the board to see how 'ol' is present in both Thiols and Alcohols as their similarity. She referred to the sulfhydryl group with its symbolic representation as the unique Thiols functional group thereby demonstrating her knowledge of what learners should know (curricular saliency, CS) and use of representation (RP). Also, she showed how similar and different the hydryl group is to the hydroxyl group thereby showing the understanding of what could be difficult for learners (WD). Making learners to understanding the difference and similarity between alcohols and thiols

(**WD**) Ss: yes **Ruth**: So we can say that sulfur S has taken the place of oxygen in OH, that's the logic, so instead of having hydroxyl, we now have sulfhydryl SH, that's the functional group for Thiols, once we see it in an organic compound, we know such a compound belongs to Thiol homologous series and one special thing about Thiols is that, they've a strong odour like that of rotten eggs, that kind of bad odour we all know right? Ss: yes	also signals Ruth's understanding of conceptual teaching strategies (CT). She further talked about Thiols identified with a strong odour like that of rotten eggs, thereby describing Thiols physical property, another important aspect for learners to know. Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to the learners' incorrect responses is given by the TSPCK map below. 
20-23min: Describing Carboxylic functional group **Ruth**: Now, let's see the next one (*she put the structure of carboxylic acid functional group on the chalk board*) **(RP)**, we can simple write it as RCOOH), yeah so which organic compound does this functional group represent? Ss: ….(No response from learners)…. **Ruth**: What does this R represent guys? SM10: Alkyl group **Ruth**: That's like CH3 right? SM10: yes **Ruth**: (She pointed at the C=O portion), what's this? SF8: it's like carbon monoxide Ss: …..(Learners laugh)…… **Ruth**: Carbon monoxide is a gas remember, it's an inorganic compound, **(LP)** please not that here (*she pointed at the structure on the chalk board*) it's our C=O is a carbonyl group, we've got carbon double bonded to oxygen, it's a functional group in organic chemistry, **(CS)** so now how about this (*she pointed at the OH portion*)? SF9: hydroxyl functional group Ruth: Functional group for SF9: Alcohols **Ruth**: So, we're saying here is our hydroxyl group OH, the functional group of alcohols homologous as we discussed before, so here our OH and C=O form the carboxylic functional group, we can write it as (she wrote COOH on the board) or (she wrote C(=O)OH on the board), we've got a carbon double bonded to an oxygen, it's also bonded to one hydroxyl group and on the other side, to an alkyl group, yeah, with this functional group we can identify and name all the compounds in the carboxylic acid homologous series like using oic for methanoic acid, ethanoic acid, propanoic acid and so, you can see the trend right, so because they've got the same functional group, they undergo same organic reactions, **(CS)** is that understood now? Ss: yes	**Comment**: The discussion here focused on describing the carboxylic acid functional group where Ruth asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of carboxylic acid functional group drawn on the board (RP), Ruth asked learners the organic compound represented by the structure **Learners' role**: Learners provided no answer in response to what organic compounds are represented by the functional group. However, SM10 and SM9 correctly identified R as the Alkyl and OH as the hydroxyl group for alcohols respectively. SF8 wrongly referred to C=O as carbon monoxide (LP). **Ruth's role:** Taking all learners' responses into consideration, Ruth first indicated the hydroxyl and carbonyl group as the constituents of carboxylic functional group used for identifying and naming all carboxylic acids. This suggests an aspect important for learners to know thereby describing Ruth's knowledge of curricular saliency (**CS**). Another important aspect describing Ruth's knowledge of curricular saliency was the effect of all members having the same functional group as seen through similar organic reactions they undergo (**CS**). Ruth's interactive use of TSPCK components (RP/LP-CS/CS) at a sophisticated level of TSPCK episode in connection to the learners' incorrect and correct responses is given by the TSPCK map below. 
23-27min: Describing Esters functional group **Ruth**: And then we have the functional group for esters here (*she drew the structure on the chalk board*) **(RP)** looking at this can anyone tell us from which compounds we could say an	**Comment**: The discussion here focused on describing the ester functional group where Ruth asked learners questions before providing explanations.

ester has possibly formed? **SM7**: carboxylic acid **Ruth**: Why? **SM7**: there's a carbonyl group **Ruth**: Carbonyl group and then? **SF8**: hydroxyl group **Ruth**: Yeah, he's right by saying carboxylic acid because here is the carbonyl group, you must always remember that carboxylic acid functional group does not consist of carbonyl group only right, it's also got an hydroxyl group as well **(LP)**, so here it is (*she pointed at the functional group of carboxylic acid*). So now we can say that the functional group for esters is derived from a carboxylic acid and from an alcohol, that's the point **(CS)** as we can see here (*she referred to the structure of ester functional group*), here is our carbonyl group C=O, and here is OH **(RP)** but now H has been replaced by alkyl, such instead of OH, we've got O-alkyl, so all compounds in the ester homologous series commonly have general molecular formula RCOOR', they all end with 'oate', you've come across that? **SF10**: Like propanoate **Ruth**: Exactly, here is an example (*she put the symbolic structure of ethyl propanoate on the board*), it's ethyl propanoate yeah, it tells us that the IUPAC name for members in the ester homologous series ends with 'oate' **(CS)** and you can see they've got hydrogen bonds right, so they are polar, they are soluble in water to an extent, chemists normally use those esters that have got low molecular weight to make fragrances which some of us use, yeah. Any question on that? **Ss**: (No response)	**In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of ester functional group drawn on the board (RP), Ruth asked learners possible compounds from which esters could have formed. **Learners' role**: Learner SM7 suggested carboxylic acid as the compound that could have produced ester. Also, learner SF8 also identified hydroxyl group in the structure of carboxylic acid. These correct learners' responses showed their good prior knowledge (LP) and understanding of the previous discussion on carboxylic functional group **Ruth's role:** Ruth expatiated on the learners' correct responses to emphasis key aspects she wanted learners to know. These included: esters as derived from carboxylic acids and alcohols with 'oate' as the suffix in naming esters; esters as polar substances making them soluble in water and their application in making fragrances. These two points were considered different but related aspects of esters that learners needed to know thereby demonstrating Ruth's knowledge of curricular saliency (CS). Ruth's interactive use of TSPCK components (to RP/LP-CS-CS at a sophisticated level of TSPCK episode in connection to the learners' correct responses is given by the TSPCK map below. 
27-29min: Ketone functional group **Ruth**: We have a ketone, its functional group can be *represented as, here it is (she drew and referred to the structure drawn on the board*), **(RP)** you can see that neh. What did we call this portion containing a double bond between carbon and oxygen the other time? **SM5**: carbonyl group **Ruth**: ok thanks; remember we said in carbonyl group, carbon is double bonded to oxygen, that's our C=O **(LP)** so, a ketone functional group consists of a carbonyl group **(CS)** as we can see in this structure (*she referred to the structure drawn on the board*) and the remaining two bonds of this carbon may consist of alkyl group R that is CH3 as shown here, ethyl group like (*she put CH_2CH_3 as representing R in the structure*), so here we've got our butanone. Ss: yes	**Comment:** The discussion here focused on describing the ketone functional group where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of ketone functional group drawn on the board (RP), Ruth asked learners to indicate what C=O represent in order to establish their understanding of previous discussions on identifying carbonyl group. **Learners' role**: Learner SM5 correctly referred to the portion as the carbonyl group showing the learner's understanding of the previous discussions (LP). **Ruth's role:** In her explanation Ruth further reminded learners of what carbonyl group is and she pointed out what constitutes the ketone functional group as an important aspect she wanted learners to understand (CS). Ruth's interactive use of TSPCK components (RP/LP-CS) at a proficient level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below.

	
29-33min: Describing Aldehyde functional group **Ruth**: Now, what do you know about aldehydes and their functional group? Yes SM12: They look like ketone in a way **Ruth**: (Smile), in which way? Learner SM12 was silent. SM13: They have got a carbonyl group **Ruth**: Yes, Aldehydes are similar organic compounds to ketones but we must be careful, we mustn't think they are the same, they are different, **(LP)** let's see the functional group (*she drew the structure of aldehyde functional group on the board*), we can see here **(RP)** aldehydes have got carbonyl group with the carbon here bonded to hydrogen on one side, same carbon is bonded to an alkyl group, R on other side this bonding arrangement very important, so unlike here in our ketone functional group (*she pointed at the structure of ketone functional group*) where carbonyl group is bonded to one alkyl group on one side and another alkyl group on the other side, **(CT)** it becomes difficult to distinguish between the two functional groups once we forget what is bonded to the central carbon atom on these two sides. **(WD)** SF2: How does that affect their names? **Ruth**: Good question, remember I said for naming ketones, you replace ane in alkanes by one just like butane to butanone but for aldehydes, their IUPAC name ends with 'al' just line replacing ane with anal (she faced the board and put the structure of ethanal on the board), so what are u gonna call this? SF3: ethanal **Ruth**: And this (she put the structure of ethenone on the board)? SF4: ethanone **Ruth**: That shows we can differentiate ketones from aldehydes Ss:….(Learners echoed 'yes') Ruth: So, let's say we've got [she put CH3C(CH3)OHCH3 on the board), and then, here is another [she put CH3CH2CH2COOH on the board], and then [she put CH3CH2COOCH2CH3 on the board], now who is gonna help us name the functional group in [she pointed at she put CH3C(CH3)OHCH3]? SM10: hydroxyl group SM11: alcohol functional group Ruth: It's an alcohol because of this OH and this one [she pointed at CH3CH2CH2COOH]? SF8: it's a carboxylic acid Ruth: because of COOH, good and this one [she pointed at she put CH3CH2COOCH2CH3]? SM2: ester functional group Ruth: yeah, RCOOR right? Ss: yes	**Comment:** The discussion here focused on describing the aldehyde functional group where Ruth asked learners questions before providing explanations. **In-depth qualitative analysis:** **Ruth's role:** Ruth asked learners what they knew about aldehydes and their functional group. **Learners' role:** Learners' responses revealed an understanding that, aldehydes are similar to ketone as they both has carbonyl group as part of their functional groups (LP). **Ruth's role:** Taking learners' correct responses into consideration, Ruth cautioned learners about thinking ketones are the same as aldehydes because of their similar functional group thereby showing awareness of a possible misconception, an aspect of learner prior knowledge (LP). As an important aspect for learner to know, she drew the structure of aldehyde functional group and explained what it is made up of. Likewise, she referred to the structure ketone in order to make the learners understand how carbonyl group is bonded. This suggests Ruth's knowledge of the use of symbolic representations (RP) in explaining the similarity and difference between aldehydes and ketones (CT). Demonstrating her knowledge of what is difficult (WD), she indicated inability to remember how carbonyl group is bonded in each case of ketone and aldehyde as what could make them difficult to differentiate. **Learners' role:** The Learner SF3 and SF4's ability to mention ethanal and ethenone as examples of aldehyde and ketone respectively suggests evidence of their understanding of the explanations Ruth provided. Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to the learners' correct responses and also accompanied by evidence suggesting learners' understanding of the explanations provided by Ruth is given by the TSPCK map below. 
33-36 min: Describing Amide functional group	**Comment:** The discussion here focused on

Ruth: And then, we have amide. Does anyone have an idea of how the functional group looks like? Ss: (no response) **Ruth**: OK, from all we have discussed so far, can someone describe the functional group for carboxylic acid? Please, think guys I need someone to help. **SM1**: It has got a carbonyl group and hydroxyl group **Ruth**: That's a good point, ok guys, one thing about functional groups is that they are similar somehow, **(LP)** so you must identify the differences and similarities between them, is that ok? Ss: yes **Ruth**: Ok guys, remember we talked about the carboxylic acid functional group right here (*She pointed at the structure*) so if here we replace the OH by **(RP)** NH_2 then we have an amide functional group, in other words, the key here is that our amide functional group is made up of a carbonyl group which is bonded to NH_2 as we can see here (*She drew and referred to the structure*). You can see the difference between carboxylic acid functional group and amide functional group right **(CT)** as we have here, while in carboxylic acid functional group we have OH as you can see here, in amide we have NH_2, so if you forget that to carbon in the carbonyl group, we have got NH_2 attached it would be hard for you to describe amide, you might find it difficult to distinguish it from carboxylic acid and others with similar structure, so please don't confuse them, **(WD)** Is that understood? Ss: yes	describing the amide functional group where Ruth asked learners questions before providing explanations. **In-depth qualitative analysis:** **Ruth's role:** Ruth asked learners about how amide functional group looks. When there was no response from learners, she asked them to describe the carboxylic acid functional group which she had earlier explained to them like. **Learners' role:** Learner SM1 correctly mentioned carboxylic acid functional group as consisting of carbonyl and hydroxyl group (LP). **Ruth's role:** Using the structure drawn on the board (RP), Ruth explained the constituent of carboxylic acid functional group as an important aspect she wanted learners to understand. She did this by differentiating amide functional group from carboxylic acid functional (CT) and cautioned learners of any learning difficulty that could emanate from the similarity of the two functional groups (WD). Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to a learners' correct responses is given by the TSPCK map below. 
36-40 min: Describing Ether functional group **Ruth**: And then we have ether. Does anyone know how the functional group look like? SM4: It contains oxygen **Ruth**: Yes, but remember oxygen alone can't form the functional group. Who has got something to say? (No response from learners) **Ruth**: As he rightly said, oxygen is part of it but oxygen alone does make the functional group for ether, **(LP)** now the functional group (*she drew the structure of ether functional group*), so here is Ether functional group, **(RP)** what has it got? In the functional group, we have got an atom of oxygen which is bonded to the alkyl R on this side and another alkyl R on the other side, you must not forget, **(CS)** our O is bonded to one alkyl group and another alkyl group, can you all see that? Ss: yes	**Comment:** The discussion here focused on describing the ether functional group where Ruth asked learners questions before providing explanations. **In-depth qualitative analysis:** **Ruth's role:** Ruth asked learners about how ether functional group looks. **Learners' role:** Learner SM4 could correctly identify the presence of oxygen atom in the ether functional group (LP). **Ruth's role:** Ruth expatiated on the learner's correct response using the structure drawn on the board to explain what ether functional group comprises of as an important aspect she wanted learners to understand. This suggests her understanding of the use of a symbolic representation (RP) and curricular saliency (CS). Ruth's interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below.

The Table 6.1 above provides the detailed analysis of Ruth's first lesson (Lesson 1). The sequence in which the identified TSPCK episodes emerged from Ruth's lessons is visually represented by the TSPCK profile as shown in the Figure 6.1 below.

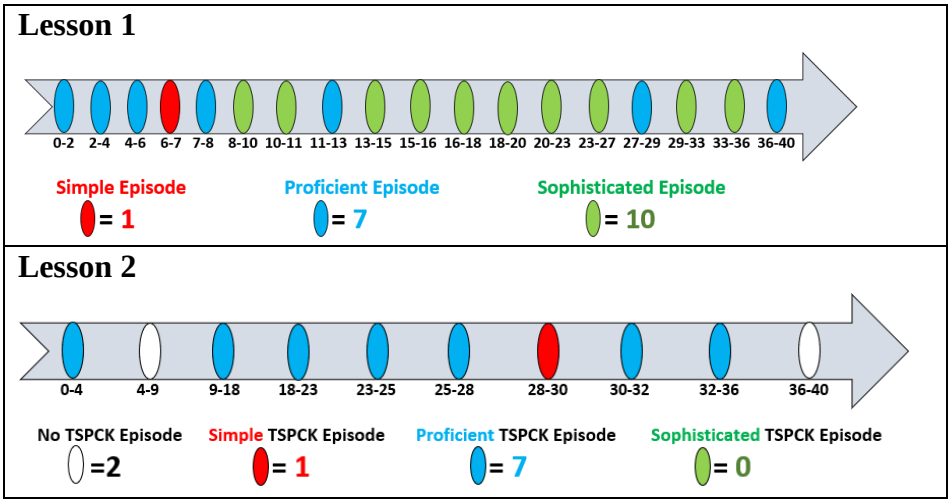


Figure 6.1: Ruth's TSPCK profile

As shown in the Figure 6.1 above, there were simple, proficient and sophisticated TSPCK episodes emerging from the explanations Ruth provided while presenting organic concepts to the learners in the actual classroom context. In the first lesson (Lesson 1), Ruth's emergence of TSPCK episodes appeared to build up from proficient TSPCK episodes with a simple TSPCK episode leading to a group of sophisticated TSPCK episodes. In such cases, Ruth's explanations suggested the quality of her interactive use of TSPCK components mostly at a sophisticated level of TSPCK episodes (n=10) followed by the proficient level of TSPCK episodes (n=7) accompanied with a simple TSPCK episode (n=1). In the second lesson (Lesson 2), the quality of her interactive use of TSPCK components was mostly at the proficient level of TSPCK episodes (n=7) with a simple TSPCK episode (n=1). For the purpose of illustrating the emergence TSPCK episodes from the participant PSTs' analysed lessons (see Appendix XXVII, XXVIII, XXIX and XXX), the Figure 6.2 below gives an overview of the TSPCK profile.

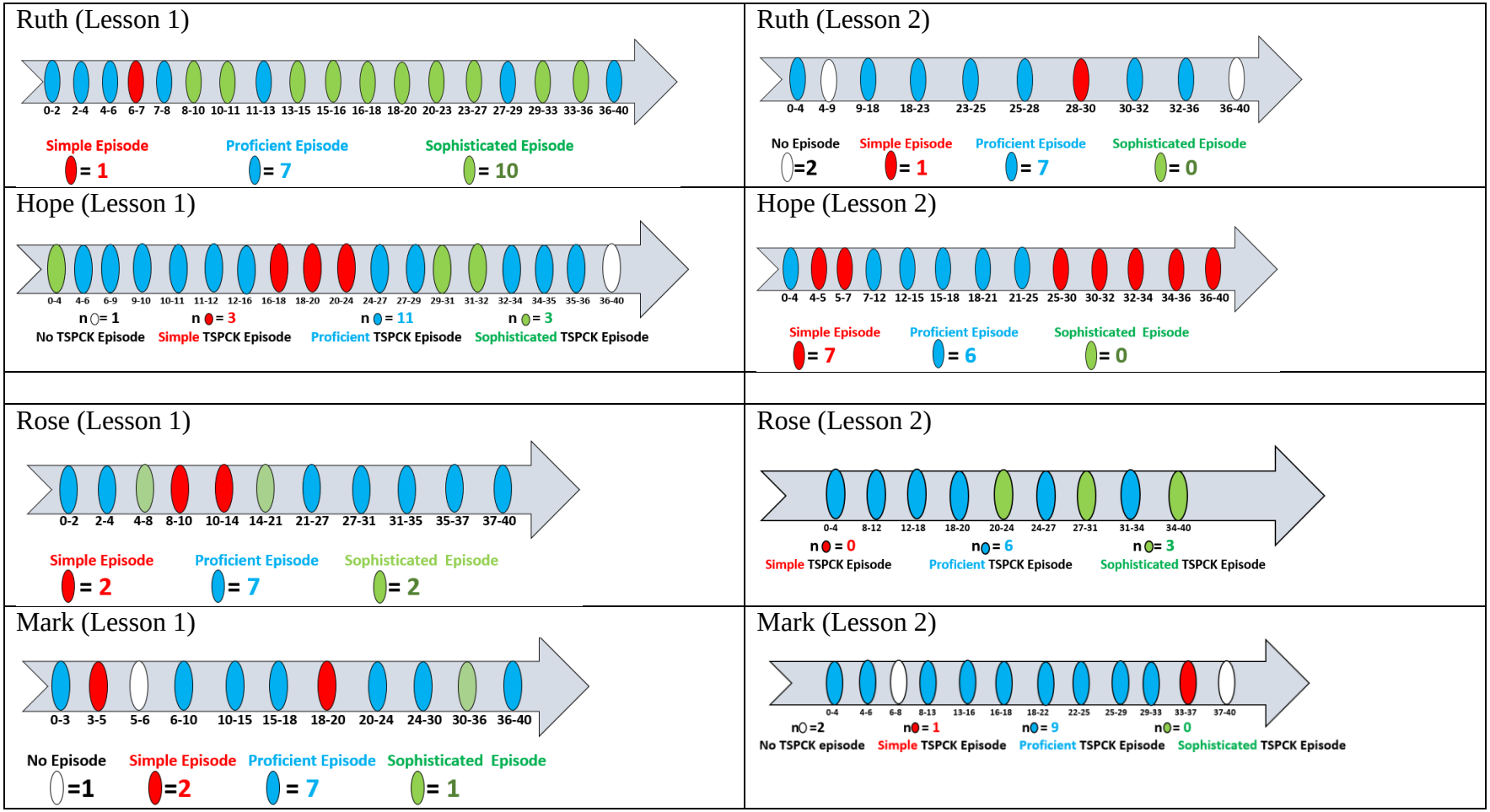


Figure 6.2: Summary of the PSTs' TSPCK profiles

From TSPCK profiles given in the Figure 6.2 above, it could be observed that, each PST had teaching segments from which the three levels of TSPCK episodes emerged collectively. There were cases of simple TSPCK episodes building up to proficient TSPCK episodes as it emerged in the Hope's lesson 2 (4-25minutes), proficient with simple TSPCK episodes building up to a cluster of sophisticated TSPCK episodes (e.g. Ruth's lesson 1, 0-27 minutes).

The Table 6.2 below summarises the categories of TSPCK episodes with the specific TSPCK components interacting as they emerged from the PSTs' teachings.

Table 6.2: Overview of PSTs' emerging TSPCK episodes and knowledge components

Category of TSPCK episode	Nature of interaction of TSPCK components	Quantity of TSPCK episodes identified in the PSTs' lessons			
		Ruth's lessons	Hope's lessons	Rose's lessons	Mark's lessons
Simple TSPCK episodes	CS/RP	2	10	-	1
	LP-CS	-	-	2	2
	TOTAL	**2**	**10**	**2**	**3**
Proficient TSPCK episodes	**LP-CS/RP**	9	11	4	10
	LP-CS/WD	-	-	1	-
	CS/CS/CS	-	-	1	-
	RP/CS/CS	-	-	-	1
	CS/RP/LP	-	3	1	1
	LP/RP-CS	4	2	4	2
	CS/CT/RP	1	-	-	-
	CS/LP/CT	-	-	1	-
	LP-CT/RP	-	1	1	1
	LP/RP/CT				1
	TOTAL	**14**	**17**	**13**	**16**
Sophisticated TSPCK episodes	**LP-CS/RP/CS**	2	1	1	-
	RP/LP-CS/WD		1	1	-
	RP/RP/CS/CS		1	-	-
	LP-CS/RP/CT	1	-	1	-
	RP/LP-CS/CS	3	-	-	1
	LP-CS/RP/CT/WD		-	-	-
	LP-RP/CT/WD	3	-	-	-
	RP/CS/LP/CS		-	1	-
	RP/LP-CS-CS		-	1	-
	RP/LP-CT/CS	1	-	-	-
	TOTAL	**10**	**3**	**5**	**1**

Note: LP=Learner Prior Knowledge; CS=Curricular saliency; WD=What is difficult to teach or understand; RP=Representations; and CT=Conceptual teaching strategies

As shown in the Table 6.2 above, the five knowledge components of TSPCK were found to interact at different levels and to varying degrees as specified in the rubric used. More prominent were the interactions between the TSPCK components of learner prior knowledge, curricular saliency and representations. The overall TSPCK episodes are visually presented in shown in the Figure 6.3 below.

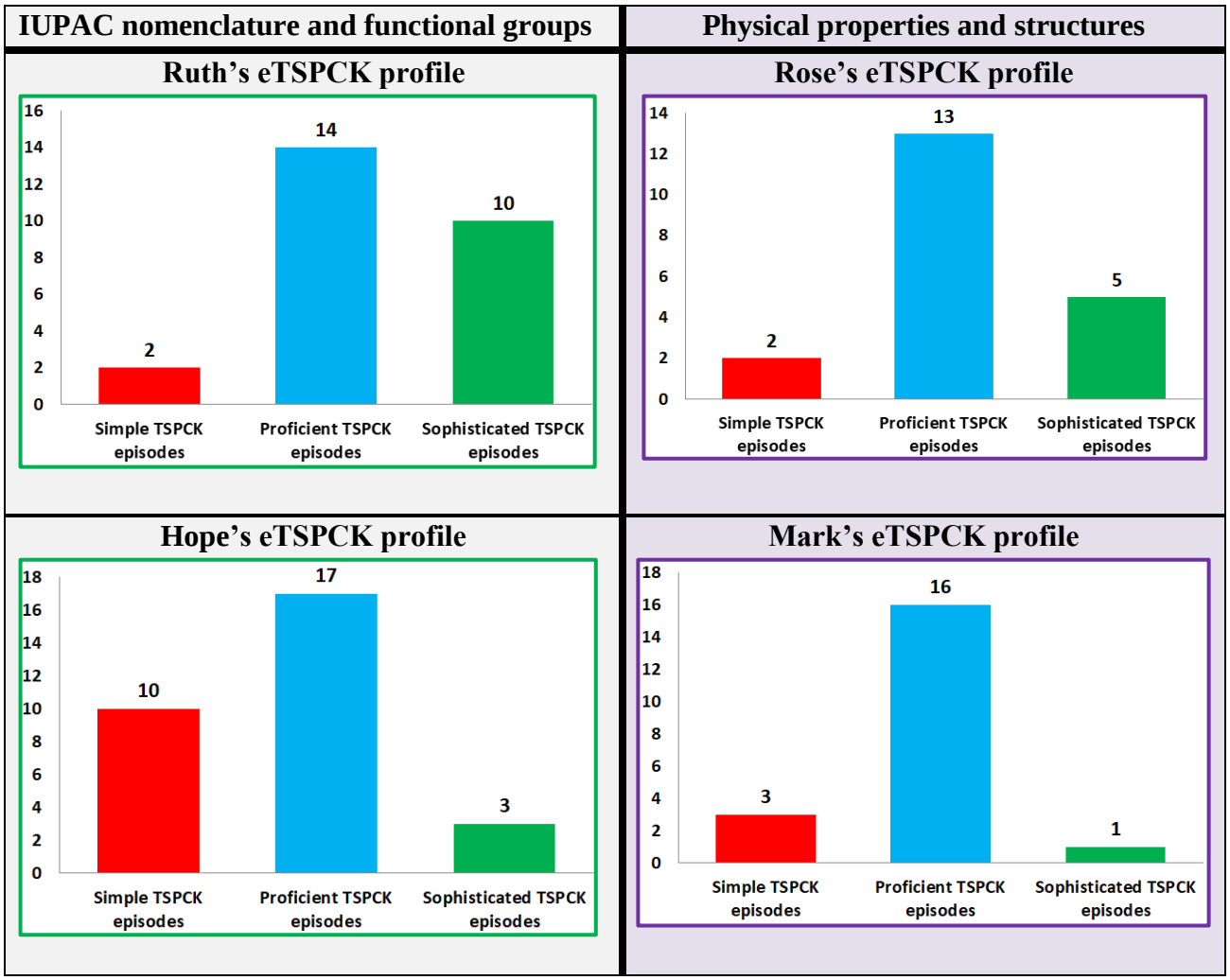


Figure 6.3: Overall TSPCK episodes emerging from the PSTs' teachings

As shown in the Figure 6.3 above, across the 4 PSTs, there are higher quantities of proficient TSPCK episodes than the simple and sophisticated TSPCK episodes. This implies that, the PSTs mostly used: (i) either three TSPCK components interactively in explaining organic chemistry concepts to the learners; or (ii) use two TSPCK components interactively where one repeated as they explained the concepts to the learners. These represent the two basic classifications of proficient TSPCK episodes according the eTPCK rubric used (Miheso, 2018). All the PSTs'

TSPCK profiles portray a combination of TSPCK episodes that are in the simple, proficient and sophisticated categories. However, more desirable proficient and even sophisticated TSPCK episodes are seen in the Ruth's and Rose's lessons and less in the Hope's and Mark's lessons. The proficient and more specifically, sophisticated TSPCK episodes are indicative of the desirable deep depth of explanations that reflect teacher's understandings of CK interaction with multiple content-specific knowledge components of TSPCK which result in pedagogical transformation of content. While all the 4 PSTs demonstrated the understanding of interactive usage of at least three of TSPCK components predominantly at a proficient level of TSPCK episodes, Ruth's and Rose's teachings seemed to be exceptional for displaying TSPCK episodes in the higher quality categories of the rubric in their lessons. The overall key findings emerging from these analyses are discussed in the sections below.

6.4 Findings

There were four key findings emerging from the analyses of PSTs' lessons in this chapter. First, the emerging TSPCK episodes from the PSTs' lessons were complex and idiosyncratic in nature. Second, there appeared to be an expansion in the TSPCK episodes identified in the PSTs' actual teaching compared to those TSPCK episodes which emerged from their lesson plans. Third, there was emergence of new TSPCK episodes observed in the PSTs' actual teaching which were not found in their lesson plans. These TSPCK episodes found newly in the actual teaching seemed to be prompted by the learners' responses to the questions the PSTs posed in order to establish their prior knowledge. Four, there seemed to be a congruency between what was discussed with the PSTs during the intervention (as discussed in Chapter 4), the knowledge components which characterized the PSTs' planned TSPCK following the intervention (as analysed in Chapter 5), and knowledge components that characterized their eTSPCK in the actual classroom teaching. Each of these findings is briefly outlined below with the supporting data.

Finding 1: Complexity and idiosyncratic nature of TSPCK episodes emerging from the PSTs' lessons

The examination of identified TSPCK episodes presented in the Table 6.2 above describes some level of complexity and idiosyncratic interactions among the knowledge components in such a

clear and distinguishable manner similar to previous studies (Aydin *et al*., 2014; Mavhunga, 2018). There appears to be two important noticeable patterns in the nature of interactions of emerging TSPCK episodes. The first pattern describes the complexity of the emerging TSPCK episodes and the second pattern describes the idiosyncratic nature of the TSPCK episodes.

First, the interactions among TSPCK components suggest occurrences of a linear standalone sequence (e.g. LP-CS) or an interwoven structural arrangement (CS/LP/CT) or the combination of both linear and interwoven emergence (RP/LP-CS-CS, LP-CT/RP). While the same knowledge components (e.g. LP, CS and RP) could be observed to be interacting in some emerging TSPCK episodes, the structural formats in which they interacted differ (e.g. LP-CS/RP, CS/RP/LP, LP/RP-CS). In some TSPCK episodes, CS was particularly noticed to be repeated more than once thereby adding additional depth to the PSTs' explanations at such moments. In the TSPCK episode (RP/RP/CS/CS) where RP was also found to be repeated, Hope was noticed to use both symbolic and sub-microscopic levels of representations in explaining alkane homologous series.

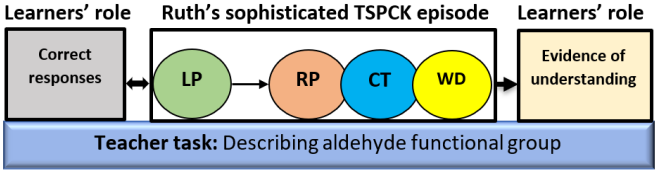
Second, the interactions of knowledge components seemed to differ across different concepts in the same PST's lessons as could be observed in the Table 6.2 above. For example, when Ruth was discussing saturated hydrocarbons with the learners (see Table 6.2, 6-7minutes), a simple TSPCK episode (CS/RP) emerged from her explanations. The discussion was preceded by her explanations on hydrocarbons (4-6 minutes) from which a proficient TSPCK episode (LP-CS/RP) emerged and the discussion was succeeded by her explanations on unsaturated hydrocarbons (7-8 minutes) from which another proficient TSPCK episode (CS/CT/RP) emerged. In another teaching segment focusing on the amide functional group (33-36 minutes) different from saturated hydrocarbons, a sophisticated TSPCK episode (LP-RP/CT/WD) emerged from the explanations Ruth provided. Likewise, on the same concept, the emergence and nature of TSPCK episodes appeared to differ with two PSTs. For example, the extracts of Ruth and Hope's teaching segments focusing on the aldehyde functional group are provided in the Table 6.3 below.

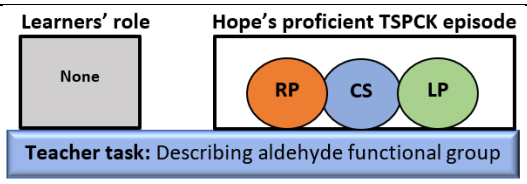
Table 6.3: Extracts of teaching segments focusing on aldehyde functional group

Extract of Ruth's teaching segment	Extract of Hope's teaching segment
Lesson 1, 29-33 minutes	Lesson 2, 15-18
29-33min: Describing Aldehyde functional group **Ruth**: Now, what do you know about aldehydes and their functional group? Yes SM12: They look like ketone in a way **Ruth**: (Smile), in which way? *Learner SM12 was silent.* SM13: They have got a carbonyl group **Ruth**: Yes, Aldehydes are similar organic compounds to ketones but we must be careful, we mustn't think they are the same, they are different, **(LP)** let's see the functional group (*she drew the structure of aldehyde functional group on the board*), we can see here **(RP)** aldehydes have got carbonyl group with the carbon here bonded to hydrogen on one side, same carbon is bonded to an alkyl group, R on other side this bonding arrangement very important, so unlike here in our ketone functional group (*she pointed at the structure of ketone functional group*) where carbonyl group is bonded to one alkyl group on one side and another alkyl group on the other side, **(CT)** it becomes difficult to distinguish between the two functional groups once we forget what is bonded to the central carbon atom on these two sides. **(WD)** SF2: How does that affect their names? **Ruth**: Good question, remember I said for naming ketones, you replace ane in alkanes by one just like butane to butanone but for aldehydes, their IUPAC name ends with 'al' just line replacing ane with anal (she faced the board and put the structure of ethanal on the board), so what are u gonna call this? SF3: ethanal **Ruth**: And this (she put the structure of ethenone on the board)? SF4: ethanone **Ruth**: That shows we can differentiate ketones from aldehydes	**Hope**: Ok, next is the aldehyde, now aldehyde functional group, it's basically carbon with oxygen up here (*she drew the structure on the board*), (**RP**) that's a double bond covalent bond between a carbon and oxygen atom (**CS**) right, you don't confuse that with a single bond covalent bond between carbon and oxygen and then probably think it's carbon monoxide, (**LP**) here our C=O here is called carbonyl group, ok and then bonded to that, is the hydrogen atom (*she pointed at the structure*), hope you got that? Learners' role: None
In-depth qualitative analysis: **Ruth's role:** Ruth asked learners what they knew about aldehydes and their functional group. **Learners' role:** Learners' responses revealed an understanding that, aldehydes are similar to ketone as they both has carbonyl group as part of their functional groups (LP). **Ruth's role:** Taking learners' correct responses into consideration, Ruth cautioned learners about thinking ketones are the same as aldehydes because of their similar functional group thereby showing awareness of a possible misconception, an aspect of learner prior knowledge (LP). As an important aspect for learner to know, she used the drew the structure of aldehyde functional group and explained it is made up of. Likewise, she referred to the structure ketone in order to make the learners understand how carbonyl group is bonded. This suggests Ruth's knowledge of the use of symbolic representations (RP) in	**In-depth qualitative analysis:** **Hope's role**: Hope explained the aldehyde functional group as consisting of carbon double covalently bonded to oxygen using its structure drawn on the board thereby describing her understanding of what learners should know (CS) and use of a symbolic representation (RP). She also cautioned learners not to confuse the carbonyl group with carbon monoxide thereby describing her awareness of a possible misconception (LP). **Learners' role**: None Hope's interactive use of TSPCK components (RP/CS/LP) at a proficient level of TSPCK episode is given by the TSPCK map below.

explaining the similarity and difference between aldehydes and ketones (CT). Demonstrating her knowledge of what is difficult (WD), she indicated inability to remember how carbonyl group is bonded in each case of ketone and aldehyde as what could make them difficult to differentiate. **Learners' role:** The Learner SF3 and SF4's ability to mention ethanal and ethenone as examples of aldehyde and ketone respectively suggests evidence of their understanding of the explanations Ruth provided.

Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to learners' correct responses and also accompanied by evidence suggesting learners' understanding of the explanations provided by Ruth is given by the TSPCK map below.





Finding 2: Identified TSPCK episodes in planning expanded in the actual teaching

Ruth's case

In the planning context, there were six instances of Ruth's written explanations from which simple TSPCK episodes emerged. These included the explanations provided on the immediate concepts, summary of important content knowledge, common misconceptions and identifying difficult concepts in the lesson. The only instance of 3 knowledge components interactively used happened while Ruth outlined the teaching strategies she would employed in her lesson. The Figure 6.4 below summarises the identified TSPCK episodes in the Ruth's lesson plan.

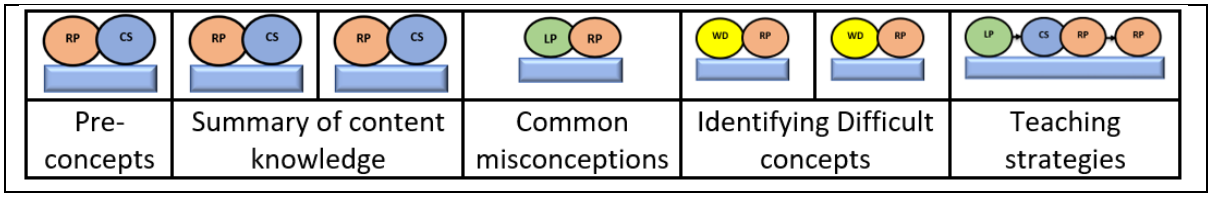


Figure 6.4: Emergence of TSPCK episodes from Ruth's lesson plan

With respect to the Figure 6.4 above, an extract of Ruth's written explanations on the aspect of the lessons considered difficult for the learners to understanding is provided in the Figure 6.5 below.

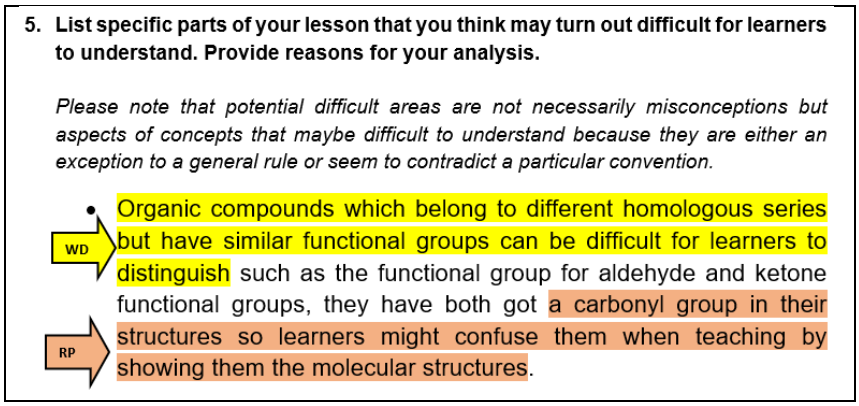


Figure 6.5: Extract of Ruth's identification of learners' difficulty in panning context

As shown in the Figure 6.5 above, Ruth highlighted learners' possibility difficulty relating to distinguishing aldehyde functional group from ketone functional group due to the similarity in their molecular structures and presence of carbonyl group in the molecules. This seemed to describe Ruth's understanding of what is difficult to understand (WD) accompanied with the use of symbolic representations (RP) as shown by the TSPCK map in the Figure 6.4 above.

The simple TSPCK episode (WD/RP) observed in the Ruth's lesson plan appeared to be expanded to a sophisticated TSPCK episode as she discussed aldehyde functional group with learners (see Table 6.3 above, 29-33 minutes). Ruth started by asking learners what they knew about aldehydes and their functional group in order to confirm their prior knowledge. The learners' responses revealed an understanding that, aldehydes are similar to ketone as they both have a carbonyl group included in their functional groups (LP). Taking learners' correct responses into consideration, Ruth cautioned learners about thinking that, ketones are the same as aldehydes because of their similar functional groups. As an important aspect she would want learners to understand, she drew on the chalk board the structures of aldehyde functional group and ketone functional group to explain the difference in how the carbonyl group is bonded in each case. This suggests the understanding of conceptual teaching strategy (CT) and use of symbolic representations (RP) demonstrated by Ruth in her teaching. In the course of her explanations, she made a statement that "….*carbonyl group is bonded to one alkyl group on one side and another alkyl group on the other side, it becomes difficult to distinguish between the two functional groups once we forget what is bonded to the central carbon atom on these two sides*". This statement seemed to reveal Ruth's effort in calling the learners' attention to what might lead to difficulty relating to distinguishing aldehydes from ketone thereby describing her knowledge

of TSPCK component WD. Following the explanations provided by Ruth, two learners (SF3 and SF4) correctly mentioned ethanal and ethenone as an example of aldehyde and ketone respectively thereby suggesting they understood the Ruth's explanations. The TSPCK maps demonstrating the simple TSPCK episode in planning context and sophisticated TSPCK episode in the actual teaching context are given in the Figure 6.6 below.

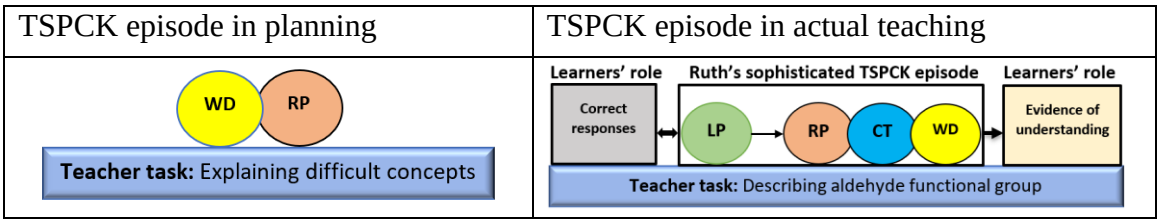


Figure 6.6: Ruth's TSPCK map in planning and actual teaching context

The Figure 6.6 above shows how a simple TSPCK episode in the planning context got expanded to a sophisticated TSPCK episode in making the learners understand the aldehyde functional group.

Hope's case

In her planning for the lesson, Hope's written explanations which demonstrated simple TSPCK episodes were observed to have emerged from the summary of content knowledge, identifying difficult concepts and summarizing teaching strategies as shown in the Figure 6.7 below.

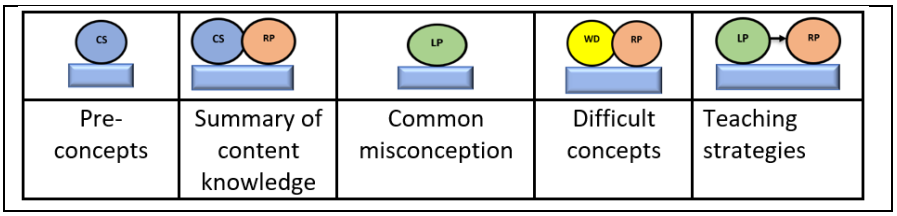


Figure 6.7: Emergence of TSPCK episodes from the Hope's lesson plan

As shown in the Figure 6.7 above, there were no TSPCK episodes in her written explanations on the immediate concepts (pre-concepts) and possible learners' misconceptions relating to the concepts of functional groups and nomenclature of organic compounds that her teaching focused on. An extract of her written explanations on what concepts might be difficult for learners to understand is given as shown in the Figure 6.8 below.

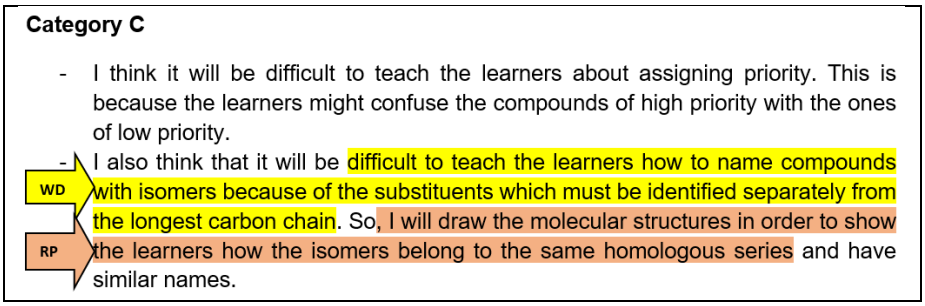
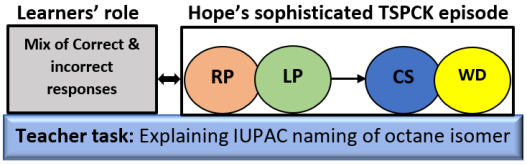


Figure 6.8: Extract of Hope's identification of learners' difficulty in panning context

As shown in the Figure 6.8 above, Hope related the difficulty in teaching IUPAC naming of isomers to identifying the longest carbon chain separately from the substituent group that may be present in the organic molecule. She also indicated her intention to use molecular structures in explaining such aspects to the learners. The written explanation seemed to suggest her understanding of what is potentially difficult (WD) and the use of symbolic representations (RP) as highlighted above.

In the actual classroom teaching of the same concepts, Hope's simple TSPCK episode demonstrated in the planning context appeared to be expanded as she discussed the naming of an isomer of octane with the learners. The extract of her discussions on naming 2-methylheptane following her explanation on naming octane (see Appendix XXVIII) is provided in the Table 6.4 below.

Table 6.4: Extract of Hope's teaching segment on naming 2-methylheptane

Lesson 1 (29-31 minutes)	**Comments/In-depth Qualitative Analysis**
Hope: Now let's see (*she drew the molecular structure of 2-methylheptane*), (**RP**) if we focus on the longest continuous chain (*she covered up the methyl group CH_3 with her palm*) so what is the prefix? SM2: It's gonna be hept Hope: Why? SM2: it's got 7 carbons Hope: Exactly, the prefix is gonna be hept according to our IUPAC nomenclature rule because we just look at the longest continuous chain and we have got seven carbon atoms bonded together with hydrogen atoms. (**LP**) Now, what do we call this type of molecule? SM3: organic compound Hope: What class? SM3: saturated hydrocarbons Hope: It's saturated hydrocarbon because? SF7: It's got single bond between all the carbons. Hope: Good, it's a saturated hydrocarbon because it has got only carbon to carbon covalent bonds so now here (*she pointed at the methyl group CH_3*) is our methyl group, it's a substituent. So now, at what carbon number is our methyl group? Yes? SM8: carbon 6 Hope: Carbon 6? SM9: carbon 2 Hope: Which one are we gonna take between carbon 2 and carbon 6? (*Learners' chorus answers….carbon 2….carbon 6…)* Hope: We need to remember our IUPAC rule. Now, if we count our longest carbon chain from right, we gonna have methyl group on carbon 6 right? Ss: yes Hope: That's gonna be 6-methyl what? SF2: heptane Hope: 6-methylheptane. And then, if we number our longest chain from the left here then, our methyl gonna be on carbon 2 and we gonna name it 2-methylheptane right? Ss: yes Hope: So, now since 2 is less than 6 and we have an alkane, then the correct name is 2-methylheptane, that's the correct name. So, now since we have got 8 carbon atoms in the whole molecule, then we call 2-methylheptane an isomer of octane. Both octane and 2-methylheptane are saturated hydrocarbons because of this single carbon to carbon covalent bonds (she pointed at the structure on the board), they both belong to the alkane homologous series remember that neh (**CS**) but what might be challenging is let's say one of this (she changed C-C to C=C on the board), that's a double bond and then, we have a substituent like that, then we must first consider the position of this double bond, don't confuse naming single covalent carbon-carbon with double covalent carbon to carbon, (**WD**) ok we gonna discuss that later. Any question on naming alkanes? *There was no response from learners.*	**Comment**: This teaching segment focused on naming an isomer of octane (2-methylheptane). **In-depth qualitative analysis** ***Hope's role***: Using the molecular structure of 2-methylheptane drawn on the chalk (RP), Hope asked about the prefix for the molecule, the understanding she expected them to have acquired from her previous discussions with them. ***Learners' role***: Learner SM2 showed a good existing knowledge of prefix hept for 7 carbon atoms in the longest continuous chain. Learner SM3 further showed the understanding that the molecule is a saturated hydrocarbon because of the single covalent bonds (LP). ***Hope's role***: Hope further asked learners about the position of the methyl group. ***Learners' role***: Learners gave a mixed of correct and incorrect responses regarding numbering the longest carbon chain (LP). ***Hope's role***: As a strategy for naming the molecule, Hope involved the learners in first numbering from the right and then from the left in order to show the learners both the correct (2-methylheptane) and wrong (6-methylheptane) name. She also referred to the molecule as an isomer of octane previously discussed with emphasis on their C-C bond. This describes Hope's understanding of symbolic representation (RP) in teaching what is important for learner to know, an element of curricular saliency (CS). She referred to a challenging aspect, naming differently when there is a double carbon to carbon covalent bond where the position of the double bond must first be considered in naming. This suggests Hope's understanding of what might be difficult for learners (WD). The Hope's understanding of the interactive use of TSPCK components (RP/LP-CS/WD) at a sophisticated level of TSPCK episode linked to learners' mix of correct and incorrect responses is provided in the TSPCK map below. 

The TSPCK maps demonstrating the simple TSPCK episode (WD/RP) in planning context and sophisticated TSPCK episode (RP/LP-CS/WD) in the actual teaching context are given in the Figure 6.9 below.

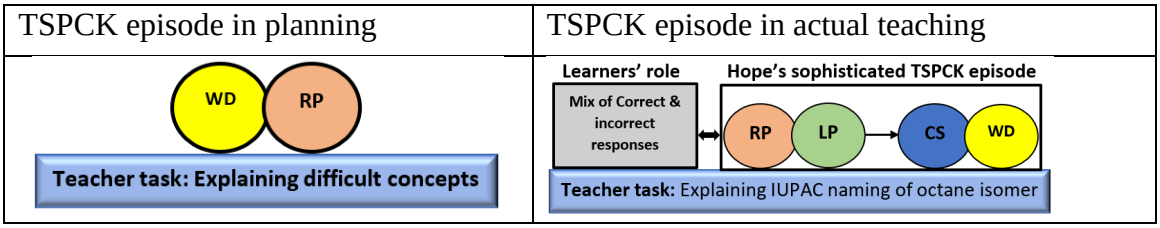


Figure 6.9: Hope's TSPCK map in planning and actual teaching context

The Figure 6.9 above shows how a simple TSPCK episode in the planning context got expanded to a sophisticated TSPCK episode in making the learners understand the aldehyde functional group.

Rose's case

In the Rose's lesson plan on the concepts of physical properties and structures of organic compounds, there were five instances written explanations from which simple TSPCK episodes emerged. The emergence of TSPCK episodes is provided as shown in the Figure 6.10 below.

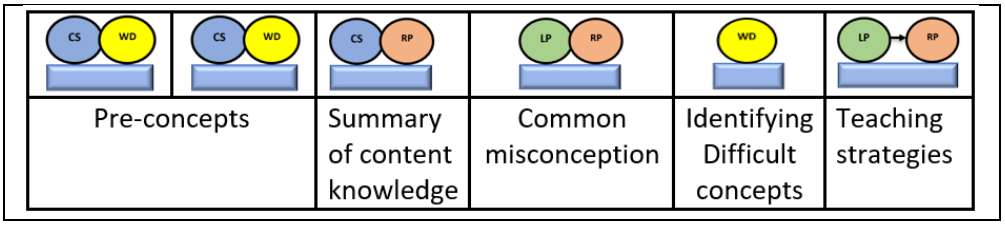


Figure 6.10: Emergence of TSPCK episodes from the Rose's lesson plan

Except on the identification of difficult concepts, simple TSPCK episodes emerged from Rose's written explanations on the immediate concepts, summary of content knowledge, common misconceptions and teaching strategies. The extract of Rose's written explanations on the immediate concepts (pre-concepts) is given in the Figure 6.11 below.

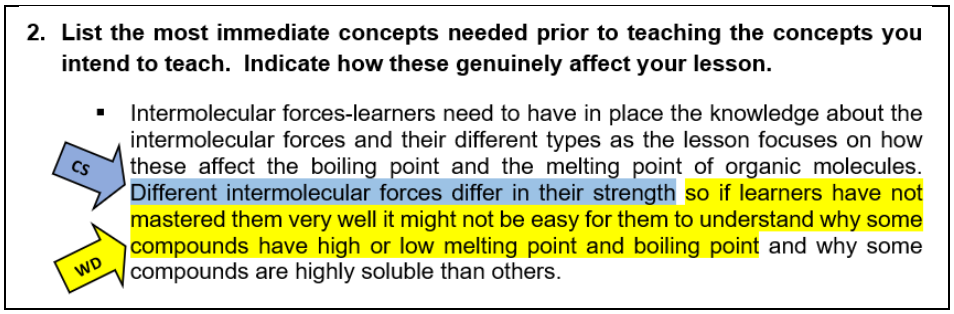
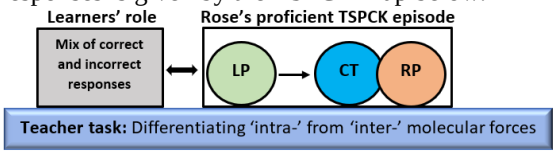


Figure 6.11: Extract of Rose's explanations on most immediate concepts

As shown in the Figure 6.11 above, Rose identified learners' prior knowledge of different types of intermolecular forces as necessary for understanding the influence of intermolecular forces on the boiling point and melting point of organic compounds. As an important aspect of this prior knowledge, she referred to the strength of intermolecular forces (CS), an element of curricular saliency. She further explained how difficult it might be learners to understand the current concepts without good mastery of the strength of intermolecular forces. This seems to describe Rose's knowledge of what is potentially difficult for learners (WD).

An extract of the detailed analysis of Rose's discussions relating to the intermolecular forces during the actual classroom teaching is presented in the Table 6.5 below.

Table 6.5: Extract of Rose's teaching segment on intermolecular forces

Lesson 1 (31-35min): Teaching segment focusing on intermolecular forces	**In-depth Qualitative Analysis**
Rose: Now, if you were given this as a question, say between propane and propanol, which one is gonna have the high boiling point, like if you compare the two between the propane and propanol? What's gonna be your answer and you have to give a reason for that? SM5: it's propanol **Rose**: why? SM5: because propanol has got a weak intramolecular force **Rose**: A weak intramolecular force? SM5: yes SM6: the propanol has got weak intermolecular forces **Rose**: A weak intramolecular force, versus weak intermolecular forces, interesting. Which one are we gonna take? Let's write it down, what do you guys mean by intermolecular forces? *There was no response?* **Rose**: Ok, anyone who agrees? Anyone who disagrees? *There was no response from learners* **Rose**: Are the intermolecular forces the same as intramolecular forces? SM1: No **Rose**: Why? *There was no response from learners* **Rose**: Intramolecular forces are not the same as the intermolecular forces as some may think, (**LP**) although they are both forces when we talk about chemical substances. When we talk of intra and inter guys (she wrote 'intra' and 'inter' on the chalk board), for intramolecular forces, we look at the forces between the atoms found inside a single molecule, please note here we refer to forces within a molecule for example *(She the put the ionic equation of NaCl on the board*), within NaCl, we've got ionic bond bringing Na^+ and Cl^- together, (**RP**) but the intermolecular forces, exist between molecules, it's the force between molecules in this case, just like the interaction between positively charged part of a molecule with negatively charged part of a neighbouring molecule, (**CT**) we call this example dipole-pole interactions, you can remember that from Grade 11 right?	**Comment**: This segment was initially meant to discuss the boiling point of propane in comparison to that of propanol but because of the mix of learners' correct and incorrect responses to the question asked, the attention was directed to explaining the difference and similarity between intermolecular forces and intramolecular forces. **In-depth Qualitative Analysis** **Rose's role**: Rose probed learners' prior knowledge of which one between propane and propanol would have a high boiling point **Learners' role**: Learners' responses showed inability to clearly differentiate intermolecular forces from intramolecular forces (LP). **Rose's role:** Taking the learners' inability to explain the difference between intermolecular forces and intramolecular forces into consideration, Rose first indicated to the learners that, both forces are associated with chemical substances. This shows her understanding of the similarity between them. She further differentiated the two molecular forces by emphasising 'forces within a molecule for intramolecular forces' and 'forces between molecules' for intermolecular with reference made the ionic equation of sodium chloride write on the board. This suggests Rose's understanding of conceptual teaching strategy (CT) and use of a symbolic representation (RP). Rose's interactive use of TSPCK components (LP-CT/RP) at a proficient level of TSPCK episode in connection to the learners' correct and incorrect responses is given by the TSPCK map below. 

The Rose's TSPCK maps demonstrating a simple TSPCK episode in planning context and proficient TSPCK episode in the actual teaching context are given in the Figure 6.12.

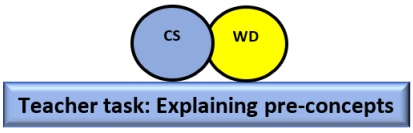
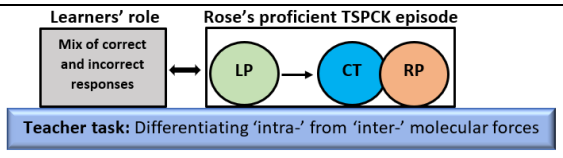
TSPCK episode in planning	TSPCK episode in actual teaching
	

Figure 6.12: Rose's TSPCK map in planning and actual teaching context

The Figure 6.12 above shows how a simple TSPCK episode in the planning context got expanded to a proficient TSPCK episode in making the learners understand the difference between intermolecular forces and intramolecular forces.

Mark's case

In the Mark's lesson plan on the concepts of physical properties and structures of organic compounds, there were five instances of written explanations from which simple TSPCK episodes emerged. The emergence of TSPCK episodes is provided as shown in the Figure 6.13 below.

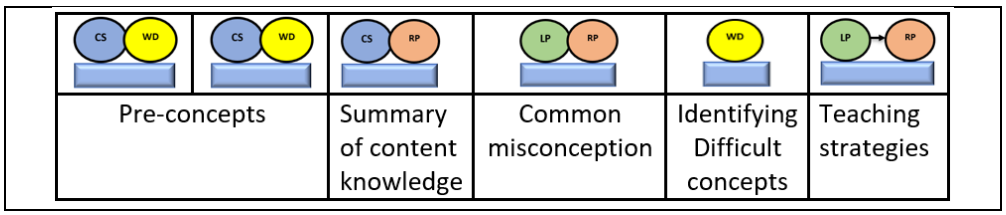
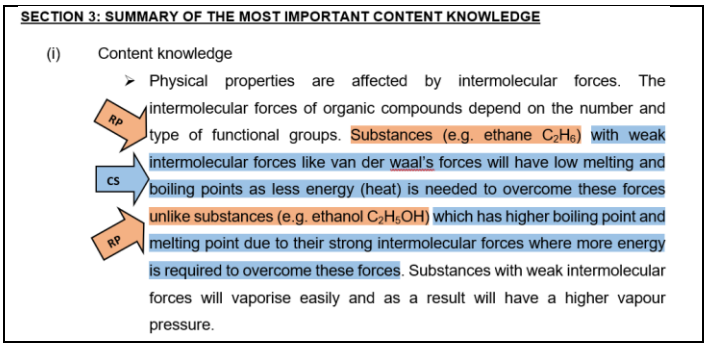


Figure 6.13: Emergence of TSPCK episodes from the Mark's lesson plan

Except on the identification of difficult concepts, simple TSPCK episodes emerged from Mark's written explanations on the immediate concepts, summary of content knowledge, common misconceptions and teaching strategies. The extract of Mark's written explanations on the summary of most important content knowledge is provided in the Figure 6.14 below.


SECTION 3: SUMMARY OF THE MOST IMPORTANT CONTENT KNOWLEDGE

(i) Content knowledge

- Physical properties are affected by intermolecular forces. The intermolecular forces of organic compounds depend on the number and type of functional groups. Substances (e.g. ethane C_2H_6) with weak intermolecular forces like van der waal's forces will have low melting and boiling points as less energy (heat) is needed to overcome these forces unlike substances (e.g. ethanol C_2H_5OH) which has higher boiling point and melting point due to their strong intermolecular forces where more energy is required to overcome these forces. Substances with weak intermolecular forces will vaporise easily and as a result will have a higher vapour pressure.

RP
CS
RP

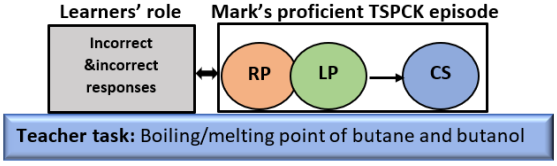
Figure 6.14: Extract of Hope's explanations on content knowledge

As shown in the Figure 6.14 above, Mark pointed out how the strength of intermolecular forces affects the melting point and boiling point and melting point of ethane and ethanol. This seems to describe Mark's understanding of a key aspect, relating to the intermolecular forces in understanding physical properties of organic compounds, an element of curricular saliency (CS).

He could also be observed to have referred to the chemical formulas for ethane and ethanol, thereby describing his understanding of symbolic representations (RP).

From the detailed analysis of his actual teaching attached as Appendix XXX, there was a teaching segment where Mark discussed the melting and boiling point of an alkane and alcohol with reference made to the intermolecular forces. The extract of such teaching segment is provided as shown in the Table 6.6 below.

Table 6.6: Extract of Mark's teaching segment on butane versus butanol boiling point

Lesson 2, 18-23minutes -	**In-depth Qualitative Analysis**
Mark: Now, each of those homologous series is identified by a functional group. Let's say (*In the molecular structure of butane on the chalk board, Mark replaced H on the first carbon with OH such that butane becomes butanol*) yeah, now let's compare it to the butane here (*He drew the molecular structure of butane again*) (**RP**), so is this gonna affect the melting point and boiling point? What can we say about the melting point and boiling point of butanol and butane here? SM8: Butane is stronger than butanol so it's gonna have higher melting point and boiling point. Mark: What do we mean by butane is stronger? SM8: ….There was no response from SM8…. **SM9**: I think the melting point and the boiling point of butanol are gonna be higher than that of butane **Mark**: the melting point and the boiling point of butanol are gonna be higher than butane according to him, the reason being? SM9: Butanol has got strong intermolecular forces **Mark**: Indeed, butanol is gonna have high melting point and boiling point because it has strong intermolecular forces ok (**LP**). The hydroxyl functional group is the key, it's our OH (*He pointed at the molecular structure on the board*) commonly identified with the alcohols homologous series, **(CS)** so butanol has melting and boiling point stronger than butane.	**Mark's role**: With reference to the structures of butane and butanol on the board (**RP**), Mark asked learners if the hydroxyl group in butanol was going to make its boiling point and melting point different from that of butane. **Learners' role**: Learner SM8 wrongly stated that, butane is stronger than butanol and hence, butane would have high melting point and boiling point. However, Learner SM9 correctly responded by stating higher melting point and boiling point in butanol than in butane. The learner also added that, butanol has stronger intermolecular forces than butane, the reason for the difference in melting point and boiling point (**LP**). **Mark's role:** Mark further confirmed the learner's correct prior understanding by re-stating the learner's response. With reference to the molecular structure of butanol, Mark referred learners to the presence of hydroxyl which is known to be the functional group of all alcohols. This seems to describe Mark's understanding of hydroxyl functional as an important aspect of alcohols. This is an element of curricular saliency (CS). Mark's interactive use of TSPCK components (RP/LP-CS) in connection to the learner' correct and incorrect responses is given by the TSPCK map below. 

As provided in the Table 6.6 above, Mark's explanations during the actual classroom teaching seemed to demonstrate understanding of the interactive use of three TSPCK components (RP/LP-CS) building on his written explanations (CS/RP) in the lesson plan. The Figure 6.15

below summarizes the change observed in the simple TSPCK episode demonstrated in planning versus the proficient TSPCK in the actual teaching.

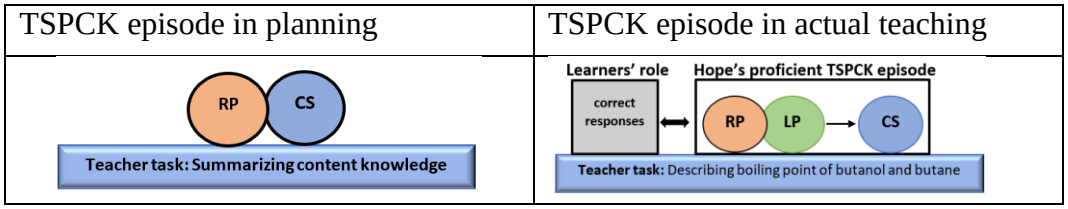


Figure 6.15: Mark's TSPCK map in planning and actual teaching context

The Figure 6.15 above shows how a simple TSPCK episode in the planning context got expanded to a proficient TSPCK episode in making the learners understand the difference between intermolecular forces and intramolecular forces.

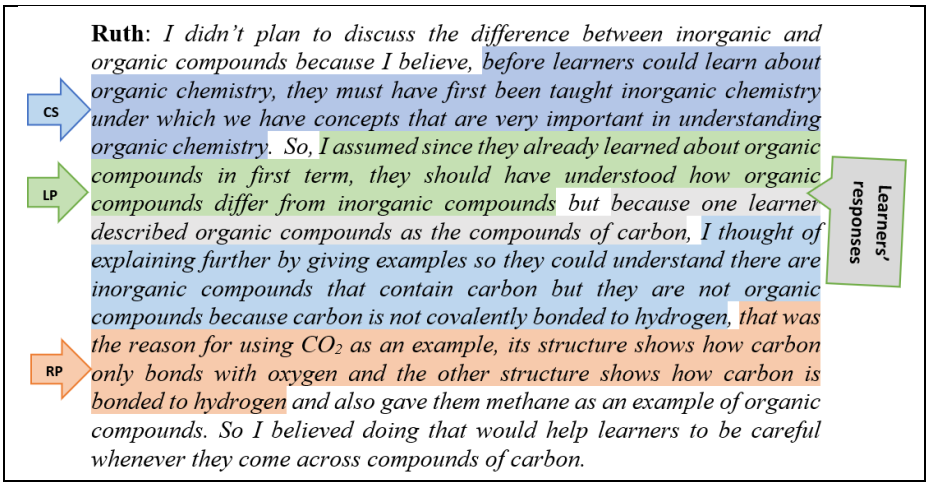
Finding 3: Development of TSPCK episodes prompted by learners' responses

I. Emergence of new TSPCK episodes linked to learners' unexpected responses

A careful examination of PSTs' actual teaching indicates certain teaching segments where there appeared to be unplanned instructional decisions made by the PSTs. These have been referred to as unplanned instructional decisions because the concepts on which they provided explanations at such moments were not highlighted in their lesson plans. At such moments, the new TSPCK episodes emerged from the PSTs' explanations were triggered by unexpected learners' responses to the questions posed.

Ruth's case: In the detailed analysis of her Lesson 1 (2-4 minutes) provided in the Table 6.2 above, Ruth's discussion centred on describing organic but based on the learners' responses, the discussions differentiated organic compounds from inorganic compounds. Ruth first asked learners what they could say about organic compounds by recalling what they previously learnt. Two learners correctly referred to organic compounds as the "compounds of carbon" and "organic compounds are made up of carbon and hydrogen" which confirmed the correct prior understanding they brought into the discussion (LP). In her response to the description of organic compounds as the "compounds of carbon", Ruth cautioned learners about assuming that all compounds of carbon are organic compounds. She cited carbon dioxide with its structure as an example of a compound of carbon but which is not an organic compound with the emphasis that, carbon is not covalently bonded to hydrogen in the molecule. This describes Ruth's

understanding of a possible misconception (LP) that could emanate from assuming that, all compounds of carbon are organic compounds and it also points at the Ruth's knowledge of what is important to emphasize, an element of curricular saliency (CS). The explanation also describes Ruth's understanding of the use of a symbolic representation (RP). She further expatiated on the second description that, organic compounds are made up of carbon and hydrogen by emphasizing carbon covalently bonded to hydrogen using the structure of methane. The emphasis on what is important for learners to know is an element of curricular saliency (CS). Ruth's entire explanations demonstrated understanding of the interactive use of TSPCK components (LP-RP/CS) at a proficient level of TSPCK episode triggered by the learners' correct responses. During the stimulated recall interview, Ruth commented on the reason for this unplanned instructional decision centred on differentiating between organic compounds and inorganic compounds. The extract of her response is provided in the Figure 6.16 as follows.



Ruth: *I didn't plan to discuss the difference between inorganic and organic compounds because I believe, before learners could learn about organic chemistry, they must have first been taught inorganic chemistry under which we have concepts that are very important in understanding organic chemistry. So, I assumed since they already learned about organic compounds in first term, they should have understood how organic compounds differ from inorganic compounds but because one learner described organic compounds as the compounds of carbon, I thought of explaining further by giving examples so they could understand there are inorganic compounds that contain carbon but they are not organic compounds because carbon is not covalently bonded to hydrogen, that was the reason for using CO_2 as an example, its structure shows how carbon only bonds with oxygen and the other structure shows how carbon is bonded to hydrogen and also gave them methane as an example of organic compounds. So I believed doing that would help learners to be careful whenever they come across compounds of carbon.*

Figure 6.16: Ruth's comment 1 during the stimulated recall interview

From the Ruth's comments in the Figure 6.16 above, she believed the understanding of organic chemistry builds on the concepts of inorganic chemistry. This is considering inorganic chemistry as the pre-concept for teaching organic chemistry which shows an element of curricular saliency (CS). She further indicated her assumption that, learners should have mastered how organic compounds differ from inorganic compounds based on their previous lessons. This is an element of Learner Prior Knowledge (LP). She indicated that, due to a learner's description of organic compounds as the compounds of carbon, she realized the need to make them understand not all compounds of carbon (e.g. carbon dioxide) are organic compounds. This is an element of a potential misconception (LP) linked to what is important for learners to understand (CS). This

means that, Ruth's decision to differentiate organic compounds from inorganic compounds was linked to a learner's response that needed more clarifications. In achieving this, she drew the structure of carbon dioxide and methane to explain how carbon must covalently bond to hydrogen before a compound could be regarded as an organic compound. This suggests Ruth's understanding of the use of symbolic representations (RP) in explaining what is important for learners to understand (CS). This observed Ruth's reasoning appears to unfold additional TSPCK episodes (CS/LP/RP) not seen in her lesson plan but reflecting the dynamic nature her enacted TSPCK in the actual classroom setting. It reveals her pedagogical strategy of first investigating learner prior knowledge and then expatiating on the learners' response by emphasizing what is important using a symbolic representation.

Likewise, Ruth's teaching segment focusing on Thiols as shown in the Table 6.1 above, lesson 1 (18-20minutes) was examined during the stimulated recall interview. Looking at the Ruth's lesson plan (see Appendix XXXI), Thiol functional group was not among the functional groups she listed to discuss with learners but she was found explaining Thiols during her teaching. In organic chemistry, thiols are regarded as the organosulfur compounds, the analogue of alkanols. Ruth commented on why she decided to talk about Thiols and differentiate them from alcohols in her teaching. The extract of her comments is given in the Figure 6.17 below.

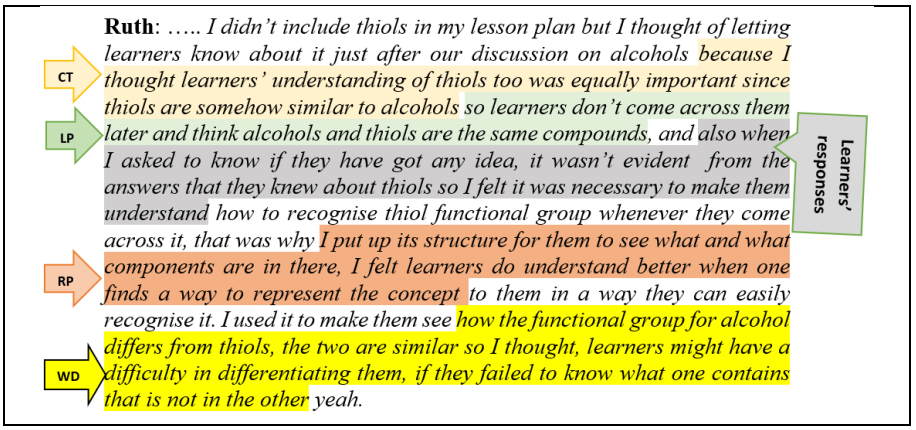


Figure 6.17: Ruth's comment 2 during the stimulated recall interview

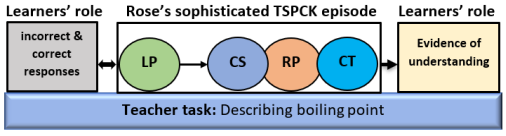
As shown in her comments (Figure 6.17) above, Ruth thought of teaching learners the alcohol and thiol functional group side by side because of their similarities. This shows her knowledge of conceptual strategy (CT) as described by the variation theory (Bussey *et al*. 2013). She realized that learners could "think alcohols and thiols are the same compounds" whenever they

come across the two concepts if they had not been taught. This suggests the understanding possessed by Ruth about a possible learner misconception, an element of Learner Prior Knowledge (LP). Her intention to explain these concepts was further prompted by the learners' inability to correctly refer to thiols when she asked them about a similar organic compound to alcohols. She eventually explained the concepts by using symbolic representations (RP) of thiol and alcohol functional groups with the knowledge that, such ways of presenting concepts enhance learners' understanding. She associated efforts put into explaining the constituents of each functional group to a possible difficulty in differentiating between the two concepts. This describes her understanding of what could be considered potentially difficult for learners (WD) as observed in her teaching. Similar cases of other PSTs are discussed below.

Hope's case: A teaching segment in Hope's lessons with the emergence of a new TSPCK episode happened in Lesson 1, 4-6 minutes (see Appendix XXVIII) as Hope discussed inorganic compounds with the learners with the intention of making learners to understand not all carbon-containing compounds are organic compounds. The critical examination of Hope's lesson plan reveals no instance of explanations relating to describing organic and inorganic compounds with emergence of a TSPCK episode. However, Hope's explanations in the classroom on this concept showed an understanding of TSPCK components (LP-CT/RP) at a proficient level of TSPCK episode.

Rose's case: There were efforts made during the post-lesson interview to look into the Rose's lesson plan and what she eventually did in the classroom with the purpose of understanding the reasons for her instructional decisions. Rose was observed to have spent some time on explaining boiling point and differentiating boiling from evaporation, the concepts not specifically highlighted in her lesson plan. As shown in the Appendix XXIX, the extract of her teaching segments on these concepts are provided in the Table 6.7 below.

Table 6.7: Extract of Rose's teaching segment on describing boiling points

Lesson 1, 4-8 minutes: Boiling point of liquids	**Comments/In-depth qualitative analysis**
Rose: So, guys since you did those things already before now, let me hear from you guys what is boiling point? **SM1**: boiling point is like the vapour pressure equals to the atmospheric pressure **Rose**: Guys, remember boiling point was one of the basic stuff you learned in Grade 11 right? **Ss**:…(yes) **Rose**: So, anyone who wants to add something to what said? *(No response from learners)* **Rose**: In terms of phases, what can you say? Like the state of reactants what can you say? Those things like solids and gases. When you say something is boiling, what does it mean? When you boil water in a kettle as we do in our homes whenever we wanna make tea, what does it mean? SF2: It goes from liquid to gas **Rose**: That's right, when you heat a liquid, it changes to gas, vapour right (**LP**). But does that mean boiling has taken place? I think you must know that boiling point is actually a particular temperature (**CS**) so it would have been perfect if the boy over there had described boiling point as temperature at which the vapour pressure equals to the atmospheric pressure, ok and that girl also said when we boil water, it goes from liquid to gaseous state, very correct but, that isn't the boiling point, you don't think when you supply heat to a liquid and it changes to gas then it has reached the boiling point, no! let's say here is a kettle containing water (*she drew a kettle of water heated and particles evaporating*), you see, (**RP**) the moment you heat up, evaporation begins, you see water molecules gradually becoming vapours, that's evaporation, it occurs at all temperatures but water only boils when it has reached a constant temperature which we call the boiling point, (**CT**) do you understand that now? **Ss**: yes **SF3**: Ma'am, that means both evaporation and boiling cause water to change from liquid to vapour right? **Rose**: Exactly, so the boiling point is the temperature at which the vapour pressure equal to the atmospheric pressure when a liquid is heated.	**Comment**: This segment focused on describing the concept of boiling point of liquids. Rose asking learners questions before providing explanations. **In-depth Qualitative Analysis**: **Rose's role**: In an attempt to probe learners' prior understanding of what they had previously learned, Rose asked learners to describe the term 'boiling point'. **Learners' role**: Learner SM1 described boiling point as equal to the atmospheric pressure whereas boiling point is considered a temperature at which the vapour pressure equals the atmospheric pressure, the correct knowledge Rose expected learners to have in place (LP). To the Rose's question asking about what happens when water boils in a kettle, learner SF2 described it as a change of state from a liquid state to a gaseous state. **Rose's role**: Rose emphasized to the learners that, by boiling point, a particular temperature is being referred to, thereby describing her understanding of what could be considered important for learners to know, an element of curricular saliency (CS). She further illustrated the similarity and difference between boiling, boiling point and evaporation with the diagram of a kettle of water being heated drawn on the chalk board (RP). This she did to make the learners understand the fact that, unlike boiling, evaporation occurs at every temperature. Such knowledge of pointing out the similarity and difference between concepts describes Rose's understanding of a conceptual teaching strategy (CT). Rose's understanding of interactive use of TSPCK components (LP-CS/RP/CT) at a sophisticated level of TSPCK episode in connection to the learner's correct and incorrect response is given by the TSPCK map below. 

On the extract of teaching segment provided in the Table 6.7 above, Rose was asked during the stimulated recall interview the reason behind her instructional decision for the explanations above. The extract of her response is given as shown in the Figure 6.18 below.

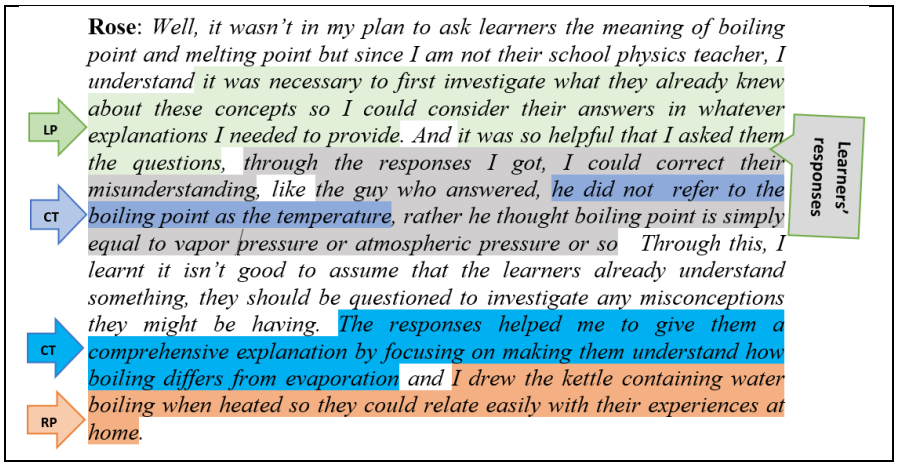
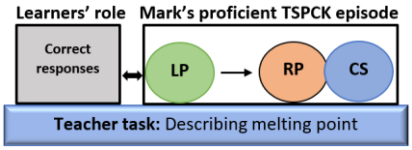


Figure 6.18: Rose's comment during the stimulated recall interview

The Rose's comments during the stimulated recall interview as given above further speak to her unplanned decision to elaborate on the boiling point and differentiate boiling from evaporation. First, her understand of learner prior knowledge (LP) reflects in her statement "*it was necessary to first investigate what they already knew about these concepts so I could consider their answers in whatever explanations I needed to provide…*". Her expectation was that, the learners should have understood how to correctly describe boiling point and bring that understanding as the prior knowledge into the discussion. Second, her comment *"…through the responses I got, I could correct their misunderstanding, like the guy who answered, he did not refer to the boiling point as the temperature, rather he thought boiling point is simply equal to vapor pressure or atmospheric pressure or so*" further confirmed the learner's incorrect response as the reason for the kind of explanation she provided during her teaching. Her comments also showed her understanding of what was important to emphasis to the learners (boiling point as a particular temperature) an element of curricular saliency (CS) and evaporation as occurring at all temperatures compared to boiling which occurs at a particular temperature, an element of conceptual teaching strategy (CT). Rose's overall comments during the interview seemed to be consistent with the TSPCK components (LP-CS/RP/CT) observed to have emerged from the explanations she provided during her teaching.

Mark's case: One instance of unplanned instructional decision in Mark's teaching was when he was observed discussing melting and melting point with learners. The detailed analysis of his teaching as provided in the Appendix XXX is given in the Table 6.8 below.

Table 6.8: Extract of Mark's teaching segment on describing melting points

Lesson 1, 15 – 18 minutes	**Comment/In-depth qualitative analysis**
Mark: Alright, now let's look at the melting point as one of the physical property, so now what do we mean by melting point, what happens when melting of a compound takes place? **SM3**: Melting happens when a solid substance changes into a liquid substance, there is a phase change. **Mark**: That was a nice contribution. What can you say about melting point? **SM4**: melting happens at the melting point **Mark**: Yeah, when something changes from solid to liquid it melts (**LP**) just like when you put ice in here (*He faced the chalk board and drew a cup containing ice cubes*), that's ice in the cup right, (**RP**) and then, you go away, the important thing happening here is that, as temperature increases, the particles gain more energy to move, so the ice begins to melt, it eventually turns into water, a liquid form (**CS**). So, melting is the change of state from solid to liquid, and you notice the phase change occurs because the temperature changes too, so note that it begins at a certain temperature that a substance begins to melt so we say the melting point is the temperature at which a solid changes into a liquid and so, now that you know melting point. Ss: yes	**In-depth Qualitative Analysis**: **Mark's role**: Before providing an explanation, Mark asked learners about melting point as a physical property and what happens when a compound melts. **Learners' role**: Learner SM3 correctly described melting as a phase change from solid to liquid however; he did not talk about melting point. Likewise, learner only referred to melting as occurring at the melting point, what melting point means was not coming out clearly (LP). **Mark's role**: Mark expatiated on the learners' correct responses regarding melting as the phase change. He referred to the structure of a cup of ice drawn on the chalk board to illustrate this. This describes his understanding of the use of symbolic representation (RP). Most importantly, he described melting point as the temperature at which melting takes place. The emphasis Mark put on the "certain temperature" while describing melting point talks to his understanding of what is important for learners to understand, an element of curricular saliency (CS). Mark's interactive use of TSCK components (LP-RP/CS) at a proficient level in connection to the learners' correct responses is given by the TSPCK map below. 

During the stimulated recall interview, Mark highlighted the reason for his unplanned decision to provide the above explanations as follows:

> ..... *I discovered none of the learners who volunteered to explain melting and melting point specifically referred to melting point as a certain temperature, to me it was important for the learners to understand that, melting point is not a process like melting, it is actually a particular temperature at which a solid changes to liquid as I made them to understand.*

Mark's explanation in the above teaching segment was prompted by his knowledge of what he considered important for the learners to understand which was missing from their answers to the question he asked them about melting point.

II. General TSPCK episodes linked to learners' responses

Ruth's case:

With reference to the detailed analysis of Ruth's lessons presented in the Table 6.1 and attached as Appendix XXVII, the emergence of identified TSPCK episodes were observed to be linked to learners' responses during her teaching segments. At such teaching segments, Ruth seemed to have applied certain Pedagogical Knowledge Strategies (PKS) associated with her explanations from which TSPCK episodes emerged. The Figure 6.19 provides the overview of Ruth's PKS with the associated TSPCK episodes.

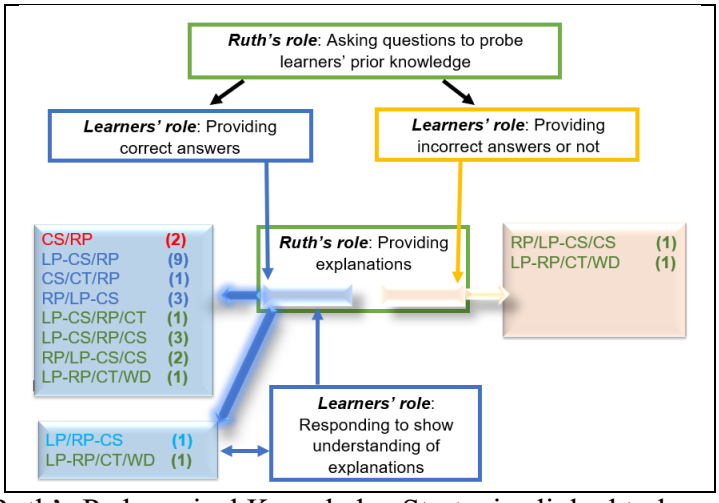


Figure 6.19: Ruth's Pedagogical Knowledge Strategies linked to learners' responses

As shown in the Figure 6.19 above, all identified simple TSPCK episodes (n=2), proficient TSPCK episodes (n=14), and most sophisticated TSPCK episodes (n=8) emerged from the Ruth's explanations associated with the learners' correct responses to the questions posed. Noticeably in this category, there was one proficient TSPCK episode and one sophisticated TSPCK episode associated emerging from Ruth's explanations which appeared to be accompanied with the instant evidence of learners' understanding of the concept discussed. Also, there were two sophisticated TSPCK episodes emerging from Ruth's explanations associated with learners' incorrect responses to the questions posed.

Hope's case:

During the stimulated recall interview, Hope made a few comments on the reasons for the pedagogical teaching strategies she employed during her teaching. The extract of her comments is provided as shown in the Figure 6.20 below.

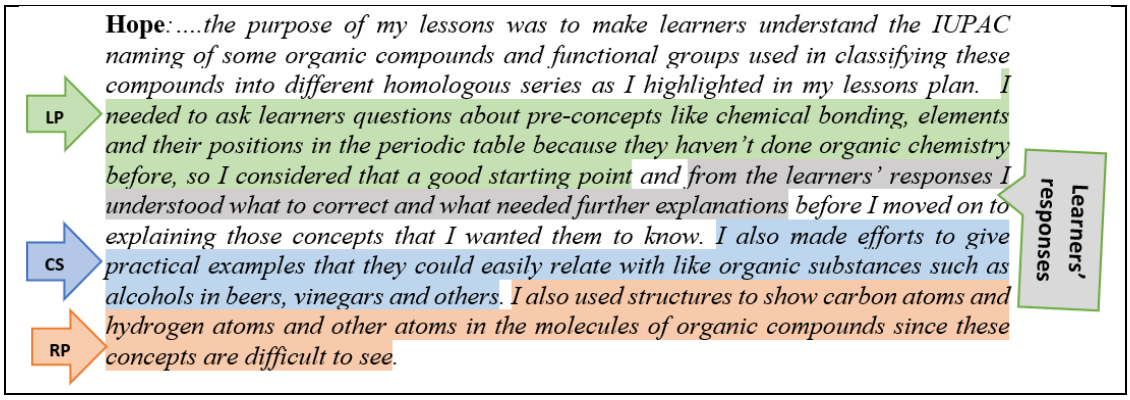


Figure 6.20: Hope's comment on teaching strategies during the stimulated recall interview

The extract of Hope's comments in the Figure 6.20 above revealed her understanding of the knowledge of pre-concepts that learners should have acquired before learning the concepts of organic chemistry. She found out this learners' understanding by asking them questions. This further confirmed her understanding of learner prior knowledge (LP) identified in her teaching. She mentioned the importance of learners' responses which served as a mediating factor in helping her to determine what further explanations learners needed. She pointed out giving familiar examples which learners could easily relate with in explaining the concepts. She indicated the place of using structures to help learners with the abstract aspects thereby describing her understanding of and the reason for the use of a symbolic representation identified in her teaching. Overall, there were instances in Hope's lessons where Hope probed learner prior knowledge and then expatiated on the learners' correct responses. There were also instances where Hope directly provided the required knowledge without investigating learner prior knowledge. With reference to the detailed analysis of Hope's lessons attached as Appendix XXVIII and the illustrated sample in the Table 6.4 above, the emergence of TSPCK episodes in Hope's teaching associated with the strategies she employed is given as shown in the Figure 6.21 below.

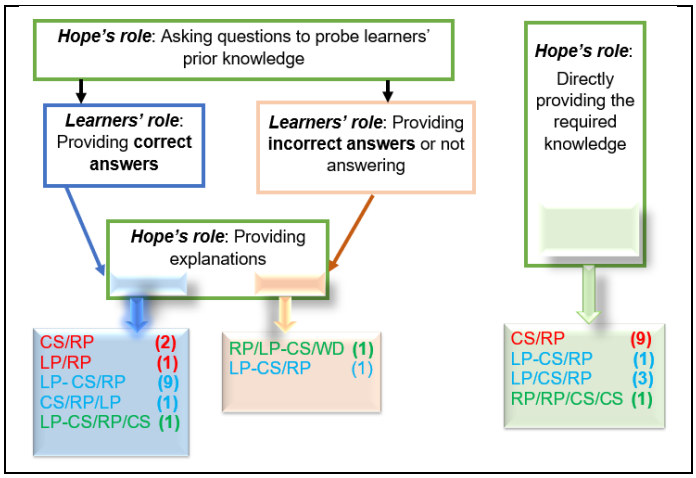


Figure 6.21: Hope's Pedagogical Knowledge Strategies linked to learners' responses

As shown in the Figure 6.21 above, there were 3 simple TSPCK episodes, 10 proficient TSPCK episodes and 1 sophisticated TSPCK episode emerging from Hope's explanations associated with the learners' correct responses to the questions posed. Also, 1 proficient TSPCK episode and 1 sophisticated TSPCK episode were linked to Hope's explanations associated with the learners' incorrect responses to the questions posed. Most of the identified Hope's simple TSPCK episodes (n=9) were emerging from her direct explanations which did not necessarily draw on the learners' responses. There were also 4 proficient TSPCK episodes and 1 sophisticated TSPCK episode connected with the direct explanations that Hope provided during her teaching.

Rose's case:

With reference to the detailed analysis of Rose's lessons attached as Appendix XXIX and the illustrated sample in the Table 6.7 above, the emergence of TSPCK episodes in Rose's teaching associated with the strategies she employed is given as shown in the Figure 6.22 below. Rose's had all of her simple TSPCK episodes (n=2), most of her proficient (n=8) and some sophisticated (n=2) TSPCK episodes associated with her explanations which drew on the learners' correct responses to the questions she asked to probe their prior knowledge. Her remaining proficient (n=5) and most sophisticated (n=3) TSPCK episodes appeared to have emerged from the explanations she provided while addressing learners' incorrect responses to the questions asked in other to probe their probe knowledge of concepts. Noticeably, there were 9 teaching segments

where the learners' responses following the explanations provided by Rose suggested that they understood Rose's explanations.

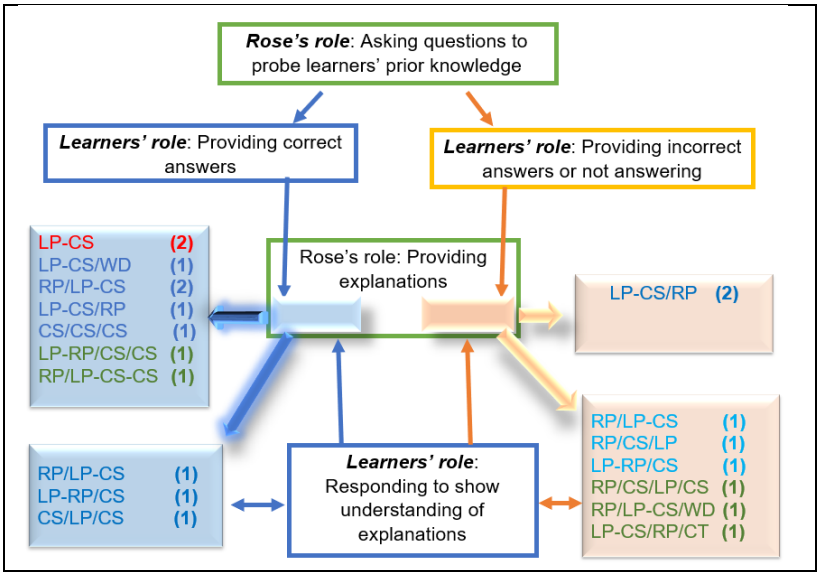


Figure 6.22: Rose's Pedagogical Knowledge Strategies linked to learners' responses

Mark's case:

During the stimulated recall interview, Mark made a few comments on the reasons for the pedagogical teaching strategies he employed during his teaching. The extract of his comments is provided as shown in the Figure 6.23 below.

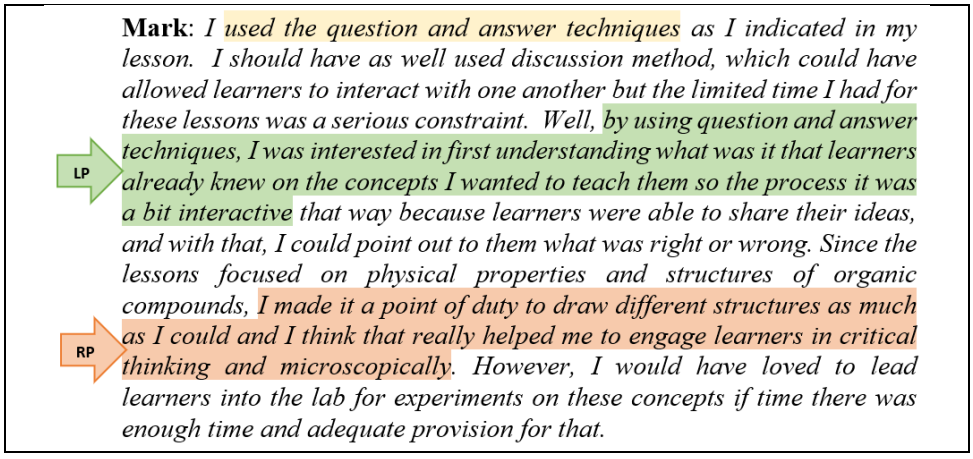


Figure 6.23: Mark's comment on teaching strategies during the stimulated recall interview

The extract of Mark's comments in the Figure 6.23 above revealed his use of questioning techniques to probe learner prior knowledge before providing explanations on the important

concepts she wanted them to learn. He also indicated engaging learners in critical thinking and microscopically as the reason for the use of use of symbolic representations in his teaching. His reflection on the pedagogical strategies employed revealed his ability to engage learners in discussions and taking them into the laboratory for macroscopic demonstrations of the concepts taught. With reference to the detailed analysis of Mark's lessons attached as Appendix XXX and the illustrated sample in the Table 6.6 above, the emergence of TSPCK episodes in Mark's teaching associated with the strategies he employed is shown in the Figure 6.24 below.

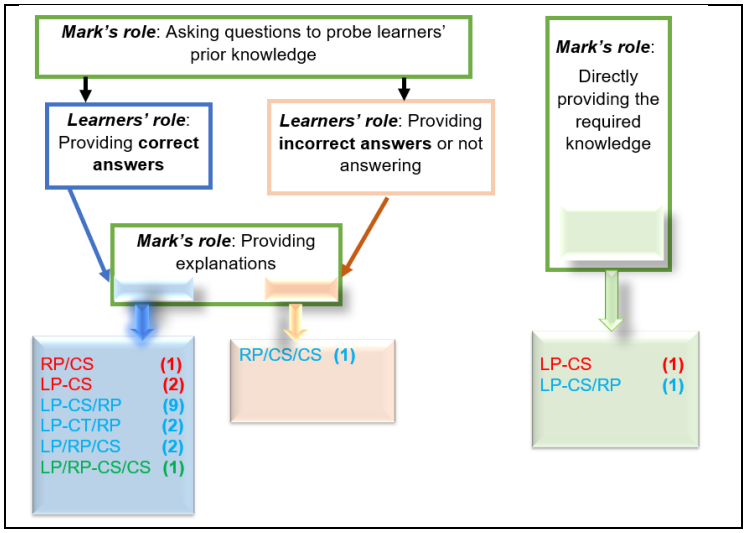


Figure 6.24: Mark's Pedagogical Knowledge Strategies linked to learners' responses

As shown in the Figure 6.24 above, the Mark's sophisticated TSPCK episode, most of his simple TSPCK episodes (n=3) and proficient TSPCK episode (n=13) were connected to his explanations that expatiated on the learners' correct responses to the questions asked. Also, there was one proficient TSPCK episode emerging from Mark's explanations associated with the learners' incorrect responses to the questions posed. One simple TSPCK episode and one proficient TSPCK episode were also observed to have emerged from the Mark's explanations which did not associate with the learners' responses.

Finding 4: Congruency between the intervention discussions, improvement observed following the intervention and knowledge components interactively used in actual classroom teaching

***Intervention*:** As alluded to in Chapter 4, there were discussions with the PSTs on the understanding of individual TSPCK component. Particularly, the discussions on the *Conceptual teaching strategies* (CT) encouraged the integration of other four TSPCK components in teaching concepts. As highlighted in Chapter 4 (section 4.3.6), such strategies involved the pedagogical transformation of content knowledge through investigating learners' existing misconceptions and addressing the misconceptions by emphasizing what is important for learners with the use representations in order to prevent of the occurrence such existing misconceptions in the course of teaching concepts that are considered difficult and confusing. The discussions also introduced the PSTs to the variation theory, a science teaching strategy of discussing two concepts side by side in order to make learners understand the difference or similarity between the concepts with focus on organic chemistry concepts.

***Planned TSPCK*:** The raw scores for the PSTs' pre-and post-TSPCK test presented in Chapter 5, Table 5.2 revealed an improvement in the quality of PSTs' planned TSPCK from Limited to Developing category following the intervention. Also, the rank order of TSPCK components as provided in the Table 5.3 (Chapter 5) showed that the greatest improvement occurred on the TSPCK component RP (*Representations*), followed by CS (*Curricular saliency*) and then, LP (*Learner Prior Knowledge*) in the post-TSPCK test compared to the pre-TSPCK test. The extract of Ruth's explanations on LP was provided in Chapter 5, Figure 5.4 as a typical example of an improvement from Limited to Developing TSPCK category.

In her post-TSPCK written response, Ruth identified and addressed a learners' misconception relating to the use of hydroxyl group (OH) in identifying alcohols. She stated her intention to name all functional groups that consist of oxygen atom because the learners could not distinguish alcohols from other compounds containing oxygen and hydrogen like sodium hydroxide. She also included the use of structural formulae to distinguish key characteristics of functional groups. The TSPCK map showing the Ruth's understanding of interactive use of TSPCK components (CS/LP/RP) as analysed in Chapter 5 is given as shown in the Figure 6.25 below.

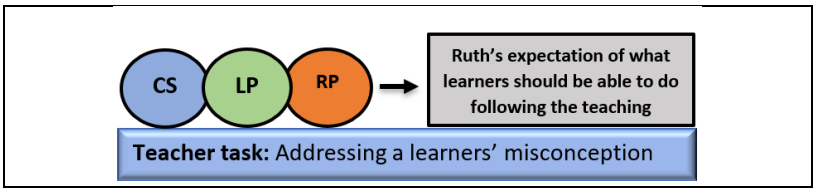


Figure 6.25: TSPCK episode in the Ruth's post-TSPCK test written response (Imported from Chapter 5, Figure 5.4)

In addition to the Ruth's TSPCK episode as shown in the Figure 6.25 above, as a method of assessing learners' understanding following the explanations, Ruth further indicated asking learners to select alcohols from the mix of inorganic and organic compounds with the expectation that, following her explanations, learners would be able to identify alcohols correctly from the list of compounds containing oxygen and hydrogen atoms.

***Actual teaching*:** In the lesson plan (see Appendix XXXI), Ruth highlighted a misconception associated with the symbolic representation of hydroxyl group. The extract of her written explanation is provided in the Figure 6.26 below.

CATEGORY B: ABOUT LEARNER PRIOR KNOWLEDGE

4. **List common misconceptions and errors by learners specific to the concepts intended for this lesson.**

   - Learners may think that the hydroxyl group (OH) in alcohols is the same as the hydroxide ion (OH^-) in inorganic compounds like NaOH because they both have similar symbol OH.

Figure 6.26: Ruth's identified misconception in the lesson plan

Her identification of a misconception relating to the symbolic representation of a hydroxyl group in alcohols and hydroxide ion in inorganic compounds seemed to suggest her understanding of interactive use of Learner Prior Knowledge (LP) and Representation (RP). In the analysis of Ruth's lessons provided in the Table 6.1 (Lesson 1, 16-18minutes) above, her discussions focused on describing alcohol functional group. In an attempt to investigate learners' existing understanding, she drew the structure of alcohol functional group on the board (***RP***) and asked learners to indicate the class of organic compound it represents. The learners correctly referred to it as the hydroxyl group representing the alcohol functional group. In her response to that, Ruth first confirmed the correctness of the learners' existing knowledge of hydroxyl group for alcohols (***LP***). Then, she cautioned the learners not to confuse the hydroxyl OH in alcohols with

the hydroxide ion, OH^-, in inorganic compounds because of their similarity in representations. This logic of describing the difference and similarity of hydroxide group and hydroxide ion seemed to describe Ruth's knowledge of a conceptual teaching strategy (***CT***) used in science teaching. In addition to emphasizing the hydroxyl functional group for alcohols, she further referred to the types of organic reactions (e.g. oxidation, esterification) that all members of alcohols undergo because they all contained the hydroxyl functional group. This appeared to describe her knowledge of a Big Idea in organic chemistry, an element of curricular saliency (***CS***).

The Figure 6.27 below summarizes the Ruth's interactive use of TSPCK components emerging from her written explanation in the lesson and explanations provided during the actual classroom teaching.

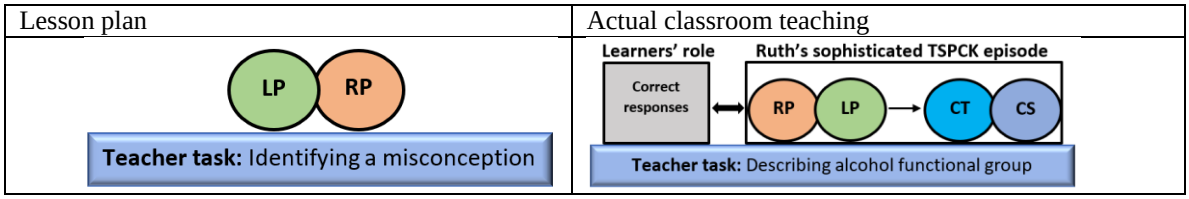


Figure 6.27: Ruth's TSPCK episodes in planning and actual classroom teaching

The Figure 6.27 above shows how a simple TSPCK episode observed in the Ruth's lesson plan on a concept translated into a sophisticated TSPCK episode in the actual classroom teaching of the same concept. Furthermore, between the time frame of 18-33 minutes in lesson 1 as analysed in the Table 6.1 above, Ruth had already discussed with learners the functional groups for alcohols, thiols, carboxylic acids, esters, ketones and aldehydes. Following a learner's curiosity to know how similar structures of aldehyde and ketone functional groups affect their nomenclature (see SF2's response in Lesson 1, 30-33minutes), Ruth explained the suffix 'al' for aldehydes replacing 'ane' in alkanes and then investigated learners' ability to classify ethanal as aldehyde, ethenone as ketone. She further put the molecules of alcohol, carboxylic acid and ester on the board. After she had explained all the concepts involved, by asking questions she evaluated learners' understanding of homologous series that each functional group discussed belongs. To these questions, learners responded correctly thereby showing that they understood Ruth's explanations. The particular aspect of evaluating learners' understanding seemed to

respond to the Ruth's expectation outlined in her post-TSPCK written response as highlighted in the Figure 6.25 above (Imported from Chapter 5, Figure 5.4).

Furthermore, Ruth had a few teaching segments which showed her understanding of conceptual teaching strategies similar to what they were taught during the intervention where they were giving examples of aldehydes versus ketones and alcohols versus phenols versus thiols (see Chapter 4, section 4.3.6 ii). Such instances in the Ruth's teaching included: Lesson 1, 7-8 minutes where she talked about the difference between saturated and unsaturated hydrocarbons; Lesson 1, 8-10minutes, where she referred to the functional group of alkanes and alkenes simultaneously; Lesson 1, 18-20minutes where she discussed thiol and alcohol functional groups side to make learners understand the difference and similarity; Lesson 1, 30-33minutes where she explained the difference and similarity between aldehydes and ketones functional groups; Lesson 1, 33-36minutes, where she talked about amide functional and referred to carboxylic acid functional she earlier discussed with learners.

On the same concepts of functional groups and nomenclature, Hope had one teaching segment where she demonstrated the understanding of the interactive use of conceptual teaching strategies (CT) with other TSPCK components. This happened in Lesson 1, 4-6 minutes (see Appendix XXVIII) as Hope discussed inorganic compounds with the learners with the intention of making learners to understand not all carbon-containing compounds are organic compounds. The critical examination of Hope's lesson plan reveals no instance of explanations relating to describing organic and inorganic compounds with emergence of a TSPCK episode. However, Hope's explanations in the classroom on this concept showed an understanding of TSPCK components (LP-CT/RP) at a proficient level of TSPCK episode.

On the concepts of physical properties and structures of organic compounds taught by Rose and Mark, Rose had three noticeable teaching segments which showed her understanding of conceptual teaching strategies interactively used with other TSPCK components while explaining discussing with the learners. The first instance happened in Lesson 1 (4-8minutes) as analysed in the Table 6.7 above where she discussed the difference between boiling and evaporation, an aspect not stated in her lesson plan. Prior to her explanations from which a new TSPCK episode emerged, the learners who responded to what boiling point is showed a mix of

correct understanding and misunderstanding. As a result, she realized the need to explaining the similarity and difference between the boiling point and evaporation of liquids. The Figure 6.28 below shows her interactive use of TSPCK components as identified in her explanations.

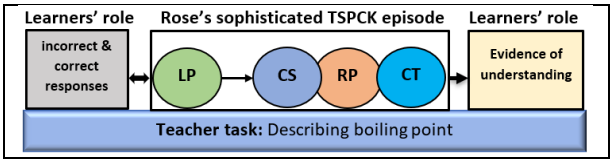


Figure 6.28: Rose's TSPCK episode in the actual teaching

The Figure 6.28 above shows the Rose's new TSPCK episode (sophisticated TSPCK episode) incorporating her understanding of conceptual teaching strategy identified in her actual teaching but not found in the lesson plan. The second instance was happened in Lesson 1 between the lesson period of 21-27minutes (see Appendix XXIX) while Rose was discussing the trend of melting point in the alkanes homologous series building on her preceding explanations on the boiling point in alkanes (Lesson 1, 14-21 minutes from which LP-RP/CS/CS emerged). Emerging from Rose explanations at this instance was a proficient TSPCK (CS/LP/CT) accompanied with the evidence that, the learners understood her explanations. While explaining the trend of boiling point and melting point in the alkane homologous series was part of Rose's purposes of lesson, there was no explanation provided with emergence of a TSPCK episode in her lesson plan on this aspect concept. The third instance occurred in Lesson 1, 31-35 minutes as Rose addressed the learners' misconception associated with the assumption that, intermolecular forces are the same as intramolecular forces as presented in the Table 6.5 above. Although Rose did not anticipate for such a misconception in her lesson plan, she was able to explain intermolecular forces as the immediate concepts required for understanding organic chemistry concepts in her lesson plan as shown in the Figure 6.10 above. Emerging from Rose's explanations was a simple TSPCK episode (CS/WD) in the lesson plan which translated into a proficient TSPCK episode (LP-CT/RP) in the actual teaching (see Table 6.6).

On the same concepts of physical properties and structures of organic compounds, Mark had one instance of discussion which showed his understanding of CT interactively used with other TSPCK components. This was observed in his Lesson 1, 0-3 minutes (see Appendix XXX) where he talked about the similarity and difference between organic compound and inorganic compound which are carbon-containing compounds. His explanation demonstrated his

understanding of interactive use of TSPCK components (LP-CT/RP) at a proficient level of TSPCK episode. There was no such instant of related written explanation in his lesson plan with the emergence of a TSPCK episode.

6.5 Summary

The application of an in-depth qualitative analysis of PCK has been of great value in this chapter which focused on capturing and portraying the PSTs' eTSPCK as the teacher knowledge visible in the actual classroom teaching. Acknowledging the understanding that, PCK is tacit in nature and therefore, difficult to capture and portray in the complexity of teaching and learning process (Henze & van Driel, 2015), efforts were made in this chapter to describe the PSTs' eTSPCK to a little extent possible. Overall, the eTSPCK profile for the 4 participant PSTs consists of a combination of simple, proficient and sophisticated TSPCK episodes to varying extents and predominatly at the proficient level of TSPCK episodes as summarized in the Figure 6.29 below.

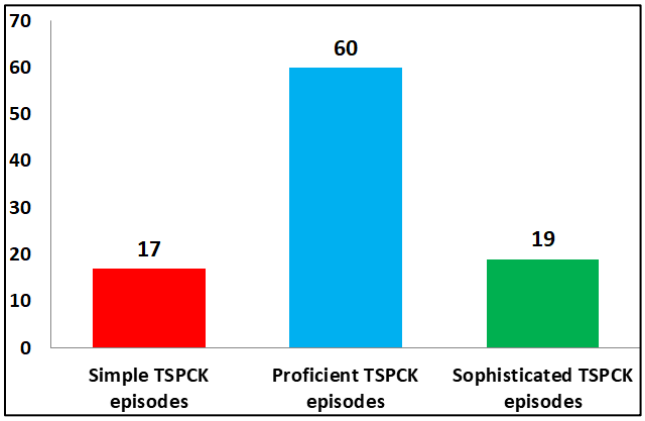


Figure 6.29: PSTs' eTSPCK profile

Based on the summarized emergence of TSPCK episodes provided as shown in the Figure 6.29 above, the findings from the analyzes of PSTs' lessons seemed to bring different insights into understanding the nature of PSTs' eTSPCK demonstrated in the actual classroom teaching of organic chemistry concepts. First, the analysis revealed that, the emerging TSPCK episodes from the PSTs' lessons were complex and idiosyncratic in nature. Second, it was found out that, there appeared to be an expansion in the TSPCK episodes identified in the PSTs' actual teaching compared to those TSPCK episodes which emerged from their lesson plan. Third, there was the emergence of new TSPCK episodes observed in the PSTs' actual teaching which were not found in their lesson plans. These TSPCK episodes newly found in the actual teaching seemed to be

prompted by the learners' responses to the questions the PSTs posed in order to establish their prior knowledge. Lastly, there seemed to be a congruency between what was discussed with the PSTs during the intervention (as discussed in Chapter 4), the knowledge components characterizing their planned TSPCK following the intervention (as analysed in Chapter 5), and knowledge components that characterized their eTSPCK in the actual classroom teaching. While this chapter serves as the continuation of the analysis of TSPCK of a group of PSTs who were exposed to the explicit intervention in Chapter 4 and subsequently showed a gain in planned TSPCK in Chapter 5, it is also working towards creating an envisaged credible base for interpreting the relationship between TSPCK and learner outcomes, the purpose of this study examined in Chapter 8. As this chapter was meant to address the second research question guiding this study, the next chapter presents the analysis of learners' conceptual performances in organic chemistry prior to and following the PSTs' teachings. The analysis served as the starting point for examining TSPCK-learner outcomes link.

CHAPTER SEVEN

7. ANALYSIS OF LEARNER ACHIEVEMENT IN ORGANIC CHEMISTRY

In Chapter 6, PSTs' eTSPCK visible as teacher knowledge in the classroom teaching of organic chemistry was captured and portrayed. The current chapter presents the analysis of achievement tests conducted prior to and following the PSTs' teachings on organic chemistry. The analysis served as the first step taken in the process of determining the correlation between the PSTs' eTSPCK and learner achievement in organic chemistry, the focus in the next Chapter. The chapter closes by summarising the key findings emerging from the analyses.

7.1 INTRODUCTION

The purpose of this chapter is to examine learner achievement in organic chemistry prior to and following the PSTs' teachings. The examination serves as the first step taken in concluding aspects of the exploration of TSPCK of a group of PSTs, who were exposed to cTSPCK in Chapter 4, subsequently showed an improvement in planned TSPCK as analysed in Chapter 5 and whose eTSPCK was visible in the actual classroom teaching as analysed in Chapter 6. The findings in this chapter are regarded as the first step towards establishing the correlation between the PST's eTSPCK and learner achievement as they reflect the collective impact of all PST's actions and other knowledge at play in the lessons other than eTSPCK. As argued in Chapter 2, learner outcomes which are defined as the learner achievement in this study represent the downstream products of educational research (Gess-Newsome, 2015). This implies that, efforts to develop teacher knowledge of a given topic target improving the quality of classroom instruction and learner achievement in the topic. Particularly, the Refined Consensus Model of PCK revolves around revealing the complex nature of science teacher knowledge which shapes and informs science teaching and in turn mediates learner outcomes (Chan & Hume, 2019). The role of learner outcomes in science teachers' PCK is essential in that, it is one way to determine the effectiveness of teachers' classroom instruction and thus, a method of assessing the usefulness PCK theoretical framework (Carlson & Daehler, 2019). Thus, this chapter presents the analysis of learner performances in the pre-and post-achievement tests. The chapter is presented in two sections. The first section of the chapter comprises a recap of the methodological approaches employed in this chapter. The second section of the chapter

comprises the results of the analysis of learner achievement. The chapter closes with a summary of the overall key findings emerging from the analyses.

7.2 A RECAP OF METHODOLOGY USED IN THIS CHAPTER

The sample for this chapter consists of a total number of 88 physical sciences high school learners who were taught organic chemistry by 4 PSTs whose eTSPCK was analysed in the previous chapter, Chapter 6. The sources of data for this chapter majorly comprised two achievement tests conducted with the learners. The first achievement test focused on functional groups and IUPAC naming of organic compounds administered to Ruth's and Hope's learners. The second achievement test focused on physical properties and structures of organic compounds administered to Rose's and Mark's learners. The learners' tests were scored using a memorandum of correct answers and analyzed for significance difference and correlation via the Rasch Model Analysis. The detailed discussions on the participant learners, content of the achievement tests, methods of data collection and analysis, establishment of reliability and validity are all explicitly provided in Chapter 3 (section 3.3.2, section 3.4.2b, section 3.5.2 and section 3.6.3). The results of the analyses are provided in the next section below.

7.3 RESULTS

The results of the analyses done in this chapter are presented in two parts. The first part of the analysis presents the measurement of learner performances on functional groups and IUPAC nomenclature of organic compounds. The second part of the analysis presents the measurement of learner performances on physical properties and structures of organic compounds. The Table 7.1 below presents the overall findings which are subsequently presented in detail within each major concept as part I and part II.

Table 7.1: Overall findings emerging from the measurement of learner performances

		Functional groups and IUPAC nomenclature		Physical properties and structures of organic compounds	
		Ruth	**Hope**	**Rose**	**Mark**
Raw scores (%)	**Pre-test mean**	19.61	0.0	21.94	20.92
	Post-test mean	73.14	40.98	73.47	61.22
	Gain	53.53	40.98	51.53	40.31
Rasch Analysis (stacked data)	**Pre-test mean**	-2.01	-3.51	-1.57	-1.36
	Post-test mean	1.90	-0.45	1.74	0.63
	Gain	3.92	3.06	3.31	1.99
Wilcoxon test	**Alpha p**	0.0000017	0.0000077	0.00098	0.0049

As shown in the Table 7.1, the participant learners' scores in the pre-tests were higher than their scores in the post-tests. It could also be observed that, the alpha p was much more less than the significant level of 0.05 which showed there was a significant improvement in the post-tests compared to the pre-tests across all the participant learners. These results are further discussed below.

7.3.1 Measurement of learner performances on functional groups and IUPAC nomenclature of organic compounds

Case 1: Ruth's learner performances

(i) Overview of the raw scores

The Table 7.2 below presents the identifying codes for individual Ruth's learners, their scores in the pre-and post-tests and *gain* representing the actual performance following Ruth's teaching on functional groups and IUPAC nomenclature of organic compounds. The calculated average scores for all the participant Ruth's learners are provided in the last row as shown in the Table 7.2 below.

Table 7.2: Ruth's learners' test scores on functional groups and nomenclature (n=30)

Learner	Pre-test raw score	%Pre-test raw score	Post-test raw score	%Post-test raw score	Gain	%Gain
Ru02	6	35.29	14	82.35	8	47.06
Ru13	2	11.76	14	82.35	12	70.59
Ru12	3	17.65	14	82.35	11	64.71
Ru15	3	17.65	14	82.35	11	64.71
Ru03	7	41.18	14	82.35	7	41.18
Ru14	2	11.76	14	82.35	12	70.59
Ru21	2	11.76	14	82.35	12	70.59
Ru10	3	17.65	14	82.35	11	64.71
Ru11	3	17.65	13	76.47	10	58.82
Ru16	3	17.65	13	76.47	10	58.82
Ru17	1	5.88	13	76.47	12	70.59
Ru19	1	5.88	13	76.47	12	70.59
Ru20	1	5.88	13	76.47	12	70.59
Ru24	1	5.88	13	76.47	12	70.59
Ru07	4	23.53	13	76.47	9	52.94
Ru18	2	11.76	13	76.47	11	64.71
Ru23	2	11.76	12	70.59	10	58.82
Ru09	5	29.41	12	70.59	7	41.18
Ru06	8	47.06	12	70.59	4	23.53
Ru08	7	41.18	12	70.59	5	29.41
Ru01	9	52.94	12	70.59	3	17.65
Ru22	1	5.88	11	64.71	10	58.82
Ru26	1	5.88	11	64.71	10	58.82
Ru04	7	41.18	11	64.71	4	23.53
Ru05	7	41.18	11	64.71	4	23.53
Ru25	2	11.76	11	64.71	9	52.94
Ru27	2	11.76	11	64.71	9	52.94
Ru28	2	11.76	11	64.71	9	52.94
Ru30	2	11.76	10	58.82	8	47.06
Ru29	1	5.88	10	58.82	9	52.94
Average	3.33	19.61	12.43	73.14	9.10	53.53

Note: *Scores are arranged in the descending order of post-test scores. *Pseudonyms for learners have been used. *Gain score = (Post-test score) – (Pre-test score)

As alluded in Chapter 3, in this study, the performance of 60% in a subject (chemistry) is considered a minimum level that a learner has to achieve in order to be considered knowledgeable enough in that subject. The performance of 60% is also regarded as the minimum qualifying mark for entry into Wits University to study Bachelor of Science degree in Chemistry. It could be observed as shown in the Table 7.5 above that, in the pre-test, none of the Ruth's learners scored the achievement mark of 60% or above. The learners had the minimum and maximum percentage scores of 5.88% and 52.94% respectively which were less than a mark 60%. However, in the post-test, 28 (i.e. 93.3%) learners scored an achievement mark of 60% or above in the class size of 30 learners while 2 (i.e. 6.7%) learners scored below the achievement mark. Such a major positive shift in the performance score across the pre-and post-test seemed

to imply that learners learned the concepts of functional groups and IUPAC nomenclature following Ruth's teachings.

(ii) Conversion of raw test scores into Rasch measures

The Ruth's learners' raw scores in the pre-and post-achievement tests as given in the Table 7.2 above were statistically analysed using the Rasch Model Analysis. The detailed discussions on of the rationale for using RMA are provided in Chapter 3 (section 3.6.3). For the pre-test and post-test, the person measures generated from the analysis are attached as Appendix XXXIII and Appendix XXXIV respectively. These measures are presented in the Table 7.3 below. The first column gives the codes for identifying each participant learner who wrote the test. The second and fifth columns tagged 'Pre-TSPCK Rasch measure' and 'Post-TSPCK Rasch measure' respectively refers to the Rasch measures for person ability in each test as generated from RMA. The indices for fit statistics are provided for determining the validity of the measures. The last rows also provided the indices for person and item reliability.

Table 7.3: Rasch Person measures for Ruth's learners' pre-and post-tests (n=30)

Identifying code for learner	**Pre-Achievement test**			**Post-Achievement test**		
	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
Ru02	0.53	1.7	1.3	2.74	1.0	1.3
Ru03	0.92	-1.2	-0.7	2.74	0.9	0.7
Ru10	-1.80	-0.9	-0.6	2.74	-1.6	-0.7
Ru12	-1.80	-0.8	-0.5	2.74	-1.6	-0.7
Ru13	-2.43	-0.8	-0.4	2.74	-1.6	-0.7
Ru14	-2.43	-0.8	-0.4	2.74	-0.3	-0.4
Ru15	-1.80	-0.3	0.2	2.74	-0.3	-0.4
Ru21	-2.43	0.9	0.6	2.74	-0.3	-0.4
Ru07	-0.89	-1.8	-1.1	1.87	0.1	0.6
Ru11	-1.80	-0.6	-0.4	1.87	-1.0	-0.8
Ru16	-1.80	0.5	0.7	1.87	-1.0	-0.8
Ru17	-3.40	-0.6	-0.6	1.87	-1.0	-0.8
Ru18	-2.43	0.4	0.5	1.87	-1.0	-0.8
Ru19	-3.40	-0.6	-0.6	1.87	-1.0	-0.8
Ru20	-3.40	-0.6	-0.6	1.87	-1.0	-0.8
Ru24	-3.40	0.9	1.2	1.87	1.9	1.6
Ru01	1.52	1.8	1.8	1.20	1.7	1.2
Ru06	1.44	-0.4	0.2	1.20	0.4	1.1
Ru08	0.92	-1.6	-1.0	1.20	0.1	-0.2
Ru09	0.21	-1.7	-1.1	1.20	-1.0	-0.9
Ru23	-2.43	1.2	0.8	1.20	-1.0	-0.9
Ru04	0.92	-0.7	-0.2	0.67	1.0	0.4
Ru05	0.92	-0.7	-0.2	0.67	0.6	0.1
Ru22	-3.40	0.8	0.5	0.67	-0.1	1.5
Ru25	-2.43	1.3	1.6	0.67	-0.7	-0.6
Ru26	-3.40	0.8	0.7	0.67	-0.9	-0.5
Ru27	-2.43	0.7	1.7	0.67	-1.4	0.2
Ru28	-2.43	0.6	0.22	0.67	-0.4	0.3
Ru29	-3.40	0.9	1.6	-0.22	0.9	0.5
Ru30	-2.43	-0.5	0.22	-0.22	-0.2	0.2
Rasch mean	-2.01			1.57		
Person reliability	0.69			0.84		
Item reliability	0.77			0.91		
Infit/Outfit indices	All INZSTD & OUTZSTD fall within the range of -2 and +2.			All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.		

Note: The order of arrangement of learners was based on descending order of Rasch measures in the post-test. The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

As shown in the Table 7.3 above, the different values indicated by the Pre-test Person Rasch measures and Post-test Person Rasch measures showed hierarchical level of difficulty experienced by learners in the pre-and post-tests. This means that, the individual learner's pattern of response has to be examined for 'fittingness', assessing for whether each learner responded in an acceptably predictable way by considering the expected hierarchy of responses. Hence, the indices for fit statistics 'IN.ZSTD' and 'OUT.ZSTD' are measuring the coherence of

the participant learners' responses to the item level of difficulty. As shown in the Table 7.6 above, all the values for 'IN.ZSTD' and 'OUT.ZSTD' are within the acceptable range of +2 to -2 which means that, none of the Ruth's learners' responses are significantly problematic in the tests. In other words, the statistical values are considered fitting and hence, working together to measure learner performances in functional groups and structures of organic compounds thereby constituting valid measures. Also, there were higher Person Rasch measures in the post-test than the pre-test. This showed a positive shift in performances across all the participant learners who wrote the tests. The higher calculated mean for post-test person measure (1.57) than the calculated mean for pre-test person measures (-2.01) reflects an improvement in learner performance following the Ruth's teaching. Likewise, the Table 7.3 above reflects good reliability for the person measure and item difficulty. For the pre-test, the person reliability generated was 0.69 and there was the item reliability of 0.77. For the post-test, the person reliability was 0.84 and the item reliability was 0.91. The higher person reliability in the post-test compared to the pre-test is an indication that enough items were sufficiently spread along the continuum and enough spread of person ability among the learners who responded to test items. In other words, to increase the person reliability value in the pre-test, the person ability should be improved, and this was achieved in the post-test. The indices for item reliability for the pre-test and post-test were also found within the range of 0 and 1 and higher than the Cronbach's alpha coefficient of 0.70. This implies that the items in the achievement test are very replicable, wide spread among the persons, very minimal standard errors and uncompromised development of reliable measures.

(iii) Comparing person measures for significant difference

As explicitly discussed in Chapter 3 (section 3.6.3), the person measures generated from Rasch analysis as shown in the Table 7.3 above were anchored to produce stacked data used for further analysis of significance difference. The stacked data generated for pre-and post-tests in the case of Ruth's learners is attached as Appendix XXXV and presented as shown in the Table 7.4 below. The Table presents the summary of the anchored Rasch person measures and standard error for the pre-test and post-test.

Table 7.4: Stacked data-Rasch Person measures from anchored pre-and post-test (n=30)

Identifying code for Learner	**Pre-achievement test** Rasch Measure	S. Error	**Post-achievement test** Rasch Measure	S. Error
Ru02	0.19	0.60	2.82	0.81
Ru03	0.92	0.63	2.82	0.81
Ru10	-1.80	0.74	2.82	0.74
Ru12	-1.80	-1.8	2.82	0.81
Ru13	-2.43	0.87	2.82	0.81
Ru14	-2.43	0.87	2.82	0.74
Ru15	-1.80	0.74	2.82	0.81
Ru21	-2.43	0.87	2.82	0.74
Ru07	-0.51	0.60	2.23	0.74
Ru11	-1.80	0.74	2.23	0.74
Ru16	-1.80	0.74	2.23	0.74
Ru17	-3.40	1.14	2.23	0.74
Ru18	-2.43	0.87	2.23	0.74
Ru19	-3.40	1.14	2.23	0.74
Ru20	-3.40	1.14	2.23	0.74
Ru24	-3.40	1.14	2.23	0.74
Ru01	0.92	0.63	1.73	0.68
Ru06	-0.15	0.59	1.73	0.68
Ru08	-0.51	0.59	1.73	0.68
Ru09	-0.89	0.63	1.73	0.68
Ru23	-2.43	0.87	1.73	0.68
Ru04	0.92	0.63	1.30	0.64
Ru05	0.55	0.63	1.30	0.64
Ru22	-3.40	1.14	1.30	0.64
Ru25	-2.43	0.87	1.30	0.64
Ru26	-3.40	1.14	1.30	0.64
Ru27	-4.83	1.89	1.30	0.64
Ru28	-4.83	1.89	1.30	0.64
Ru29	-3.40	1.14	-0.51	0.60
Ru30	-4.83	1.89	-0.51	0.60
Mean	**-2.01**		**1.90**	

Note: Item measure set to zero; Units per Logit=1(UIMEAN=0 &USCALE=1)

The Rasch Person measures in the Table 7.4 above were further analysed by subjecting them to the Wilcoxon Paired Signed-rank test which measures the magnitude of the difference between the pairs of data as alluded to in Chapter 3. The result of the analysis is presented as shown in the Figure 7.1 below.

Pre-Test Person measure	Anchored Post-Test Person measure	Diff= (Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	465
0.19	2.82	2.63	2.63	8.00	8	n=	30
0.92	2.82	1.9	1.9	5.00	5	σ{T}	97.2368243
-1.8	2.82	4.62	4.62	17.00	17	α	0.05
-1.8	2.82	4.62	4.62	17.00	17	Action(L)	-190.6
-2.43	2.82	5.25	5.25	23.00	23	Action(U)	190.6
-2.43	2.82	5.25	5.25	23.00	23	z	4.8
-1.8	2.82	4.62	4.62	17.00	17	Reject Null at 0.05	
-2.43	2.82	5.25	5.25	23.00	23	*p*	0.0000017
-0.51	2.23	2.74	2.74	9.00	9		
-1.8	2.23	4.03	4.03	12.50	12.5		
-1.8	2.23	4.03	4.03	12.50	12.5		
-3.4	2.23	5.63	5.63	26.50	26.5		
-2.43	2.23	4.66	4.66	19.00	19		
-3.4	2.23	5.63	5.63	26.50	26.5		
-3.4	2.23	5.63	5.63	26.50	26.5		
-3.4	2.23	5.63	5.63	26.50	26.5		
0.92	1.73	0.81	0.81	3.00	3		
-0.15	1.73	1.88	1.88	4.00	4		
-0.51	1.73	2.24	2.24	6.00	6		
-0.89	1.73	2.62	2.62	7.00	7		
-2.43	1.73	4.16	4.16	14.00	14		
0.92	1.3	0.38	0.38	1.00	1		
0.55	1.3	0.75	0.75	2.00	2		
-3.4	1.3	4.7	4.7	20.50	20.5		
-2.43	1.3	3.73	3.73	11.00	11		
-3.4	1.3	4.7	4.7	20.50	20.5		
-4.83	1.3	6.13	6.13	29.50	29.5		
-4.83	1.3	6.13	6.13	29.50	29.5		
-3.4	-0.51	2.89	2.89	10.00	10		
-4.83	-0.51	4.32	4.32	15.00	15		

Figure 7.1: Wilcoxon signed-rank test for comparing Ruth's learners' performances

As shown in the Figure 7.1 above, the alpha *p*-value is equal to 0.0000017 which is much more less than the significance level (α) of 0.05. This suggests a significance difference at 95% (0.05) does exist between the Ruth's learners' performance in the pre-test and post-test as given by the Rasch Person measures. In order words, Ruth's learners' conceptual ability following the teaching was better than their conceptual ability prior to the teaching at the 95% level of confidence.

(iv) Rank order for Item Rasch measures

As discussed to in Chapter 3, Rasch Analysis Model provides insightful information about aspects of difficulty and success on the test items. In the light of this understanding, Rasch Item measures are interpreted in such a way that, the higher the Rasch Item measure generated for a given test item, the more difficult the item. In order to understand the extent of learners' engagement with the test items, the Item measures generated from Rasch analysis in the case of Ruth's learners are discussed below. The Item measures generated from the Rasch analysis of Ruth's learners' pre-test and post-test are attached as Appendix VI and Appendix VII respectively. The Table 7.5 below presents the summary of rank order of item difficulty and the

number of learners who answered each item correctly (denoted as 'number of correct responses') for illustrative purposes. The columns for the pre-test present the Rasch Item measures (IM_1) and number of correct responses (X) generated from the analysis of pre-achievement test. The columns for the post-test present the Rasch Item measures (IM_2) and number of correct responses (Y) for the post-achievement test. The column tagged 'gain' presents the change in the pre-test item measures and post-item measures and also, the difference between the number of correct responses in the post-test and number of correct responses in the pre-test. The test items in the first column were arranged in the decreasing order of learners' gain of correct responses represented as Y-X, the difference between the number of correct responses in the post-test (Y) and correct responses in the pre-test (X).

Table 7.5: Rasch Item measures for Ruth's learners' achievement test (n=17)

Item	**Pre-test**		**Post-test**		**Gain**	
	Rasch Item measure (IM_1)	Number of Correct responses (X)	Rasch Item measure (IM_2)	Number of Correct responses (Y)	(IM_2)-(IM_1)	X-Y
item1	3.55	5	-3.41	29	-2.28	24
item2	-1.83	13	-2.59	28	-2.28	20
item3	2.44	6	-2.59	28	-2.28	22
item4	1.83	8	-2.59	28	-2.28	20
item9	0.58	11	-2.23	27	-2.28	16
item10	0.58	11	-2.23	27	-2.28	16
item7	1.33	9	-0.98	26	-1.16	17
item8	1.33	9	-0.98	26	-1.16	17
item5	-0.78	12	-0.98	26	-1.16	17
item11	2.32	7	-0.98	26	-1.16	19
item16	2.32	7	-0.98	26	-1.16	19
item14	1.01	10	-0.67	25	-1.16	15
item17	0.58	11	-0.98	26	-1.16	15
item6	-2.84	14	-0.48	23	0.72	9
item12	3.63	0	6.55	0	2.92	0
item13	3.63	0	6.55	0	2.92	0
item15	3.63	0	6.55	0	2.92	0
Item reliability	**0.77**		**0.91**			

Note: **Note**: The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1). Items arranged in the increasing order of Post-test Rasch Item measures.

The results in the Table 7.5 above showed that all items in the pre-and post-achievement tests were ranked similarly, indicating different extents of learners' engagement in attempts to answer the questions in the achievement tests. Except in the cases of the test item 12, item 13 and 15 on which none of the learners could provide correct answers, the learner performances improved in the post-test compared to the pre-test. This seemed to be evident as indicated by the higher

number of learners (Y) who responded correctly in the post-test compared to the lower number of learners (X) who responded correctly in the pre-test across all the remaining 14 test items. A critical look at the post-item measures and learners' gain revealed that, item 1 emerged as least difficult item on which learner performance improved from 3.55 (pre-test Rasch item measure) to -3.41 (post-test Rasch item measure). As summarized in Chapter 3 (Table 3.5), the Item 1 required the participant learners to identify the functional group on a given structure of ethanoic acid. As shown in the Table 7.5 above, only 5 learners in a class size of 30 responded correctly in the pre-test by indicating carboxylic acid functional as the required functional group on the given structure of ethanoic acid. However, in the post-test, 29 learners responded correctly by referring to carboxylic acid functional as the required functional group on the given structure of ethanoic acid. The typical extracts of two learners' written work on this item are provided as shown in the Figure 7.2 below.

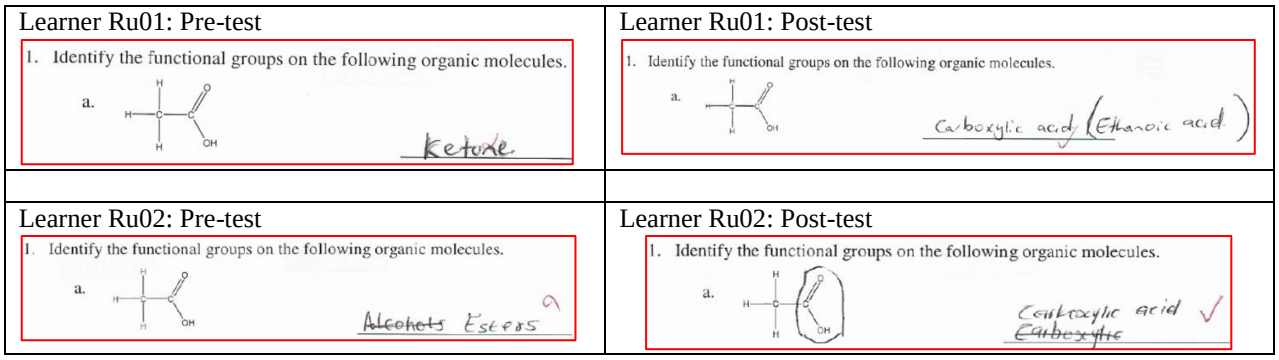


Figure 7.2: Extracts of Ruth's learners' written work on test item 1

In the both the cases of learner Ru01 and Ru02, their wrong answers in the pre-test suggest their possible awareness that, there are ketone and ester functional groups. However, they were able to correctly identify carboxylic acid functional in the post-test having been taught by Ruth. According to the Bloom's taxonomy for learning, learners' ability to *identify* represents the application of knowledge acquired (Krathwohl, 2002).

Another test item on which Ruth's learners provided responses which could give an insight about the shift in their thinking in the both the pre-and post-test was question item 14. As summarized in Chapter 3 (Table 3.6), the Item 14 asked learners to write a structural formula for a molecule of dichloromethane. The Table 7.5 above indicates that, learner performance on Item 14 improved from pre-test Rasch Item measure of 1.01 to post-test Rasch Item measure of -0.67 with the number of learners who responded correctly increasing from 10 in the pre-test to 25 in

the post-test. The typical extracts of two learners' written responses in the pre-test and post-test are provided as shown in the Figure 7.3 below.

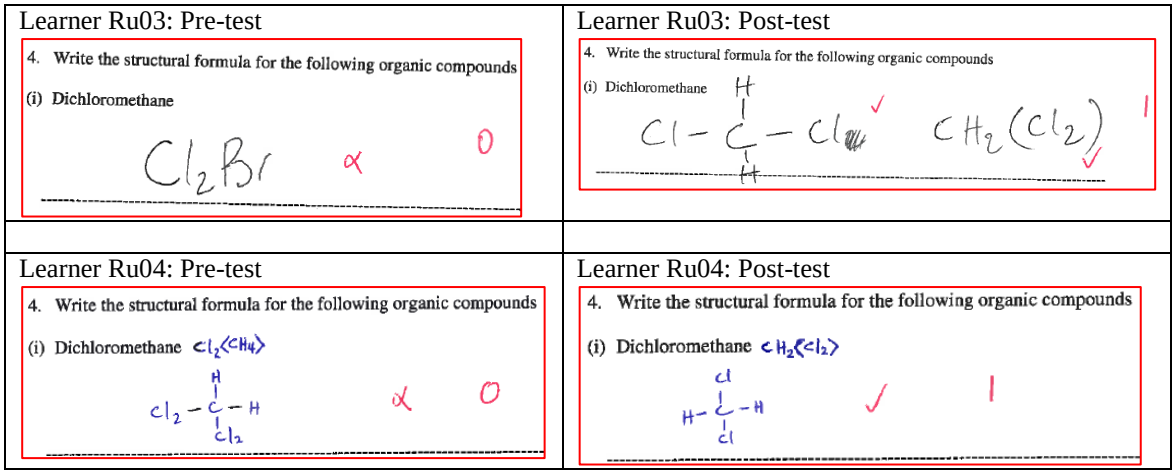


Figure 7.3: Extracts of Ruth's learners' written work on test item 14

In both the cases of learner Ru03 and Ru04, it could be observed that, they seemed to understand 'dichloro' to mean 'Cl_2' in the pre-test but incorporating the knowledge in write the structural formula for dichloromethane was challenging for them. However, in the post-test, the learners were both able to write the molecular and structural formula for the molecule correctly. This seemed to denote learners' ability to recall what was learned during Ruth's teaching as 'write' is interpreted in the Bloom's taxonomy of learning (Krathwohl, 2002).

In spite of the conceptual improvement Ruth's learners experienced following the teaching, none of the learners could provide correct answers on item 12, 13 and 15. The descriptions of these three test items are provided in Chapter 3 (Table 3.5). The observed learners' errors on these three items are discussed later in this section.

Case 2: Hope's learner performances

(i) Overview of the raw scores

Similar to the case of Ruth's learners discussed above, the Table 7.6 below presents the identifying codes for individual Hope's learners, their scores in the pre-and post-tests and *gain* representing the actual performance following Hope's teaching on functional groups and IUPAC nomenclature of organic compounds. The calculated average scores for all the participant Hope's learners are provided in the last row as shown in the Table 7.6 below.

Table 7.6: Hope's learners' test scores on functional groups and nomenclature (n=30)

Learner	Pre-test raw score	%Pre-test raw score	Post-test raw score	%Post-test raw score	Gain	% Gain
Ho01	0	0.00	10	58.82	10	58.82
Ho02	0	0.00	10	58.82	10	58.82
Ho03	0	0.00	10	58.82	10	58.82
Ho04	0	0.00	10	58.82	10	58.82
Ho05	0	0.00	9	52.94	9	52.94
Ho06	0	0.00	9	52.94	9	52.94
Ho08	0	0.00	9	52.94	9	52.94
Ho07	0	0.00	9	52.94	9	52.94
Ho09	0	0.00	9	52.94	9	52.94
Ho10	0	0.00	8	47.06	8	47.06
Ho13	0	0.00	8	47.06	8	47.06
Ho15	0	0.00	8	47.06	8	47.06
Ho16	0	0.00	8	47.06	8	47.06
Ho22	0	0.00	8	47.06	8	47.06
Ho11	0	0.00	7	41.18	7	41.18
Ho12	0	0.00	7	41.18	7	41.18
Ho14	0	0.00	7	41.18	7	41.18
Ho17	0	0.00	6	35.29	6	35.29
Ho18	0	0.00	6	35.29	6	35.29
Ho20	0	0.00	6	35.29	6	35.29
Ho21	0	0.00	5	29.41	5	29.41
Ho23	0	0.00	5	29.41	5	29.41
Ho24	0	0.00	5	29.41	5	29.41
Ho25	0	0.00	5	29.41	5	29.41
Ho26	0	0.00	5	29.41	5	29.41
Ho27	0	0.00	4	23.53	4	23.53
Ho19	0	0.00	4	23.53	4	23.53
Ho28	0	0.00	4	23.53	4	23.53
Ho29	0	0.00	4	23.53	4	23.53
Ho30	0	0.00	4	23.53	4	23.53
Average	0.00	0.00	6.97	40.98	6.97	40.98

Note: *Scores are arranged in the descending order of post-test scores. *Pseudonyms for learners have been used. *Gain score = (Post-test score) – (Pre-test score)

As shown in the Table 7.6 above, all the participant Hope's learners got a mark of zero in the pre-test. This is not surprising due to the fact, organic chemistry is only taught in Grade 12 which means Hope's learners had no prior knowledge of the concepts as explicitly discussed in Chapter 3 (section 3.3.2). However, in the post-test, all the participant learners scored above a mark of zero where nine (9) learners highlighted in green had their scores within the range of 50% to 59%. The remaining twenty-one (21) learners had a post-test score above 0% but less than 50%. While it could be seen that, all Hope's learners scored above 0% in the post-test, they all performed below 60% which has been considered the minimum level that a learner has to achieve in order to be considered knowledgeable enough in that subject. Nevertheless, an improvement to varying extents could be observed in the participant learners' conceptual

performances following Hope's teaching as the post-test scores were higher than the pre-test scores.

(ii) Conversion of raw test scores into Rasch measures

The Hope's learners' raw scores in the pre-and post-achievement tests as given in the Table 7.6 above were statistically analysed using the RMA which transforms raw scores (ordinal data) into interval measures placed on a linear equidistant scale. The Table 7.7 below presents the person measures for the analysis of Hope's learners' achievement tests.

Table 7.7: Rasch Person measures for Hope's learners' pre-and post-tests (n=30)

Identifying code for learner	**Pre-Achievement test**			**Post-Achievement test**		
	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
Ho01	-3.51	n/a	n/a	1.15	0.1	0.3
Ho02	-3.51	n/a	n/a	1.15	0.2	0.1
Ho03	-3.51	n/a	n/a	1.15	0.9	1.4
Ho04	-3.51	n/a	n/a	1.15	-0.1	-0.3
Ho05	-3.51	n/a	n/a	0.68	-0.5	-0.2
Ho06	-3.51	n/a	n/a	0.68	-0.2	0.6
Ho08	-3.51	n/a	n/a	0.68	-1.1	-1.8
Ho07	-3.51	n/a	n/a	0.68	-1.3	-1.3
Ho09	-3.51	n/a	n/a	0.68	-1.6	-1.5
Ho10	-3.51	n/a	n/a	0.05	-0.9	-1.1
Ho13	-3.51	n/a	n/a	0.05	0.5	1.3
Ho15	-3.51	n/a	n/a	0.05	0.4	0.7
Ho16	-3.51	n/a	n/a	0.05	0.3	0.1
Ho22	-3.51	n/a	n/a	0.05	0.3	0.7
Ho11	-3.51	n/a	n/a	-1.42	0.1	-0.3
Ho12	-3.51	n/a	n/a	-1.42	0.3	0.8
Ho14	-3.51	n/a	n/a	-1.42	0.3	1.2
Ho17	-3.51	n/a	n/a	-2.86	0.4	0.5
Ho18	-3.51	n/a	n/a	-2.86	0.4	0.5
Ho20	-3.51	n/a	n/a	-2.86	0.4	0.5
Ho21	-3.51	n/a	n/a	-2.86	0.5	1.2
Ho23	-3.51	n/a	n/a	-2.86	0.5	1.2
Ho24	-3.51	n/a	n/a	-2.86	0.2	-0.1
Ho25	-3.51	n/a	n/a	-2.86	0.5	1.7
Ho26	-3.51	n/a	n/a	-2.86	0.4	0.5
Ho27	-3.51	n/a	n/a	-3.55	0.5	1.7
Ho19	-3.51	n/a	n/a	-3.55	0.2	-0.7
Ho28	-3.51	n/a	n/a	-3.55	0.5	-0.8
Ho29	-3.51	n/a	n/a	-3.55	0.3	0.6
Ho30	-3.51	n/a	n/a	-3.55	0.6	-1.1
Rasch mean	-3.51			-1.22		
Person reliability	Not available			0.66		
Item reliability	Not available			0.85		
Infit/Outfit indices	All IN.ZSTD & OUT.ZSTD could not be computed			All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.		

Note: The order of arrangement of learners was based on descending order of Rasch measures in the post-test. The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

As highlighted in the Table 7.7 above, there were only constant negative statistical values for Hope's pre-test person measures and the indices for IN.ZSTD and OUT.ZSTD fit statistics could not be computed for person measures in the test since the entire participant Hope's learners got zero in the test due to their lack of prior knowledge of organic compounds. However, the different values indicated by the Post-test Rasch measures showed that the participant Hope's learners had a hierarchy of level of difficult in the post-test. All the values for 'IN.ZSTD' and

'OUT.ZSTD' are within the acceptable range of +2 to -2 in the post-test measures. This implies that, the values for each participant learner's response are considered fitting and hence, working together to measure learner performances in functional groups and IUPAC nomenclature of organic compounds. There were higher Person Rasch measures in the post-test compared than the pre-test. This showed a positive shift in performance across all the participant learners who wrote the tests. Also, the higher calculated mean for post-test person measure (-3.51) than the lower calculated mean for pre-test person measures (-1.22) reflects an improvement in the learners' conceptual performance following Hope's teaching. Likewise, the Table 7.7 above reflects good reliability for the person measure and item difficulty. For the post-test, the person reliability generated was 0.66 and there was the item reliability of 0.85. The item reliability for the post-test was also found within the range of 0 and 1 and higher than the Cronbach's alpha coefficient of 0.70. This implies that the items in the achievement test are very replicable, wide spread among the persons, very minimal standard errors and uncompromised development of reliable measures.

(iii) Comparing person measures for significant difference

The stacked data generated for pre-and post-tests in the case of Hope's learners is presented as shown in the Table 7.8 below. This presents the summary of the anchored Rasch person measures and standard error for the pre-test and post-test.

Table 7.8: Stacked data for Hope's learners' Rasch Person measures (n=30)

	Pre-achievement test		**Post-achievement test**	
Learner	Rasch Measure	S. Error	Rasch Measure	S. Error
Ho01	-3.51	n/a	1.44	0.68
Ho02	-3.51	n/a	1.44	0.68
Ho03	-3.51	n/a	1.44	0.68
Ho04	-3.51	n/a	1.44	0.68
Ho05	-3.51	n/a	1.02	0.62
Ho06	-3.51	n/a	1.02	0.57
Ho08	-3.51	n/a	1.02	0.59
Ho07	-3.51	n/a	1.02	0.62
Ho09	-3.51	n/a	1.02	0.62
Ho10	-3.51	n/a	0.32	0.68
Ho13	-3.51	n/a	0.32	0.79
Ho15	-3.51	n/a	0.32	0.79
Ho16	-3.51	n/a	0.32	0.79
Ho22	-3.51	n/a	0.32	0.79
Ho11	-3.51	n/a	-0.02	1.05
Ho12	-3.51	n/a	-0.02	1.05
Ho14	-3.51	n/a	-0.02	1.05
Ho17	-3.51	n/a	-1.24	1.05
Ho18	-3.51	n/a	-1.24	1.05
Ho20	-3.51	n/a	-1.24	1.05
Ho21	-3.51	n/a	-1.65	1.05
Ho23	-3.51	n/a	-1.65	1.05
Ho24	-3.51	n/a	-1.65	1.05
Ho25	-3.51	n/a	-1.65	1.05
Ho26	-3.51	n/a	-1.65	1.05
Ho27	-3.51	n/a	-2.78	1.05
Ho19	-3.51	n/a	-2.78	1.84
Ho28	-3.51	n/a	-2.78	1.84
Ho29	-3.51	n/a	-2.78	1.84
Ho30	-3.51	n/a	-2.78	1.84
Mean	**-3.51**		**-0.45**	

Note: Item measure set to zero; Units per Logit=1(UIMEAN=0 &USCALE=1)

The Rasch Person measures in the Table 7.8 above were further analysed by subjecting them to the Wilcoxon Paired Signed-rank test which measures the magnitude of the difference between the pairs of data. The result of the analysis is presented as shown in the Figure 7.6 below.

Pre-Test Person measure	Anchored Post-Test Person measure	Diff= (Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	465
-3.51	1.44	4.95	4.95	28.50	28.5	n=	30
-3.51	1.44	4.95	4.95	28.50	28.5	σ{T}	97.2368243
-3.51	1.44	4.95	4.95	28.50	28.5	α	0.05
-3.51	1.44	4.95	4.95	28.50	28.5	Action(L)	-190.6
-3.51	1.02	4.53	4.53	24.00	24	Action(U)	190.6
-3.51	1.02	4.53	4.53	24.00	24	z	4.8
-3.51	1.02	4.53	4.53	24.00	24	Reject Null at 0.05	
-3.51	1.02	4.53	4.53	24.00	24	*p*	0.0000077
-3.51	1.02	4.53	4.53	24.00	24		
-3.51	0.32	3.83	3.83	19.00	19		
-3.51	0.32	3.83	3.83	19.00	19		
-3.51	0.32	3.83	3.83	19.00	19		
-3.51	0.32	3.83	3.83	19.00	19		
-3.51	0.32	3.83	3.83	19.00	19		
-3.51	-0.02	3.49	3.49	15.00	15		
-3.51	-0.02	3.49	3.49	15.00	15		
-3.51	-0.02	3.49	3.49	15.00	15		
-3.51	-1.24	2.27	2.27	12.00	12		
-3.51	-1.24	2.27	2.27	12.00	12		
-3.51	-1.24	2.27	2.27	12.00	12		
-3.51	-1.65	1.86	1.86	8.00	8		
-3.51	-1.65	1.86	1.86	8.00	8		
-3.51	-1.65	1.86	1.86	8.00	8		
-3.51	-1.65	1.86	1.86	8.00	8		
-3.51	-1.65	1.86	1.86	8.00	8		
-3.51	-2.78	0.73	0.73	3.00	3		
-3.51	-2.78	0.73	0.73	3.00	3		
-3.51	-2.78	0.73	0.73	3.00	3		
-3.51	-2.78	0.73	0.73	3.00	3		
-3.51	-2.78	0.73	0.73	3.00	3		

Figure 7.4: Wilcoxon signed-rank test for comparing Hope's learner performances

As shown in the Figure 7.4 above, the alpha *p*-value is equal to 0.0000077 which is much more less than the significance level (α) of 0.05. This suggests a significance difference at 95% (0.05) does exist between Hope's learners' performance in the pre-test and post-test as given by the Rasch Person measures. In order words, Hope's learners' conceptual ability following the teaching was better than their conceptual ability prior to the teaching at the 95% level of confidence.

(iv) Rank order for Item Rasch measures

The Item measures generated from the Rasch analysis of Hope's learners' pre-and post-achievement tests are summarized as shown in the Table 7.9 below. The rank order of item difficulty and the number of learners who answered each item correctly are provided in the Table 7.9 below.

Table 7.9: Rasch Item measures for Hope's learners' achievement test (n=17)

Item	Pre-test		Post-test		Gain	
	Rasch Item measure (IM_1)	Number of Correct responses (X)	Rasch Item measure (IM_2)	Number of Correct responses (Y)	(IM_2)-(IM_1)	X-Y
Item1	4.08	0	-3.48	16	-7.56	16
item4	4.08	0	-3.48	16	-7.56	16
item7	4.08	0	-3.02	15	-7.1	15
item14	4.08	0	-3.02	15	-7.1	15
item3	4.08	0	-2.88	14	-6.96	14
item5	4.08	0	-2.88	14	-6.96	14
item11	4.08	0	-2.88	14	-6.96	14
item6	4.08	0	-1.67	13	-5.75	13
item2	4.08	0	0.45	12	-3.63	12
item16	4.08	0	0.45	12	-3.63	12
item10	4.08	0	0.92	11	-3.16	11
item8	4.08	0	1.67	10	-2.41	10
item9	4.08	0	1.67	10	-2.41	10
item17	4.08	0	2.31	9	-1.77	9
item12	4.08	0	3.64	0	-0.44	0
Item13	4.08	0	3.64	0	-0.44	0
Item15	4.08	0	3.64	0	-0.44	0
Item reliability	**N/A**		**0.85**			

Note: **Note**: The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1). Items arranged in the increasing order of Post-test Rasch Item measures.

As shown in the Table 7.9 above, the ranking of items in the pre-test showed the same and high level of difficulty experienced by learners as all the item measures were positive and of equal value which implies that, none of the learners was able to correctly answer the questions. The difficulty learners experienced in the pre-test might be linked to their lack prior knowledge of organic chemistry as at the time the pre-test was conducted. However, following Hope's teaching, there were learners' correct responses to varying extents on all items in the post-test except in the cases of item 12, 13 and 15 on which none of the learners could provide correct answers. The detailed descriptions of these three items are provided in Chapter 3, Table 3.5. It could be observed that, learners improved in their conceptual performances following Hope's teaching as evident in the higher number of learners (Y) who responded correctly in the post-test compared to the lower number of learners (X) who got the answer wrong in the pre-test across all the test items. Two noticeable test items on which learners responded by writing what could provide an insight about the shift in their thoughts prior to and following Hope's teaching were item 5 and 8. As discussed in Chapter 3 (Table 3.5), item 5 required the participant learners to identify the functional group on the given molecule of 2-bromobutane. The typical extracts of

two Hope's learners' written responses in the pre-and post-test are provided as shown in the Figure 7.5 below.

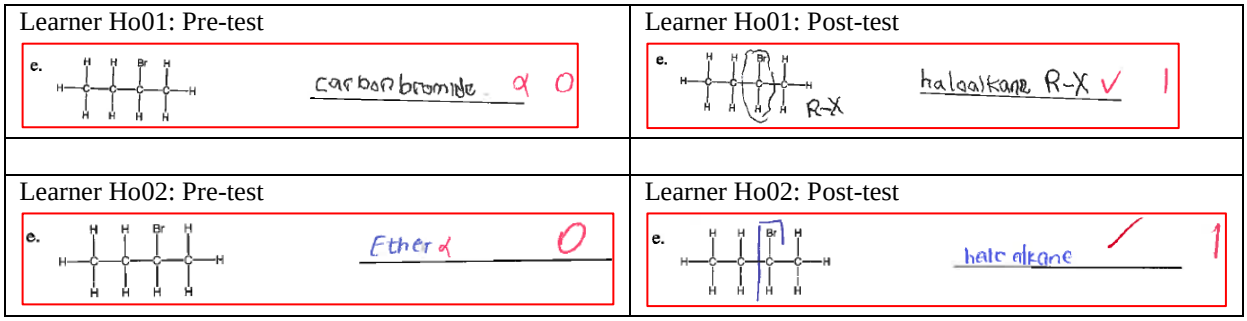


Figure 7.5: Extracts of Hope's learners' written responses on the test item 5

As shown in the Figure 7.5 above, the learner Ho01's answer in the pre-test was wrong because carbon bromide was referred to as the functional group on the given haloalkane. Nevertheless, it could be observed that the learner seemed to demonstrate the understanding that, the chemical symbol 'C' in the molecule represents carbon and 'Br' represents bromine. As a result, while the correct conceptual understanding was lacking in the learner, the correct knowledge of relevant pre-concepts was in place. Likewise, learner Ho02's answer in the pre-test revealed the possible awareness of ether as an organic molecule. However, following Hope's teaching, both learners correctly referred to the haloalkane functional group as shown in the given structure.

Furthermore, the test item 8 required learners to draw a simple organic molecule which contains a functional group of ether. Hope's learners improvement in the conceptual performance on this test item from Rasch Item measure of 4.08 in the pre-test to Rasch Item measure of 1.67 in the post-test. While none of the learners could correctly draw the simple organic molecule containing the functional group of ether in the pre-test, there were 10 learners in the class size of 30 who responded correctly in the post-test. The typical extracts of two learners who responded in both the pre-and post-test are provided as shown in the Figure 7.6 below.

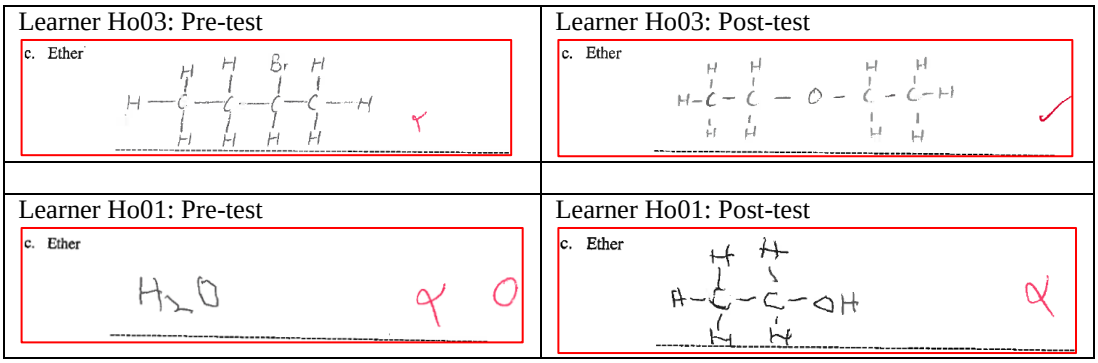


Figure 7.6: Extracts of Hope's learners' written responses on the test item 8

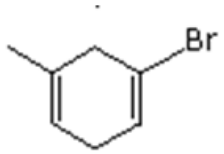
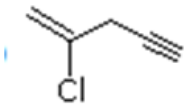
As shown in the Figure 7.6 above, in the pre-test, learner Ho03 drew the molecular structure of 2-bromobutane, a haloalkane instead of the required molecular structure of ether. Likewise, learner Ho01 wrote the chemical formula instead of the required molecular formula for ether. The two responses showed the learners' ability to symbolically represent molecules. Following Hope's teaching, only the understanding learner Ho03 could be observed to have improved from drawing the molecular structure of haloalkane to drawing the required molecular structure of ether. However, it was still difficult for learner Ho01 to correctly drew the molecular structure for ether although the picture in the learner's mind seemed to have changed from categorising ether as an inorganic compound like water (H_2O) to categorising it as an organic compound similar to ethanol.

With the low level of conceptual improvement experienced by Hope's learners following the teaching, similar to the case of Ruth's learners, the item 12, 13 and 15 still emerged as the most difficult for Hope's learners following the teaching. The common learners' errors are later discussed below.

Common errors on item 12, 13 and 15 in the cases of Ruth's and Hope's learners

In spite of the conceptual improvements experienced by Ruth's and Hope's learners following the teachings, none of the learners could provide correct answers on item 12, 13 and 15 in both the pre-and post as reported in the Table 7.5 and 7.9 above. The Table 7.10 below presents the question items as they appear in the achievement test.

Table 7.10: Content of test item 12, 13 and 15

Question: Name the following compounds accroding to the IUPAC sytem		Question: Write the structural formula for this compound
		butane-1,4-diamine
Item 12	Item 13	Item 15

On naming the test item 12 according to the IUPAC system, apart from the learners who left the answer space blank, three common answers supplied by the participant learners are as follows: (i) 1-bromobenzene; (ii) 1, 3-bromobenzene; and (iii) bromobenzene. Based on these responses, the participant learners understood this is an aromatic molecule of benzene but they seemed not to be aware that, apart from bromine, there is another constituent which is a methyl group. The possible source this error might be unfamiliarity with line structural way of representing organic molecules and considering the position of the double bonds especially in aromatic hydrocarbons.

On naming the test item 13 according to the IUPAC system, apart from the learners who left the answer space blank, the two common learners' responses included: (i) chloroethane; and (ii) 1-chlorobutene. It could be observed that, some learners seemed to identify Cl as representing chlorine substituent; however, the line structure was incorrectly misinterpreted. This might be as a result of unfamiliarity with a molecule of hydrocarbon consisting of a double and triple carbon-carbon covalent bond.

On writing the structural formula for 'butane 1, 4-diamine' most learners who responded rather wrote the structure for butane. This error might be linked to the lack of understanding of amines.

When the analysed PSTs' teachings presented in the previous chapter, Chapter 6 were carefully examined, it was discovered that, the participant PSTs did not cover aspects of the aromatic compounds, using line structures to represent organic molecules and naming and writing structures of amines.

7.3.2 Measurement of learner performances on physical properties and structures of organic compounds

Case 1: Rose's learner performances

(i) Overview of the raw scores

The Table 7.11 below presents the identifying codes for individual Rose's learners, their scores in the pre-and post-tests and *gain* representing the actual performance following Rose's teaching focusing on physical properties and structures of organic compounds. The calculated average scores for the all the participant Rose's learners are provided in the last row as shown in the Table 7.11 below.

Table 7.11: Rose's learners' test scores on physical properties and structures (n=14)

Learner	Pre-test raw score	%Pre-test raw score	Post-test raw score	%Post-test raw score	Gain	%Gain
Ro01	8	57.14	12	85.71	4	28.57
Ro05	2	14.29	12	85.71	10	71.43
Ro08	1	7.14	12	85.71	11	78.57
Ro02	10	71.43	11	78.57	1	7.14
Ro03	6	42.86	11	78.57	5	35.71
Ro06	2	14.29	11	78.57	9	64.29
Ro07	1	7.14	11	78.57	10	71.43
Ro09	2	14.29	11	78.57	9	64.29
Ro04	6	42.86	10	71.43	4	28.57
Ro12	1	7.14	10	71.43	9	64.29
Ro10	1	7.14	9	64.29	8	57.14
Ro11	1	7.14	8	57.14	7	50.00
Ro13	1	7.14	8	57.14	7	50.00
Ro14	1	7.14	8	57.14	7	50.00
Average	3.07	21.94	10.29	73.47	7.21	51.53

Note: *Scores are arranged in the descending order of post-test scores. *Pseudonyms for learners have been used. *Gain score=(Post-test score) – (Pre-test score)

As shown in the Table 7.11 above, it could be observed, in the pre-test, only 1 (7.1%) learner in the class size of 14 scored above an achievement mark of 60%. Other learners had the minimum and maximum percentage scores of 7.14% and 57.14% respectively which were less than a mark 60%. However, in the post-test, 11 (i.e. 78.6%) learners scored an achievement mark of 60% or above in the class size of 14 learners while 3 (i.e. 21.4%) learners scored below the achievement mark. Such a major positive shift in the performance score across the pre-and post-test seemed to imply that learners learned the concepts of physical properties and structures of organic compounds following Rose's teachings.

(ii) Conversion of raw test scores into Rasch measures

The Rose's learners' raw scores in the pre-and post-tests as given in the Table 7.11 above were statistically analysed using the RMA similar to the analyses done in the cases to Ruth's and Hope's learners. The person measures are presented in the Table 7.12 below.

Table 7.12: Rasch Person measures for Rose's learners' pre-and post-tests (n=14)

Identifying code for learner	**Pre-Achievement test**			**Post-Achievement test**		
	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
Ro01	0.81	1.5	1.8	0.94	0.8	1.3
Ro05	-1.87	-0.7	-0.6	0.94	-1.3	-0.5
Ro08	-2.72	0.3	0.3	0.94	0.1	2.0
Ro02	1.88	1.6	0.5	0.83	-0.1	0.2
Ro03	-0.02	-1.7	0.3	0.83	-0.1	1.2
Ro06	-1.87	-0.3	-0.3	0.83	0.7	0.6
Ro07	-2.72	0.2	-0.4	0.83	0.5	0.6
Ro09	-1.87	0.4	0.1	0.83	-0.5	-0.5
Ro04	-0.02	-1.3	-1.8	0.75	0.7	0.5
Ro12	-2.72	0.4	-0.4	0.75	-0.3	-0.7
Ro10	-2.72	0.3	0.3	0.70	0.7	0.6
Ro11	-2.72	0.3	0.3	0.66	0.3	0.3
Ro13	-2.72	-0.1	-0.2	0.66	-1.7	-1.3
Ro14	-2.72	0.3	-0.4	0.66	-1.9	-1.0
Rasch mean	-1.57			0.79		
Person reliability	0.67			0.88		
Item reliability	0.81			0.93		
Infit/Outfit indices	All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.			All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.		

Note: The order of arrangement of learners was based on descending order of Rasch measures in the post-test. The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

As shown in the Table 7.12 above, the different values indicated by the Pre-Rasch measures and Post-Rasch measures showed that the participant learners had a hierarchy of level of difficult in the pre-and post-test. This means that, the individual learner's pattern of response has to be examined for 'fittingness', assessing for whether each learner responded in an acceptably predictable way considering the expected hierarchy of responses. All the values for 'IN.ZSTD' and 'OUT.ZSTD' are within the acceptable range of +2 to -2. This implies that, the values for each participant learner's response are considered fitting and hence, working together to measure learner performances in physical properties and structures of organic compounds thereby constituting valid measures. There were higher Person Rasch measures in the post-test compared to the pre-test. This showed a positive shift in performance across all the participant learners

who wrote the tests. Also, the higher calculated mean for post-test person measure (0.79) than the lower calculated mean for pre-test person measures (-1.57) reflects an improvement in the learners' conceptual performance following Rose's teaching. Likewise, the Table 7.14 above reflects good reliability for the person measure and item difficulty. For the pre-test, the person reliability generated was 0.67 and there was the item reliability of 0.81. For the post-test, the person reliability was 0.88 and the item reliability was 0.93. The higher person reliability in the post-test compared to the pre-test is an indication that enough items were sufficiently spread along the continuum and enough spread of person ability. The indices for item reliability for the pre-test and post-test were also found within the range of 0 and 1 and higher than the Cronbach's alpha coefficient of 0.70. This implies that the items in the achievement test are very replicable, wide spread among the persons, very minimal standard errors and uncompromised development of reliable measures.

(iii) Comparing person measures for significant difference

The stacked data generated for pre-and post-tests in the case of Rose's learners is presented as shown in the Table 7.13 below. This presents the summary of the anchored Rasch person measures and standard error for the pre-test and post-test.

Table 7.13: Stacked data-Rasch Person measures from anchored pre-and post-test (n=14)

	Pre-achievement test		**Post-achievement test**	
Learner	Rasch Measure	S. Error	Rasch Measure	S. Error
Ro01	0.81	0.67	3.51	1.48
Ro05	-1.87	0.81	3.51	1.48
Ro08	-2.72	1.06	3.51	1.48
Ro02	1.88	0.83	2.00	1.03
Ro03	-0.02	0.64	2.00	1.03
Ro06	-1.87	0.81	2.00	1.03
Ro07	-2.72	1.06	2.00	1.03
Ro09	-1.87	0.81	2.00	1.03
Ro04	-0.02	0.64	1.16	0.84
Ro12	-2.72	1.06	1.16	0.84
Ro10	-2.72	1.06	0.55	0.75
Ro11	-2.72	1.06	0.32	0.71
Ro13	-2.72	1.06	0.32	0.71
Ro14	-2.72	1.06	0.32	0.71
Mean	**-1.57**		**1.74**	

Note: Item measure set to zero; Units per Logit=1(UIMEAN=0 &USCALE=1)

The Rasch Person measures in the Table 7.13 above were further analysed by subjecting them to the Wilcoxon Paired Signed-rank test which measures the magnitude of the difference between

the pairs of data. The result of the analysis is presented as shown in the Figure 7.7 below for Rose's learners' achievement tests.

Pre-Test Person measure	Anchored Post-Test Person measure	Diff= (Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	105
0.81	3.51	2.7	2.7	4.00	4	n=	14
-1.87	3.51	5.38	5.38	13.00	13	σ{T}	31.8590646
-2.72	3.51	6.23	6.23	14.00	14	α	0.05
1.88	2	0.12	0.12	1.00	1	Action(L)	-62.4
-0.02	2	2.02	2.02	3.00	3	Action(U)	62.4
-1.87	2	3.87	3.87	9.50	9.5	z	3.3
-2.72	2	4.72	4.72	12.00	12	Reject Null at 0.05	
-1.87	2	3.87	3.87	9.50	9.5	*p*	0.00098154
-0.02	1.16	1.18	1.18	2.00	2		
-2.72	1.16	3.88	3.88	11.00	11		
-2.72	0.55	3.27	3.27	8.00	8		
-2.72	0.32	3.04	3.04	6.00	6		
-2.72	0.32	3.04	3.04	6.00	6		
-2.72	0.32	3.04	3.04	6.00	6		

Figure 7.7: Wilcoxon signed-rank test for comparing Rose's learner performances

As shown in the Figure 7.7 above, the alpha *p*-value is equal to 0.00098 which is much more less than the significance level (α) of 0.05. This suggests a significance difference at 95% (0.05) does exist between Rose's learners' performance in the pre-test and post-test as given by the Rasch Person measures. In order words, Rose's learners' conceptual ability in the post-test was better than their conceptual ability in the pre-test at the 95% level of confidence.

(iv) Rank order of item difficulty

The Table 7.14 below presents the rank order of item difficulty and the number of learners who answered each item correctly (denoted as 'number of correct responses') for illustrative purposes. The test items in the first column were arranged in the decreasing order of learners' gain of correct responses represented as Y-X, the difference between the number of correct responses in the post-test (Y) and correct responses in the pre-test (X).

Table 7.14: Rasch Item measures for Rose's learners' achievement test (n=14)

Item	Pre-test		Post-test		Gain	
	Rasch Item measure (IM_1)	Number of Correct responses (X)	Rasch Item measure (IM_2)	Number of Correct responses (Y)	(IM_2)-(IM_1)	X-Y
item1	-0.54	4	-3.86	12	-3.32	8
item2	-0.54	4	-3.86	12	-3.32	8
item9	0.91	2	-3.86	12	-4.77	10
item3	-1.67	6	-1.56	11	0.11	5
item5	-0.54	4	-1.56	11	-1.02	7
item4	-1.13	5	-0.69	10	0.44	5
item7	0.12	3	-0.69	10	-0.81	7
item6	-0.54	4	-0.69	10	-0.15	6
item10	1.99	1	-0.69	10	-2.68	9
item8	0.12	3	0.77	9	0.65	6
item11	0.91	2	1.15	8	0.24	6
item12	0.91	2	1.15	8	0.24	6
Item13	2.68	0	2.56	0	-0.12	0
Item14	2.68	0	2.56	0	-0.12	0
Item reliability	**0.81**		**0.93**			

Note: The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1). Items arranged in the increasing order of Post-test Rasch Item measures

The results in the Table 7.14 above showed that all items in the pre-and post-achievement tests were ranked similarly, indicating different extents of learners' engagement in attempts to answer the achievement test questions. Except on the item 13 and item 14 on which none of the participant Mark's learners responded correctly, there were improvements in the learners' conceptual performances in the post-test compared to the pre-test. This seemed to be evident in the higher number of learners (Y) who responded correctly in the post-test compared to the lower number of learners (X) who responded correctly in the pre-test across all the items. For example, a careful look at the post-test Rasch Item measures revealed that, item 1, 2 and 9 with the Post-test Rasch item measure of -3.86 each emerged as the least difficult for learners following Rose's teaching. The participant learners experienced the greatest conceptual improvement on these three test items following Rose's teaching as their Rasch Item measures were lower in the post-test compared to the pre-test. For example, the test item 9 and 10 are conceptually related. While item 9 required the participant learners to state whether the boiling points of carboxylic acids would be higher than the boiling points of alcohols with the same number of carbon atoms, item 10 asked them to explain their answer to Item 9 as highlighted in Chapter 3 (Table 3.6). The typical extracts of learners' written responses on these two test items are provided below in

order to gain an insight into the possible shift in the learners' conceptual performance in the post-test compared to the pre-test.

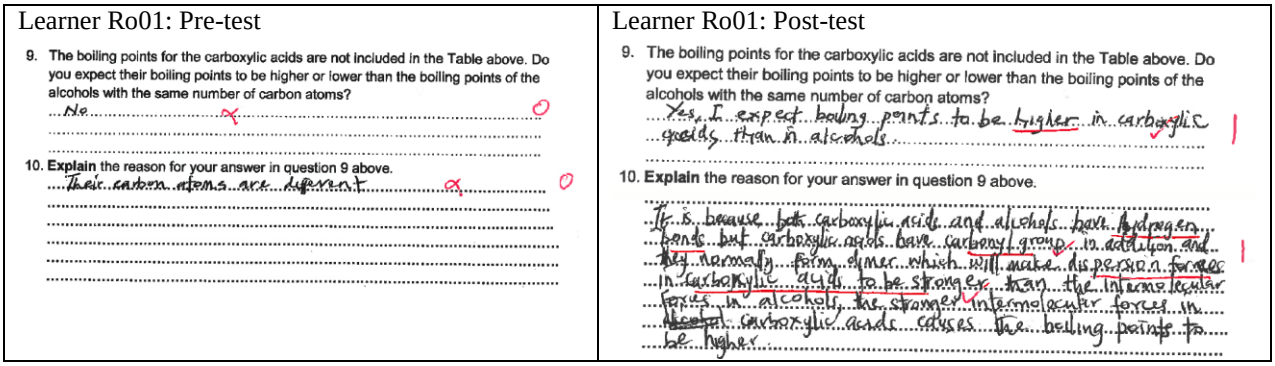


Figure 7.8: Extracts of learner Ro01's written responses on the test item 9 and 10

As shown in the Figure 7.8 above, learner Ro01's answer to question 9 in the pre-test was not clear as he only wrote 'no' instead of indicating whether the boiling points of carboxylic acids would be higher or lower than that of alcohols of the same number of carbon atoms. Likewise, his answer to item 10 question showed lack of understanding of same number of carbon atoms bonded in the two molecules as the question indicated. However, following Rose's teaching as learner responded in the post-test, he correctly indicated his expectation that, the boiling points of carboxylic acids should be higher than the boiling points of alcohols containing the same number of carbon atoms. While stating his reason in response to item question 10, he explained that, both carboxylic acids and alcohols have the hydroxyl group however, the formation of dimers by the hydrogen bond in carboxylic acids strengthens the intermolecular forces in carboxylic acids which in turn increases their boiling points. Learner Ro01's correct explanation in the post-test compared to his incorrect explanation in the pre-test showed an improvement in his conceptual understanding of the trend of boiling points in the carboxylic acids compared to the alcohols. A similar level of understanding was observed in the responses provided by another learner Ru02 whose extracts of written work are provided in the Figure 7.9 below.

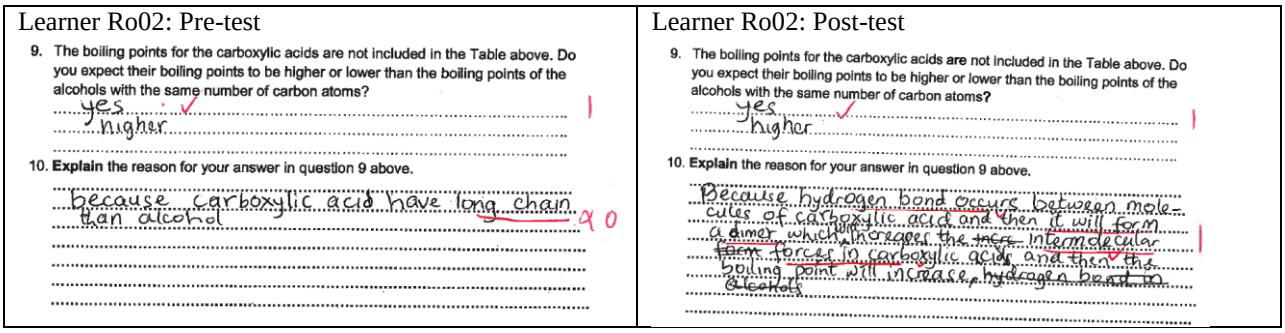


Figure 7.9: Extracts of Rose's learner Ro02's written work on test item 9 and 10

As shown in the Figure 7.9 above, learner Ro02 indicated in the both the pre-test and post-test that, the boiling points for carboxylic acids should be higher than the boiling points of alcohols of the same number of carbon atoms. This showed a good understanding prior to and following Rose's teaching. However, while answering question item 10 in the pre-test, Ro02 wrongly linked the reason for his expectation to the longer carbon chain in carboxylic acids than in alcohols. Meanwhile, following Rose's teaching as Ro02 responded to question item10 in the post-test, he referred to the occurrence of hydrogen bonds in carboxylic acids for dimers which increases their intermolecular forces making their boiling points to be higher than that of alcohols. This showed an improvement in the learners' conceptual understanding of the trend of boiling points in carboxylic acids compared to the alcohols.

Moreover, on the test item 7, Rose's learners' conceptual performance improved from the Rasch item measure of 0.12 in the pre-test to the Rasch item measure of -0.16 in the post-test with the number of learners who responded correctly in the pre-test increasing from 3 to 10 in the post-test. As highlighted in Chapter 3 (Table 3.6), the test item 7 asked learners to explain why the boiling point for hexane is so much lower than the boiling point of hexan-1-ol. For learners to answer this question correctly, they should have understood the strength of the intermolecular forces in the two organic molecules as a result of their functional groups. The typical extracts of two learners' written responses in the pre-and post-test are provided as shown in the Figure 7.10 below.

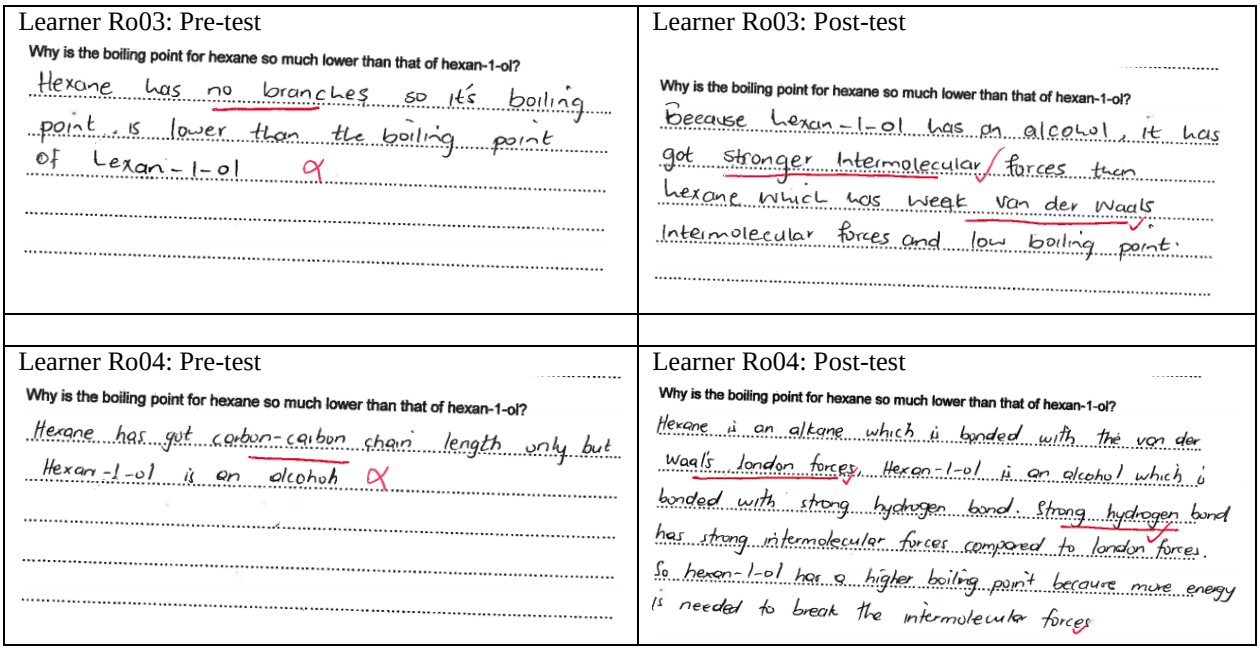


Figure 7.10: Extract of Rose's learners' pre-and post-test written work on Item 7

As shown in the Figure 7.10 above, the learner Ro03's written response in the pre-test showed no good understanding of why the boiling point of hexane is much lower than the boiling point of hexan-1-ol. However, in the post-test, the learner correctly referred to weak van der Waal's forces in hexane compared to the strong intermolecular forces in hexan-1-ol. While the Peter's written response in the post-test showed a good understanding, the explanation did not specifically identify the type of intermolecular forces (hydrogen bond) in hexan-1-ol as a result of the hydroxyl functional group. In the case of learner Ro04, her pre-test written response revealed her understanding that, hexane consists of carbon to carbon covalent bond and hexan-1-ol as an alcohol. Nevertheless, the response does not correctly answer the question asked. In the post-test, Ro05 correctly identified weak van der Waal's London forces in hexane compared to strong hydrogen bond in hexan-1-ol as a result of the hydroxyl group. She also revealed the understanding of how such strong intermolecular forces in hexan-1-ol requires more energy for breaking bonds which eventually leads to the higher boiling point. This conceptual improvement observed in the learners suggests that, they better learned the concepts following Rose's teaching. However, on the Item 13 and 14, there were no correct answers provided by the participant Rose's learners in both the pre-and post-tests. The analysis of learners' errors on these items is provided later below at the end of the section.

Case 2: Mark's learner performances

(i) Overview of the raw scores

The Table 7.15 below presents the identifying codes for individual Mark's learners, their scores in the pre-and post-tests and *gain* representing the actual performance following Mark's teaching physical properties and structures of organic compounds. The calculated average scores for all the participant Mark's learners are provided in the last row as shown in the Table 7.15 below.

Table 7.15: Mark's learners' test scores on physical properties and structures (n=14)

Learner	Pre-test raw score	%Pre-test raw score	Post-test raw score	%Post-test raw score	Gain	%Gain
Ma01	8	57.14	12	85.71	4	28.57
Ma02	7	50.00	12	85.71	5	35.71
Ma04	5	35.71	12	85.71	7	50.00
Ma06	1	7.14	11	78.57	10	71.43
Ma03	8	57.14	10	71.43	2	14.29
Ma05	2	14.29	9	64.29	7	50.00
Ma07	1	7.14	9	64.29	8	57.14
Ma08	1	7.14	8	57.14	7	50.00
Ma11	2	14.29	7	50.00	5	35.71
Ma09	1	7.14	7	50.00	6	42.86
Ma10	1	7.14	6	42.86	5	35.71
Ma13	1	7.14	6	42.86	5	35.71
Ma14	2	14.29	6	42.86	4	28.57
Ma12	1	7.14	5	35.71	4	28.57
Average	2.93	20.92	8.57	61.22	5,64	40.31

Note: *Scores are arranged in the descending order of post-test scores. *Pseudonyms for learners have been used. *Gain score=(Post-test score) – (Pre-test score)

As shown in the Table 7.15 above, it could be observed, in the pre-test, none of the Mark's learners scored an achievement mark of 60% or above. The learners had the minimum and maximum percentage scores of 7.14% and 57.14% respectively which were less than a mark 60%. However, in the post-test, 7 (i.e. 50%) learners scored an achievement mark of 60% or above in the class size of 14 learners while 7 (i.e. 50%) learners scored below the achievement mark. Such an average positive shift in the performance score across the pre-and post-test seemed to imply that learners learned the concepts of physical properties and structures of organic compounds following Mark's teachings.

(ii) Conversion of raw test scores into Rasch measures

The Mark's learners' raw scores in the pre-and post-tests as given in the Table 7.15 above were statistically analysed using the RMA similar to the analyses done in the cases to Ruth's and Hope's learners. The person measures are presented in the Table 7.16 below.

Table 7.16: Rasch Person measures for Mark's learners' pre-and post-tests (n=14)

Identifying code for learner	**Pre-Achievement test**			**Post-Achievement test**		
	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD	Person Rasch measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
Ma01	1.03	1.2	1.5	1.76	1.7	1.0
Ma02	0.59	1.9	1.9	1.76	0.4	1.7
Ma04	-0.20	-1.5	-1.4	1.76	-1.6	-0.9
Ma06	-2.40	0.3	0.2	1.21	-0.8	-0.4
Ma03	1.03	-0.6	-0.6	0.74	1.3	1.4
Ma05	-1.58	-0.2	-0.4	0.31	0.1	-0.2
Ma07	-2.40	0.1	-0.2	0.31	-1.1	-0.9
Ma08	-2.40	0.3	0.2	-0.47	-1.5	-0.8
Ma09	-2.40	0.3	0.2	-0.87	-0.5	0.6
Ma11	-1.58	0.1	-0.1	-0.87	-0.6	-0.3
Ma10	-2.40	0.3	0.2	-1.29	-0.4	1.0
Ma13	-2.40	0.3	0.2	-1.29	0.9	0.3
Ma14	-1.58	-0.2	-0.4	-1.29	0.4	0.1
Ma12	-2.40	0.3	0.2	-2.37	-0.9	-0.2
Rasch mean	-1.36			-0.04		
Person reliability	0.65			0.76		
Item reliability	0.83			0.87		
Infit/Outfit indices	All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.			All IN.ZSTD & OUT.ZSTD fall within the range of -2 and +2.		

Note: The order of arrangement of learners was based on descending order of Rasch measures in the post-test. The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

As shown in the Table 7.16 above, the different values indicated by the Pre-Rasch measures and Post-Rasch measures showed that the participant learners had a hierarchy of level of difficult in the pre-and post-test. All the values for 'IN.ZSTD' and 'OUT.ZSTD' are within the acceptable range of +2 to -2, none of the Mark's learners' responses are significantly problematic in the pre-test and post-test measures. This implies that, the values for each participant learner's response are considered fitting and hence, working together to measure the learner performances in physical properties and structures of organic compounds thereby constituting valid measures. Also, the higher calculated mean for post-test person measure (-0.04) than the lower calculated mean for pre-test person measures (-1.37) reflects an improvement in the learner performances following Mark's teaching. Likewise, the Table 7.16 above reflects good reliability for the

person measure and item difficulty. For the pre-test, the person reliability generated was 0.65 and there was the item reliability of 0.83. For the post-test, the person reliability was 0.76 and the item reliability was 0.87. The higher person reliability in the post-test compared to the pre-test is an indication that enough items were sufficiently spread along the continuum and enough spread of person ability among the learners who responded to test items. In other words, to increase the person reliability value in the pre-test, the person ability should be improved, and this was achieved in the post-test. The indices for item reliability for the pre-test and post-test were also found within the range of 0 and 1 and higher than the Cronbach's alpha coefficient of 0.70. This implies that the items in the achievement test are very replicable, wide spread among the persons, very minimal standard errors and uncompromised development of reliable measures.

(iii) Comparing person measures for significant difference

The person measures generated by RMA as displayed in the Table 7.16 above were anchored to produce stacked data used for further analysis of significance difference. The stacked data generated for pre-and post-tests in the case of Mark's learners is presented as shown in the Table 7.17 below. This presents the summary of the anchored Rasch person measures and standard error for the pre-test and post-test.

Table 7.17: Stacked data-Person measures from anchored pre-and post-test (n=14)

	Pre-achievement test		**Post-achievement test**	
Learner	Rasch Measure	S. Error	Rasch Measure	S. Error
Ma01	1.03	0.70	2.50	0.82
Ma02	0.59	0.65	2.50	0.82
Ma04	-0.20	0.63	2.50	0.82
Ma06	-2.40	1.05	1.89	0.75
Ma03	1.03	0.70	1.37	0.69
Ma05	-1.58	0.79	0.93	0.65
Ma07	-2.40	1.05	0.93	0.65
Ma08	-2.40	1.05	0.14	0.61
Ma09	-2.40	1.05	-0.23	0.62
Ma11	-1.58	0.79	-0.23	0.62
Ma10	-2.40	1.05	-0.63	0.64
Ma13	-2.40	1.05	-0.63	0.64
Ma14	-1.58	0.79	-0.63	0.64
Ma12	-2.40	1.05	-1.61	0.79
Mean	**-1.36**		**0.63**	

Note: Item measure set to zero; Units per Logit=1(UIMEAN=0 &USCALE=1)

The Rasch Person measures in the Table 7.17 above were further analysed by subjecting them to the Wilcoxon Paired Signed-rank test which measures the magnitude of the difference between

the pairs of data. The result of the analysis is presented as shown in the Figure 7.11 below for Mark's learners' achievement tests.

Pre-Test Person measure	Anchored Post-Test Person measure	Diff= (Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	105
1.03	2.5	1.47	1.47	5.00	5	n=	14
0.59	2.5	1.91	1.91	8.00	8	σ{T}	31.859065
-0.2	2.5	2.7	2.7	12.00	12	α	0.05
-2.4	1.89	4.29	4.29	14.00	14	Action(L)	-62.4
1.03	1.37	0.34	0.34	1.00	1	Action(U)	62.4
-1.58	0.93	2.51	2.51	10.00	10	z	3.3
-2.4	0.93	3.33	3.33	13.00	13	Reject Null at 0.05	
-2.4	0.14	2.54	2.54	11.00	11	*p*	0.00493
-2.4	-0.23	2.17	2.17	9.00	9		
-1.58	-0.23	1.35	1.35	4.00	4		
-2.4	-0.63	1.77	1.77	6.50	6.5		
-2.4	-0.63	1.77	1.77	6.50	6.5		
-1.58	-0.63	0.95	0.95	3.00	3		
-2.4	-1.61	0.79	0.79	2.00	2		

Figure 7.11: Wilcoxon signed-rank test for comparing Mark's learner performances

As shown in the Figure 7.11 above, the alpha *p*-value is equal to 0.0049 which is less than the significance level (α) of 0.05. This suggests a significance difference does exist between Mark's learners' performance in the pre-test and post-test as given by the Rasch Person measures. In order words, Mark's learners' conceptual ability in the post-test was better than their conceptual ability in the pre-test at the 95% level of confidence.

(iv) Rank order of item difficulty

The Item measures generated from the Rasch analysis of Mark's learners' pre-and post-achievement tests are provided as shown in the Table 7.18 below. As shown in the Table, the rank order of item difficulty and the number of learners who answered each item correctly are provided.

Table 7.18: Rasch Item measures for Mark's learners' achievement tests (n=14)

Item	Pre-test		Post-test		Gain	
	Rasch Item measure (IM_1)	Number of Correct responses (X)	Rasch Item measure (IM_2)	Number of Correct responses (Y)	(IM_2)-(IM_1)	X-Y
item3	-1.94	7	-3.64	12	-1.70	5
item1	-0.23	4	-3.02	11	-2.79	7
item4	2.55	3	-2.71	10	-5.26	7
item6	-0.23	4	-2.71	10	-2.48	6
item8	-0.68	5	-1.21	9	-0.53	4
item10	-0.68	5	-1.21	9	-0.53	4
item2	2.55	3	-0.91	8	-3.46	5
item5	2.55	3	-0.91	8	-3.46	5
item9	-1.04	6	-0.91	8	0.13	2
item7	2.55	3	0.53	7	-2.02	4
item11	-1.04	6	0.53	7	1.57	1
item12	2.55	3	1.57	6	-0.98	3
Item13	2.56	0	3.02	0	0.46	0
Item14	2.56	0	3.02	0	0.46	0
Item reliability	**0.83**		**0.87**			

Note: The mean for item measure was set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1). Items arranged in the increasing order of Post-test Rasch Item measures

The results in the Table 7.18 above showed that all items in the pre-and post-achievement tests were ranked similarly, indicating different extents of learners' engagement in attempts to answer the achievement test questions. Except on the item 13 and item 14 on which none of the participant Mark's learners responded correctly, there were improvements in the learners' conceptual performances in the post-test compared to the pre-test. This seemed to be evident in the higher number of learners (Y) who responded correctly in the post-test compared to the lower number of learners (X) who responded correctly in the pre-test across all the items. For example, a careful look at the post-test Rasch Item measures revealed that, item 3 with the Rasch item measure of -3.64 emerged as the least difficult for learners following Mark's teaching. On this item, there were seven (7) participant Mark's learners who provided correct answers in the pre-test however in the post-test, twelve (12) answered the question correctly. Item 3 and 4 are conceptually related such that while item 3 required the learners to write about the pattern observed across the boiling points of alcohols, item 4 asked them to explain their reason for pattern observed in item 3. The typical extracts of learners' written responses on these two test items are provided in the Figure 7.12 below in order to gain an insight into the possible shift in the learners' conceptual performance in the post-test compared to the pre-test.

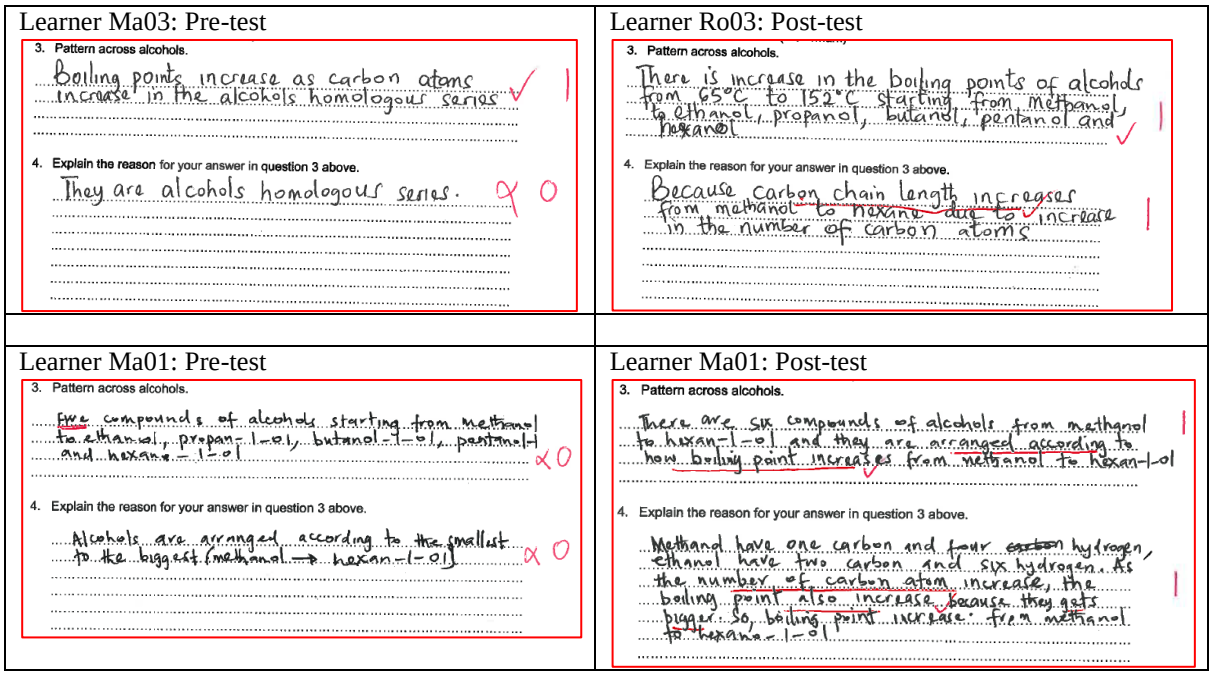


Figure 7.12: Extracts of Mark's learners' pre-and post-test written work on Item 3 and 4

As shown in the Figure 7.12 above, in the pre-test, learner Ma03 could correctly state the observed pattern in relation to the increase in boiling points in the listed members of alcohols however, he could not correctly highlight the reason for the observed trend in the boiling point. Following Mark's teaching as Ma03 responded in the post-test, he was able to correctly relate the observed pattern in the boiling points of alcohols to the increase in the number of carbon atoms. Likewise in the case of learner Ma01, in the pre-test, he was unable to correctly describe the pattern observed in the listed alcohol members in relation to increase in the boiling points. However, in the post-test, learner Ma01 improved on stating the observed pattern and reason in relation to increase in boiling points as the number of carbon atoms increases.

One of the difficult items for Mark's learners in the pre-and post-tests was the test item 7 which asked learners to explain why the boiling point for hexane is so much lower than the boiling point of hexan-1-ol (see Chapter 3, Table 3.6). For learners to answer this question correctly, they should have understood the strength of the intermolecular forces in the two organic molecules as a result of their functional groups. As shown in the Table 7.18 above, prior to Mark's teaching, only 3 learners in a class size of 14 provided correct answers in the pre-test, whereas in the post-test, only 7 learners were able to answer the question correctly. The extracts

of two learners' written responses in the pre-and post-achievement tests are given in the Figure 7.13 below.

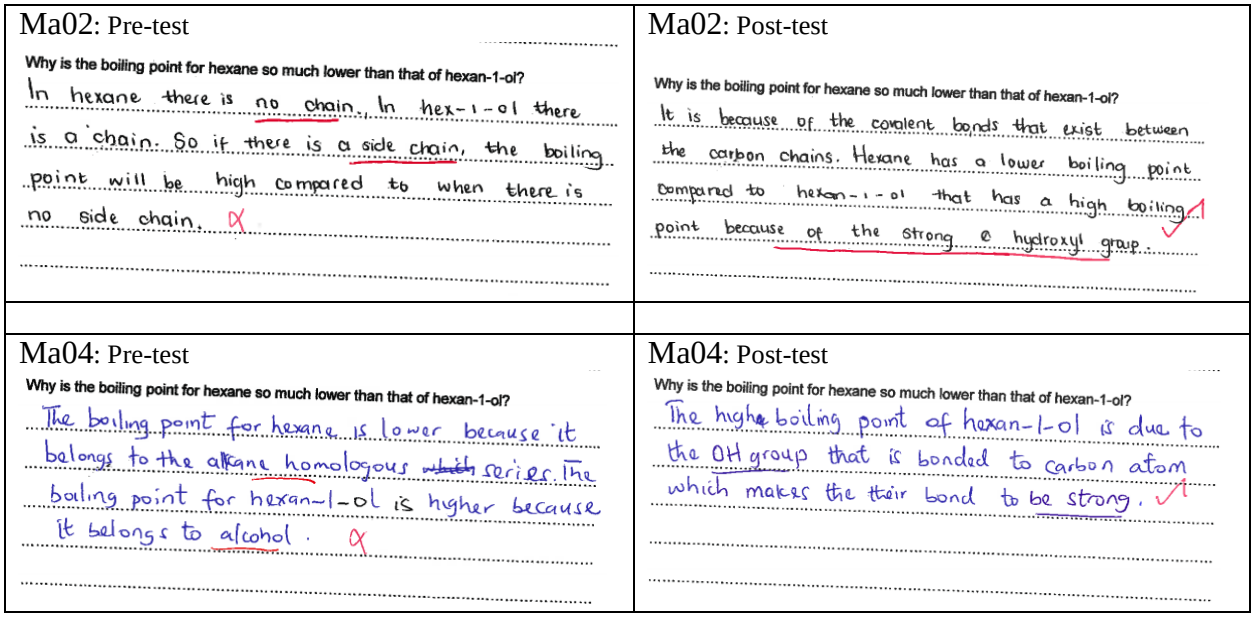


Figure 7.13: Extract of Mark's learners' pre-and post-test written responses on item 7

As shown in the Figure 7.13 above, Ma02 showed no good understanding for why the boiling point of hexane is lower than the boiling of hexan-1-ol as he referred the side chain in hexanol and no side chain in hexane. However, the learner's understanding seemed to have improved in the post-test as he only referred to hexanol having high boiling because of the hydroxyl group. What appeared to be lacking in his post-test written response was the understanding that, hydrogen bond is stronger in hexanol due to the presence of hydroxyl group. He rather referred to hydroxyl group as being strong.

In the case of learner Ma04, the learner's written response in the pre-test showed she understood hexane belonging to the alkane homologous series and hexan-1-ol belonging to the alcohol homologous series. However, the difference in the boiling point of the two organic molecules mentioned was not clear in the learner's explanation. In the post-test, Ma02 specifically referred to the higher boiling point of hexan-1-ol due to the presence of hydroxyl group which is not presence in hexane. Notwithstanding, the explanation in the post-test does not revealed the type of intermolecular forces present in each organic molecule and how they strength differs. It could be observed that, learners were not really able to provide more than they information acquired during Mark's teaching. However, to some extent, learners improved in their conceptual

performances following the teaching. In spite of the varying extents of improvement observed in the Mark's learners' understanding, none of them could correctly provide answers on item 13 and 14. This was found to be similar to the case of Rose's learners. The analysis of participant learners' errors on these two items is discussed below.

Analysis of Rose's and Mark's learners' errors on item 13 and 14

With the varying extents of improvement observed in the Rose's and Mark's learners' conceptual performances following the teaching, item 13 and 14 emerged as the most difficult items on which none of the learners provided correct answers in both the pre-and post-test. The participant learners were given four organic compounds as shown in the Figure 7.14 below. While item 13 asked them to arrange the compounds in the order of decreasing boiling points, item 14 required them to give the reasons for their arrangement.

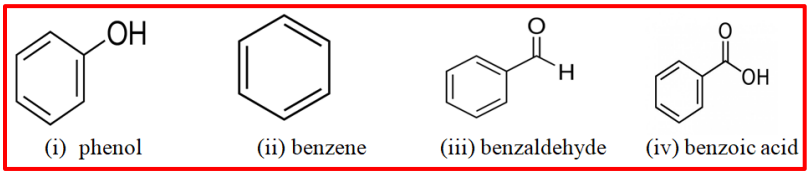


Figure 7.14: Organic compounds to arrange according to boiling points

The extract of written responses by one the Mark's learners is provided as shown in the Figure 7.15 below.

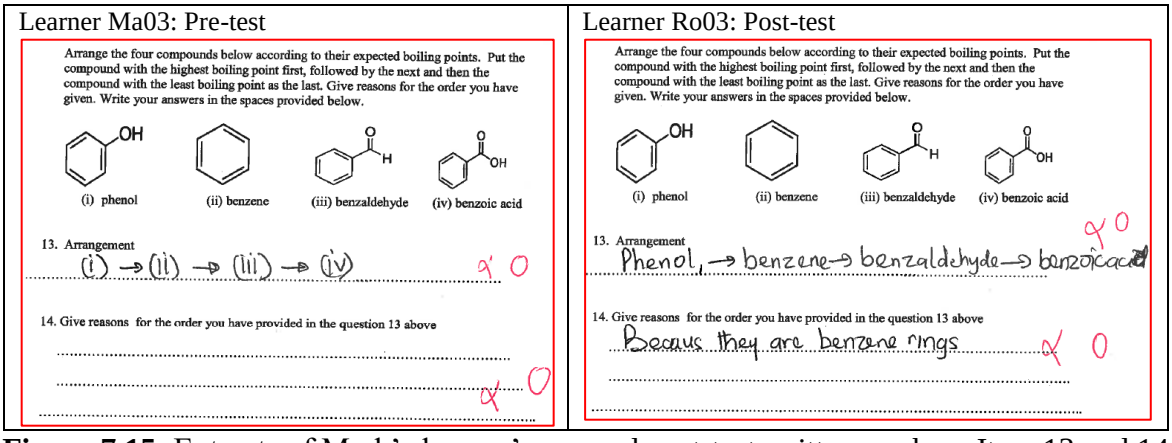


Figure 7.15: Extracts of Mark's learner's pre-and post-test written work on Item 13 and 14

On the arrangement of organic molecules in the Figure 7.15 above, there were three common types of answers provided by the participant Rose's and Mark's learners and these included are given in the Figure 7.16 below.

(iii), (iv), (ii), (i)	(iv), (i), (iii), (ii)	(i), (ii), (iii), (iv)

Figure 7.16: Learners' common responses on the arrangement of compounds

The participant learners' arrangement showed uncertainty about which of benzoic acid and benzaldehyde should have the highest boiling point. Likewise, they seemed to be confused about which of phenol and benzene should have the lowest boiling point. These errors are linked to the learners' lack of understanding of the functional groups on each organic molecule represented in the Figure 7.18 above. As a result, the participant learners were unable to relate functional groups to the strength of intermolecular forces in deciding on correctly arranging the above organic molecules in the order of the decreasing boiling points. When the PSTs' teachings analysed in the previous chapter, Chapter 6 was carefully examined, it was discovered that, they did not cover the aspects of aromatic compounds and their boiling points. The participant learners lacked the understanding that stronger intermolecular forces result in higher boiling points. The intermolecular forces in benzoic acid are stronger because of the carbonyl and hydroxyl group which constitute its functional group. This is followed by benzaldehyde which has more diplo-dipole interactions due to its additional oxygen atom. The next compound is the phenol which can form intermolecular H-bonds and then benzene with the lowest boiling point since it has no polar groups.

7.4 SUMMARY

This chapter focused on measuring the learner performances prior to and following the PSTs' teachings on the concepts of organic chemistry. The measurement was done as the first step taken towards determining the influence of PSTs' eTSPCK on learners' conceptual performances, the focus in the next chapter, Chapter 8. It was found out that, all the participant learners experienced a significant improvement (also see Table 7.4) in their understanding of the concepts of organic chemistry covered by the PSTs during teaching. Across the pre-and post-test scores, the participant learners significantly improved from an overall average performance of 15.6% in the pre-test to an overall average performance of 62.2% in the post-test as shown in the Figure 7.17 below.

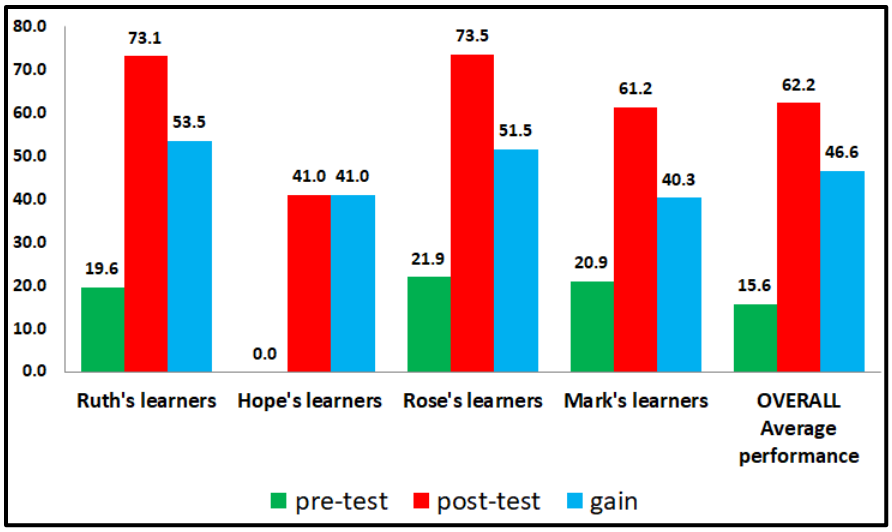


Figure 7.17: Learner performances in the pre-and post-test

As shown in the Figure 7.17 above, except in the case of Hope's learners, all the participant learners taught by the PSTs experienced both a significant improvement (also see Table 7.4) in their post-test achievement scores and also reached the desirable 60% achievement mark in the topic of the intervention (organic chemistry). The conceptual performance of Hope's learners below the acceptable mark of 60% brings to view the idea of cumulative learning in developing knowledge and skills. For learner to adequately learn newly introduced concepts, according to cummulative learning theory, they must develop the ability to link such concepts to the previously acquired knowledge and the concepts must be returned to some other time with emphasis and then, adding-on more adavnced elements (Maton, 2009; Muklis *et al*., 2018). While the participant Ruth's, Rose's and Mark's learners had the privilege of having the new concepts of functional groups and other organic chemistry concepts covered by the PSTs built on their prior knowledge of hydrocarbons, Hope's learners were introduced to these same concepts of organic chemistry for the first time. Nevertheless, it was interesting to see that, following Hope's teaching the participant learners improved to some extents in their understanding of organic chemistry concepts covered. Furthermore, the Rasch Person Measures generated from the Rasch analysis of learners' conceptual performances is shown in the Figure 7.18 below.

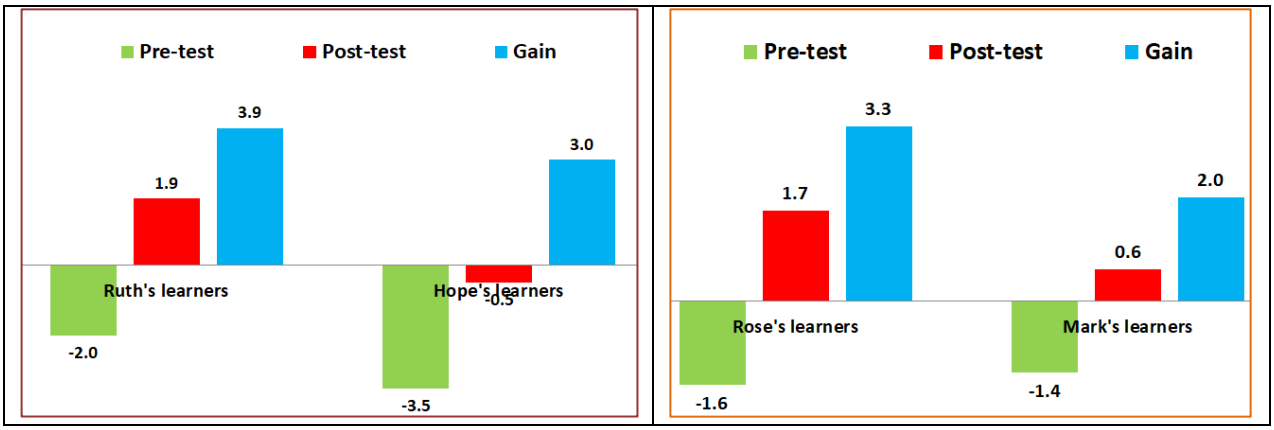


Figure 7.18: Rasch Person Measures for learner performances

As shown in the Figure 7.18 above, from Rasch Analysis of learners' pre-and post-tests, the reported gains in conceptual performance following the PSTs teachings were 3.92, 3.06, 3.31 and 1.99 for Ruth's learners, Hope's learners, Rose's learners and Mark's learners respectively. It could be observed that, despite Hope's learners being Grade 11 learners, their gain was higher than the gain for Mark's learners who were in Grade 12. It was interesting to see that, Hope's learners' gain was similar to Ruth's and Rose's learners who were in Grade 12 although Hope's learners' post-test scores were lower than the desirable 60% mark neverthless Hope had moved the learners to the same extent as others.

In spite of the learners' conceptual improvement observed, certain test items were found to be difficult for the participant learners to process in both the pre-test and post-tests following the PSTs' teachings. For example, on the concepts of functional groups and IUPAC nomenclature of organic compounds, item 12, 13 and 15 emerged as the most difficult. Likewise, on the concepts of physical properties and structures of organic compounds, item 13 and 14 emerged as the most difficult for learners. While the PSTs discussed functional groups, naming of organic compounds using IUPAC system and how intermolecular forces affect boiling points of compounds in aliphatic compounds, the participant learners were unable to transfer same understanding from alipahtic to aromatic compounds. This was due to the fact that, aromatics were not used as examples in the PSTs' discussions of functional groups, IUPAC naming and physical properties and structures of organic compounds in all cases. The key and common element associated with these test items is that, they were not explcitly covered in the lessons in all the cases. The analysis of learners' errrors on these items also revealed unfamiliarity with the concepts of aromatic compounds, use of line structures in representing organic molecules and

having a single, double and triple carbon-carbon covalent bonds present in one single organic molecule. It is understood in this study that, teachers are expected to cover all aspects of aliphatic and aromatic compounds when presenting organic chemistry to learners as stated in the South African physical science curriculum. Teachers normally take about 3-4 weeks to cover these concepts. However, the participant PSTs in this study were only able to focus on certain aspects of organic chemistry for 2 lessons of 1 hour 20 minutes as the time permitted. In addition, the content of the achievement tests were concealed from the PSTs to prevent them from making the test the focus of the teaching at the expense of learners' conceptual understanding. Hence, it was not surprising that the PSTs could only cover certain aspects of organic chemistry within this time frame.

Moreover, it is important to note that the above findings on the learners' conceptual improvement following the PSTs' teachings are a result of all the factors that were in play in the lessons. This includes the possible influence of PST's beliefs of their roles as science teachers; their own understanding of content knowledge of the topic (CK); their pedagogical knowledge (PK) and also their topic specific pedagogical content knowledge (TSPCK). However, since the study is focussed succintly on the influence of their personal TSPCK in enactment, it is thus important to minimize the effect of the others and try to filter-out that of their eTSPCK. The next chapter, attempts at this by using the idea of isolating TSPCK episodes that seemed evidently containing conceptual explanations corresponsing to the test items in the achievement tests.

CHAPTER EIGHT

8. ANALYSIS OF RELATIONSHIP BETWEEN ENACTED TSPCK AND LEARNER ACHIEVEMENT

In Chapter 6, the PSTs' eTSPCK visible as teacher knowledge in the classroom teaching of organic chemistry was captured and portrayed. In Chapter 7, the analyses of learners' achievement tests were presented in order to establish the learner achievement in organic chemistry following the PSTs' teachings. The current chapter presents the analyses which examine whether or not there is any relationship between the PSTs' eTSPCK and learner achievement in the topic of organic chemistry. The chapter closes by summarizing the key findings emerging from the analyses.

8.1 INTRODUCTION

The current chapter presents the correlation analysis focusing on the PSTs' eTSPCK and learner achievement in organic chemistry. The analysis was guided by the third research question stated as follows: *How does the quality of pre-service teachers' TSPCK seen in the actual classroom teaching of organic chemistry influence learner achievement in organic chemistry?* The examination in this chapter represents the concluding aspects of the exploration of TSPCK of a group of PSTs, who were exposed to cTSPCK in Chapter 4, subsequently showed an improvement in planned TSPCK as analyzed in Chapter 5 and whose eTSPCK was visible in the actual classroom teaching of organic chemistry as analyzed in Chapter 6. The analyses of achievement tests presented in Chapter 7 revealed that, the participant learners taught by the PSTs improved significantly as a collective class in their conceptual performances, and to varying extents as individuals with majority achieving comfortably, the desirable 60% marked in the topic of organic chemistry. The emphasis in this study has been on improving the PSTs' understanding of the interactive use of content-specific knowledge components in pedagogically transforming their content knowledge of organic chemistry, and how in turn this has a direct bearing on the learner achievement. Such interactive use of knowledge components in describing how PCK, and in this case, TSPCK relates to learner outcomes has been reported in the PCK literature as an unanswered question (Akın & Uzuntiryaki-Kondakci, 2018; Aydin & Boz, 2013). This has been gap that this study attempted to address. The learner outcome represents the downstream products of educational research (Gess-Newsome, 2015) making its

link to science teachers' PCK important such that, it serves as one way to determine the effectiveness of teachers' classroom instruction and thus, a method of assessing the effectiveness of TSPCK construct (Carlson & Daehler, 2019; Rollnick & Mavhunga, 2015). As alluded to in the literature review chapter (Chapter 2), this study acknowledges the complexity of instruction and learning due to myriad of factors and hence, the difficulty in accurately establishing the link between PCK and learner outcomes (Cross & Lepareur, 2015; Gess-Newsome *et al*., 2019). There is also an understanding that, what a teacher knows, how the teacher presents what he knows to the learners in the classroom including the kind of explanations provided by the teacher, all contributes to what learners eventually learn. In this line of thought, science education researchers in the area of teacher knowledge have been majorly focusing on how teachers' PCK manifests in the course of explaining and presenting concepts to the learners (Aydin *et al*., 2014; Chan & Yung, 2015). Thus, in examining TSPCK-learner outcomes link, this chapter focused on the TSPCK episodes (constituting eTSPCK) emerging from various explanations provided by the PSTs in the actual classroom teaching of organic chemistry in relation to the learner achievement in the topic. For the purpose of gaining insights into some other factors which might have contributed to strengthening or weakening any possible relationship between the PSTs' eTSPCK and learner achievement, learners' views were collected about their learning of the concepts covered by the PSTs, and analyzed in the next chapter, Chapter 9. Thus, this chapter is presented in two sections. The first section of the chapter comprises of a recap of methodological approaches employed including a brief description of the participants, types of data collected and methods of analysis. The second section of the chapter presents the quantitative analysis followed by the qualitative examination of the relationship between the PSTs' eTSPCK and learner achievement in organic chemistry. The chapter closes with the concluding remarks.

8.2 A recap of methodological approaches used in this chapter

The analysis in this chapter focused on the emerging PSTs' TSPCK episodes indentified in Chapter 6 and the pre-and post-test learner performances presented in Chapter 7. As a result, the sample size for this chapter consists of 4 PSTs and 88 physical sciences high school learners. The sources of data were the PSTs' lessons and completed learner pre-and post-tests. The detailed discussions on the participants PSTs and their respective learners, method of data

collection and analysis and how the credibility of analysis was ensured are presented in Chapter 3 (section 3.3.2, section 3.4.2b and section 3.6.3). The results of the correlation analysis are presented in the section below.

8.3 RESULTS

The analyses done in this chapter are presented in two sections. The first section presents the quantitative measurement of correlation between the PSTs' eTSPCK and learner performances in organic chemistry. The second section presents the collaborating qualitative examination of correlation between the PSTs' eTSPCK and learner performances in organic chemistry.

8.3.1 Quantitative analysis of correlation between PSTs' eTSPCK and learner performances

The quantitative analyses in this section are presented in three parts. The first part focuses on the concepts of functional groups and IUPAC nomenclature of organic compounds delivered by Ruth and Hope. The second part focuses on the concepts of physical properties and structures of organic compounds delivered by Rose and Mark. The third part summarizes the findings emerging the quantitative analyses.

Case 1: Ruth's eTSPCK and learner performances on functional groups and IUPAC nomenclature of organic compounds

On the concepts of functional groups and IUPAC nomenclature, Ruth covered a number of contents in her teaching as analyzed in Chapter 6. The sequence of the contents covered with emerging TSPCK episodes and the Rasch item measures generated from the Rasch Analysis of TSPCK episodes are presented in the Table 8.1 below. The original version of the Rasch Analysis of Ruth's TSPCK episodes is attached as Appendix XXXVIII.

Table 8.1: Overview of Ruth's TSPCK episodes converted to Rasch measures (n=28)

Time (min)	Content discussed	TSPCK episode	Rubric score	Rasch measure
	Lesson 1			
0-2	Carbon bonding	LP-CS/RP	2	-1.16
2-4	Organic compounds	LP-CS/RP	2	-1.16
4-6	Hydrocarbons	LP-CS/RP	2	-1.16
6-7	Saturated hydrocarbons	CS/RP	1	0.72
7-8	Unsaturated hydrocarbons	CS/CT/RP	2	-1.16
8-10	Functional groups	LP-CS/RP/CT	3	-2.58
10-11	Alkane functional group	LP-CS/RP/CS	3	-2.58
11-13	Haloalkane functional group	RP/LP-CS	2	-1.16
13-15	Alkene functional group	LP-CS/RP/CS	3	-2.58
15-16	Alkyne functional group	LP-CS/RP/CS	3	-2.58
16-18	Alcohol functional group	RP/LP-CT/CS	3	-2.58
18-20	Thiols functional group	LP-RP/CT/WD	3	-2.58
20-23	Carboxylic functional group	RP/LP-CS/CS	3	-2.58
23-27	Ester functional group	RP/LP-CS/CS	3	-2.58
27-29	Ketone functional group	RP/LP-CS	2	-1.16
29-33	Aldehyde functional group	LP-RP/CT/WD	3	-2.58
33-36	Amide functional group	LP-RP/CT/WD	3	-2.58
36-40	Ether functional group	LP-RP/CS	2	-1.16
	Lesson 2			
00-04	Homologous series	LP-CS/RP	2	-1.16
04-09	IUPAC rules stated	CS	0	3.02
09-18	Naming alkanes	RP/LP-CS	2	-1.16
18-23	Naming haloalkanes	RP/LP-CS	2	-1.16
23-25	Naming alkenes	LP-RP/CS	2	-1.16
25-28	Naming alkynes	LP-RP/CS	2	-1.16
28-30	Naming cycloalkanes	CS/RP	1	0.72
30-32	Naming alcohols	LP-CS/RP	2	-1.16
32-36	Naming ethers	LP-CS/RP	2	-1.16
36-40	Evaluation	LP	0	3.02

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

As shown in the Table 8.1 above, there were 28 teaching segments from which 26 TSPCK episodes emerged. For the correlation analysis, the Rasch measures (representing TSPCK episodes) in the Table 8.1 above, pre-test Rasch Person measures and post-test Rasch Person measures (see Chapter 7, Table 7.3) were all put onto SPSS software to estimate the correlation coefficient between Ruth's TSPCK and learner performances. As alluded to in Chapter 3, the statistical correlation is conventionally defined for paired observations (Greasley, 2007). Since there were 28 teaching segments (see Table 8.1) and 30 participant learners (see Chapter 7, Table 7.3), there was a strategic random sampling done in two batches in order to ensure the pairing of variables in calculating the correlation between Ruth's TSPCK episodes and learner performances. The results of this correlation analysis are presented in the Figure 8.1 below.

Correlations

		Ruth's TSPCK episodes	Learners' pre-test Person measures Batch 1	Learners' pre-test Person measures Batch 2	Learners' post-test Person measures Batch 1	Learners' post-test Person measures Batch 2
Ruth's TSPCK episodes	Pearson correlation	1	-.112	-.032	.836**	.854**
	Sig. (2-tailed)		.652	.877	.002	.000
	N	22	22	22	22	22

Figure 8.1: Correlation between Ruth's TSPCK episodes and learner performances

As shown in the Figure 8.1 above, the Pearson correlation coefficients between Ruth's TSPCK episodes and pre-test learner performances were r = -0.112 (p = 0.652) and r = -0.032 (p = 0.877). In the two batches, the strength and direction of correlation coefficient (r), at the alpha values which are much greater than the significant level of 0.05, indicate the existence of a statistically insignificant and negative negligible correlation between Ruth's TSPCK and pre-test learner performances. However, the Pearson correlation coefficients for the analysis of Ruth's TSPCK episodes versus post-test learner performances were r = 0.836 (p = 0.002) and 0.854 (p = 0.000). In the two bacthes, the strength and direction of correlation coefficient at the alpha values which are much less than the significant level of 0.05 imply the existence of a statistically significant and positive high correlation between Ruth's TSPCK and post-test learner performances following the teaching. These interpretations of the strength and direction of correlation coefficient is in accordance with the Hinkle et al.'s (2003) outlined guidelines for interpreting the sizes correlation coefficients as alluded to in Chapter 3 (Table 3.8). The scatter plots in the Figure 8.2 below further illustrate the strength and direction of correlation.

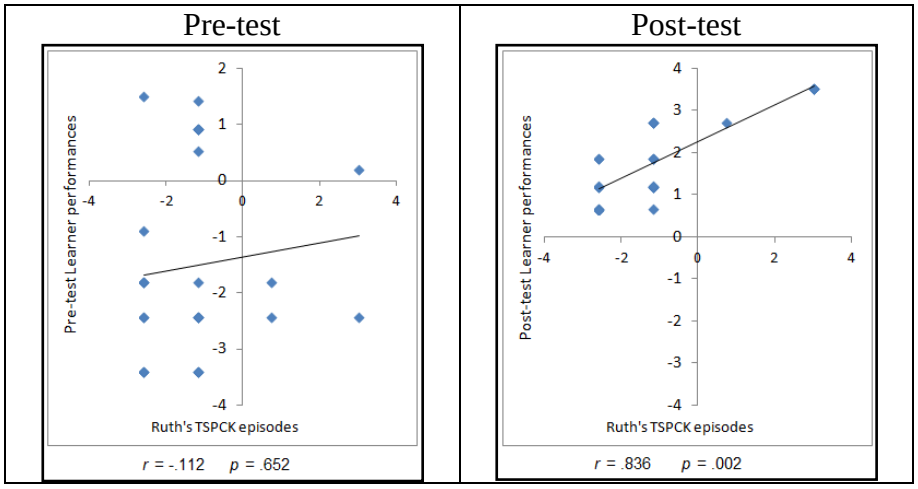


Figure 8.2: Scatter plots for Ruth's TSPCK versus learner performances

As displayed in the Figure 8.2 above, the points in the pre scatter plot could be noticed to be all over the first, third and fourth quadrants without a clear description of the relationship between Ruth's TSPCK episodes and pre-test learner performances. However, the points in the post scatter plot seemed to reveal more strongly association between Ruth's TSPCK episodes and post-test learner performances as majority of the points lied in the first quadrant.

Case 2: Hope's eTSPCK and learner performances **on functional groups and IUPAC nomenclature of organic compounds**

The Table 8.2 below presents the sequence of the contents covered by Hope in her teaching, the TSPCK episodes emerging with the rubric scores and the corresponding Rasch measures. The original version of the Rasch Analysis of Hope's TSPCK episodes is attached as Appendix XXXIX.

Table 8.2: Overview of Hope's TSPCK episodes converted to Rasch measures (n=31)

Lesson time	Content discussed	TSPCK episode	Rubric score	Rasch measure
	Lesson 1			
00-04	Organic compounds	LP-CS/RP/CS	3	-2.60
04-06	Inorganic compounds	LP-CS/RP	2	-1.17
06-09	Hydrocarbons	LP-CS/RP	2	-1.17
09-10	Saturated hydrocarbons	LP/CS/RP	2	-1.17
10-11	Unsaturated hydrocarbons	LP/CS/RP	2	-1.17
11-12	Carbon bonding	LP-CS/RP	2	-1.17
12-16	Homologous series (Alkanes)	LP-CS/RP	2	-1.17
16-18	Alkenes homologous series	CS/RP	1	0.74
18-20	Alkyne homologous series	CS/RP	1	0.74
20-24	IUPAC rules	CS/RP	1	0.74
24-27	Naming pentane	LP-CS/RP	2	-1.17
27-29	Naming octane	LP-CS/RP	2	-1.17
29-31	Naming octane isomer	RP/LP-CS/WD	3	-2.60
31-32	Alkanes members displayed	RP/RP/CS/CS	3	-2.60
32-34	Naming alkenes	LP-CS/RP	2	-1.17
34-35	Naming alkynes	CS/RP	1	0.74
36-37	Cyclohydrocarbons	LP-CS/RP	2	-1.17
35-40	Evaluation	LP	0	3.05
	Lesson 2			
00-04	Alkane functional group	LP-CS/RP	2	-1.17
04-05	Alkene functional group	CS/RP	1	0.74
05-07	Alkyne functional group	CS/RP	1	0.74
07-12	Haloalkane functional group	LP-CS/RP	2	-1.17
12-15	Alcohol functional group	LP-RP/CS	2	-1.17
15-18	Aldehyde functional group	CS/RP/LP	2	-1.17
18-21	Ketone functional group	CS/RP/LP	2	-1.17
21-25	Carboxylic functional group	LP-CS/RP	2	-1.17
25-30	Thiols functional group	CS/RP	1	0.74
30-32	Amine functional group	CS/RP	1	0.74
32-34	Amide functional group	CS/RP	1	0.74
34-36	Ether functional group	CS/RP	1	0.74
36-40	Ester functional group	CS/RP	1	0.74

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

As shown in the Table 8.2 above, there were 31 teaching segments from which 30 TSPCK episodes emerging from Hope's teaching segments. For the correlation analysis, the above Rasch measures (see Table 8.3 above), pre-test Rasch Person measures and post-test Rasch Person measures (see Chapter 7, Table 7.7) were all put onto SPSS software to estimate the correlation coefficient between Hope's TSPCK and learner performances. Since, there were 31 teaching segments and 30 participant learners the correlation analysis involved a strategic random sampling as explicitly discussed in Chapter 3 (section 3.6.3). The results of this correlation analysis are presented in the Figure 8.3 below.

Correlations

		Hope's TSPCK episodes	Learners' pre-test Person measures Batch 1	Learners' pre-test Person measures Batch 2	Learners' post-test Person measures Batch 1	Learners' post-test Person measures Batch 2
Hope's TSPCK episodes	Pearson correlation	1	.a	.a	.653**	.647**
	Sig. (2-tailed)		.	.	.008	.012
	N	22	22	22	22	22

Figure 8.3: Correlation between Hope's TSPCK episodes and learner performances

As shown in the Figure 8.3 above, the Pearson correlation coefficients could not be computed for the correlation between Hope's TSPCK episodes versus learner performances due to the fact that, all the variables were constant. This is because all the participant learners got a mark of zero in the test as analyzed in Chapter 7. However, between Hope's TSPCK episodes and post-test learner performances, the Pearson correlation coefficients were $r = 0.653$ ($p = 0.008$) and r = 647 ($p = 0.012$). At a significant level $\alpha = 0.05$, the strength and direction of correlation coefficient implies the existence of a statistically significant and positive moderate correlation between Hope's TSPCK and post-test learner performances following the teaching. The scatter plots which graphically illustrate how Hope's TSPCK relates to learner performances are displayed in the Figure 8.4 below.

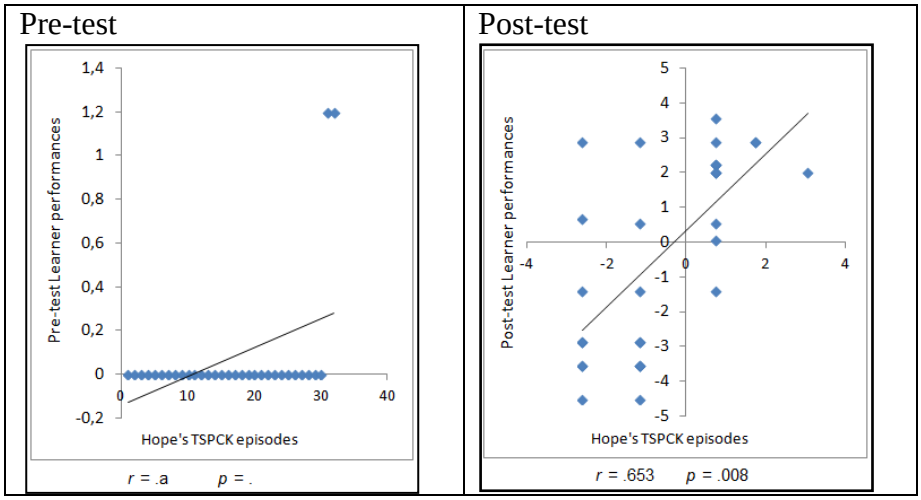


Figure 8.4: Scatter plots for Hope's TSPCK episodes and learner performances

As shown in the Figure 8.4 above, there was no pattern of correlation that could be clearly deduced from the pre scatter plot. However, more points were related in the second and fourth quadrant and a few points in the first quadrant. This seems to describe an average level of relationship between Hope's TSPCK and learner post-test performances.

Case 3: Rose's eTSPCK and learner performances on physical properties and structures of organic compounds

The Table 8.3 below presents the sequence of the contents covered by Rose in her teaching, the TSPCK episodes emerging with the rubric scores and the corresponding Rasch measures. The original version of the Rasch Analysis of Rose's TSPCK episodes is attached as Appendix XL.

Table 8.3: Overview of Rose's TSPCK episodes converted to Rasch measures (n=20)

Lesson time	Content discussed	TSPCK episode	Rubric score	Rasch measure
	Lesson 1			
00-02	Organic chemistry	CS/CS/CS	2	-1.19
02-04	Functional group	LP-CS/RP	2	-1.19
04-08	Boiling point	LP-CS/RP/CT	3	-2.36
08-10	Melting point	LP-CS	1	0.92
10-14	Solubility	LP-CS	1	0.92
14-21	Boiling point in Alkanes	LP-RP/CS/CS	3	-2.36
21-27	Melting point in Alkanes	CS/LP/CT	2	-1.19
27-31	Alkane/Alcohol distinguished	RP/LP-CS	2	-1.19
31-35	Inter/Intra-molecular forces	LP-CT/RP	2	-1.19
35-37	Strength of intermolecular forces	LP-CS/WD	2	-1.19
37-40	Boiling point of Alkane/Alcohol	LP-CS/RP	2	-1.19
	Lesson 2			
00-08	Polar solvent (water)	LP-CS/RP	2	-1.19
08-12	Solubility of propane/propanol	RP/CS/LP	2	-1.19
12-18	Boiling/melting point in Alkane and isomer	RP/LP-CS	2	-1.19
18-20	Carboxylic acid functional group	RP/LP-CS	2	-1.19
20-24	Carboxylic acid boiling/melting point	RP/LP-CS-CS	3	-2.36
24-27	Hydrogen bond in methanoic acid	RP/LP-CS	2	-1.19
27-31	Boiling/melting point in methanoic acid and methanol compared	RP/CS/LP/CS	3	-2.36
31-34	Solubility in methanoic acid and methanol compared	LP-RP/CS	2	-1.19
34-40	Solubility in alcohols	RP/LP-CS/WD	3	-2.36

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

As shown in the Table 8.3 above, there were overall 20 TSPCK episodes emerging from the Rose's teaching segments. For the correlation analysis, the above Rasch measures, the pre-test Rasch Person measures and post-test Rasch Person measures (see Chapter 7, Table 7.12) were all put onto SPSS software to estimate the correlation coefficient. Since there were 20 overall TSPCK episodes and 14 participant learners, a strategic random sampling was done in two batches in order to ensure pairing of variables in calculating the correlation between the Rose's TSPCK episodes and learner performances. The results of this correlation analysis are presented in the Figure 8.5 below.

Correlations

		Rose's TSPCK episodes	Learners' pre-test Person measures Batch 1	Learners' pre-test Person measures Batch 2	Learners' post-test Person measures Batch 1	Learners' post-test Person measures Batch 2
Rose's TSPCK episodes	Pearson correlation	1	.052	-.054	.761**	.742**
	Sig. (2-tailed)		.741	.853	.004	.011
	N	14	14	14	14	14

Figure 8.5: Correlation between Rose's TSPCK episodes and learner performances

As shown in the Figure 8.5 above, the Pearson correlation coefficients between Rose's TSPCK episodes and pre-test learner performances were r = 0.052 (p = 0.741) and r = -0.054 (p = 0.853). In the two batches, the strength and direction of correlation coefficient (r), at the alpha values which are much greater than the significant level of 0.05, indicate the existence of a statistically insignificant and negligible correlation between Rose's TSPCK and pre-test learner performances. However, the Pearson correlation coefficients for the analysis of Rose's TSPCK episodes versus post-test learner performances were r = 0.761 (p = 0.004) and 0.742 (p = 0.011). In the two bacthes, the strength and direction of correlation coefficient at the alpha values which are much less than the significant level of 0.05 imply the existence of a statistically significant and positive high correlation between Rose's TSPCK and post-test learner performances following the teaching. The scatter plots in the Figure 8.6 below further illustrate the how Rose's TSPCK associates with learner performances.

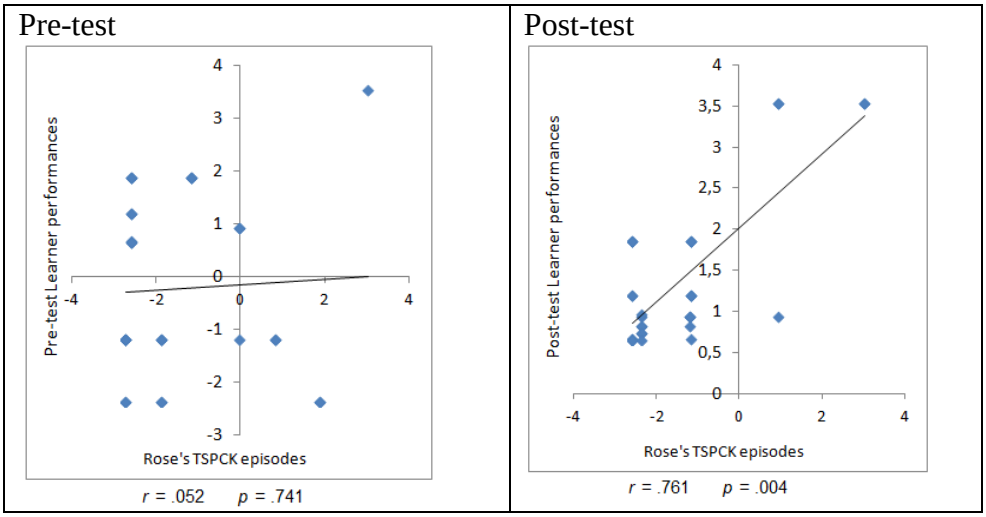


Figure 8.6: Scatter plot for Rose's TSPCK episodes and learner performances

The major finding emerging from Figure 8.6 above is that, learner performances were more strongly associated with Rose's TSPCK episodes in the post scatter plot compared to the pre scatter plot where the points were all over the quadrant with no clear relationship.

Case 4: Mark's eTSPCK and learner performances on physical properties and structures of organic compounds

The Table 8.4 below presents the sequence of the contents covered by Mark in his teaching, the TSPCK episodes emerging with the rubric scores and the corresponding Rasch measures. The original version of the Rasch Analysis of Mark's TSPCK episodes is attached as Appendix XLI.

Table 8.4: Overview of Mark's TSPCK episodes converted to Rasch measures (n=23)

Lesson time	Content discussed	TSPCK episode	Rubric score	Rasch measure
	Lesson 1			
00-03	Organic chemistry	LP-CT/RP	2	-1.19
03-05	Physical properties	LP-CS	1	0.92
05-06	Focus of Lesson	CS	0	3.55
06-10	Carbon chain length	LP-CS/RP	2	-1.19
10-15	Functional group	LP-CS/RP	2	-1.19
15-18	Melting point	LP-CS/RP	2	-1.19
18-20	Boiling point	LP-CS	1	0.92
20-24	Solubility	LP- CS/RP	2	-1.19
24-30	Polar solvent	LP/RP/CS	2	-1.19
30-36	Functional group effect in butane and chlorobutane compared	LP/RP-CS/CS	3	-2.36
36-40	Intermolecular effect in butane and chlorobutane compared	LP-RP/CS	2	-1.19
	Lesson 2			
00-04	Boiling/melting versus chain length in Alkanes	RP/CS/CS	2	-1.19
04-06	Boiling/melting point in alkane and isomer	LP-RP/CS	2	-1.19
06-08	Questioning on functional group	LP	0	3.55
08-13	Boiling/melting point in butane and butanol compared	LP-RP/CS	2	-1.19
13-16	Boiling/melting point in alcohols	LP-RP/CS	2	-1.19
16-18	Ketone functional group	LP-CS	1	0.92
18-22	Aldehyde functional group	LP-CS/RP	2	-1.19
22-25	Boiling/melting point in aldehyde and ketone compared	LP-CS/RP	2	-1.19
25-29	Boiling points in carboxylic acids	LP-RP/CS	2	-1.19
29-33	Boiling/melting point in ketone, carboxylic acid and alcohol compared	LP-RP/CS	2	-1.19
33-37	Solubility in hydrocarbons and alcohols compared	RP/CS	1	0.92
37-40	Evaluation	LP	0	3.55

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

As shown in the Table 8.4 above, there were 23 teaching segments from which 20 TSPCK episodes emerged. For the correlation analysis, the above Rasch measures (representing TSPCK episodes), the pre-test Rasch Person measures and post-test Rasch Person measures (see Chapter 7, Table 7.16) were all put onto SPSS software to estimate the correlation coefficient. Since there were 23 teaching segments and 14 participant learners, a strategic random sampling was done in two batches in order to ensure pairing of variables in calculating the correlation between the Mark's TSPCK and learner performances. The results of this correlation analysis are presented in the Figure 8.7 below.

Correlations

		Mark's TSPCK episodes	Learners' pre-test Person measures Batch 1	Learners' pre-test Person measures Batch 2	Learners' post-test Person measures Batch 1	Learners' post-test Person measures Batch 2
Mark's TSPCK episodes	Pearson correlation	1	-.126	-.186	.605**	.565**
	Sig. (2-tailed)		.935	.524	.018	.021
	N	14	14	14	14	14

Figure 8.7: Correlation Mark's TSPCK episodes and learner performances

As shown in the Figure 8.7 above, the Pearson correlation coefficients between Mark's TSPCK episodes and pre-test learner performances were r = -0.126 (p = 0.935) and r = - 0.186 (p = 0.524). In the two batches, the strength and direction of correlation coefficient (r), at the alpha values which are much greater than the significant level of 0.05, indicate the existence of a statistically insignificant negative negligible correlation between Mark's TSPCK and pre-test learner performances. However, the Pearson correlation coefficients for the analysis of Mark's TSPCK episodes versus post-test learner performances were r = 0.605 (p = 0.018) and 0.565 (p = 0.021). In the two bacthes, the strength and direction of correlation coefficient at the alpha values which are less than the significant level of 0.05 imply the existence of a statistically significant and positive moderate correlation between Mark's TSPCK and post-test learner performances following the teaching. The scatter plots in the Figure 8.8 below further illustrate the relationship between Mark's TSPCK and learner performances.

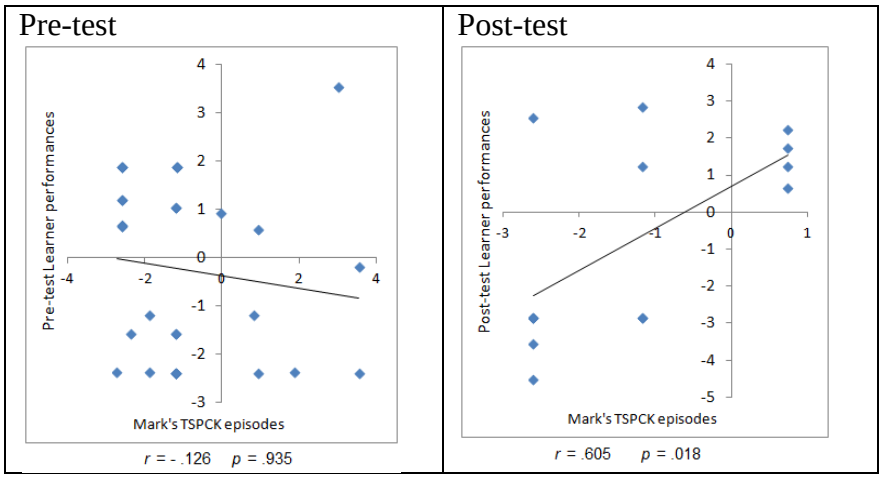


Figure 8.8: Scatter plot for Mark's TSPCK episodes and learner performances

As shown in the Figure 8.8 above, in the pre scatter plot, the points were scattered all over the first, third and fourth quadrant making it unclear to describe the relationship between Mark's TSPCK and pre-test learner performances. However, in the post scatter plot, more points were related in the second and fourth quadrant. This seems to describe an average level of relationship between Mark's TSPCK and learner post-test performances.

Case 5: PSTs' overall eTSPCK versus Overall learner overall performances in organic chemistry

In the lessons delivered by the 4 PSTs, there were overall 102 teaching segments from which TSPCK episodes emerged. Also, there were 88 physical sciences learners in total. In order to determine the relationship between the PSTs' overall TSPCK episodes and overall learner performances, there was a random strategic sampling procedure followed in the correlation analysis as it was done for the individual PSTs and their respective learners. The results of the analysis are provided in the Figure 8.9 below.

Correlations

		PSTs' overall TSPCK episodes	Learners' pre-test Person measures Batch 1	Learners' pre-test Person measures Batch 2	Learners' post-test Person measures Batch 1	Learners' post-test Person measures Batch 2
PSTs' overall TSPCK episodes	Pearson correlation	1	-.178	-.178	.765**	.761**
	Sig. (2-tailed)		.970	.970	.001	.005
	N	51	51	51	51	51

Figure 8.9: Correlation between PSTs' overall TSPCK episodes versus learner performances

As shown in the Figure 8.9 above, the Pearson correlation coefficient between PSTs' overall TSPCK episodes and pre-test learner performances in the two batches was r = -0.178 (p = 0.970). The strength and direction of correlation coefficient (r), at the alpha values which are much greater than the significant level of 0.05, indicate the existence of a statistically insignificant negative negligible correlation between PSTs' overall TSPCK and overall pre-test learner performances. However, the Pearson correlation coefficients for the analysis of PSTs' overall TSPCK episodes versus overall post-test learner performances were r = 0.765 (p = 0.001) and 0.761 (p = 0.005). In the two batches, the strength and direction of correlation coefficient at the alpha values which are less than the significant level of 0.05 imply the existence of a statistically significant and positive high correlation between PSTs' overall TSPCK episodes and overall post-test learner performances following the teaching.

Summary of the key finding from the four cases (Quantitative analyzes)

The correlation analysis revealed a negative negligible correlation between the PSTs' overall TSPCK episodes versus pre-test learner performances but a positive high correlation between the PSTs' overall TSPCK episodes versus post-test learner performances. This is summarized in the Figure 8.10 below.

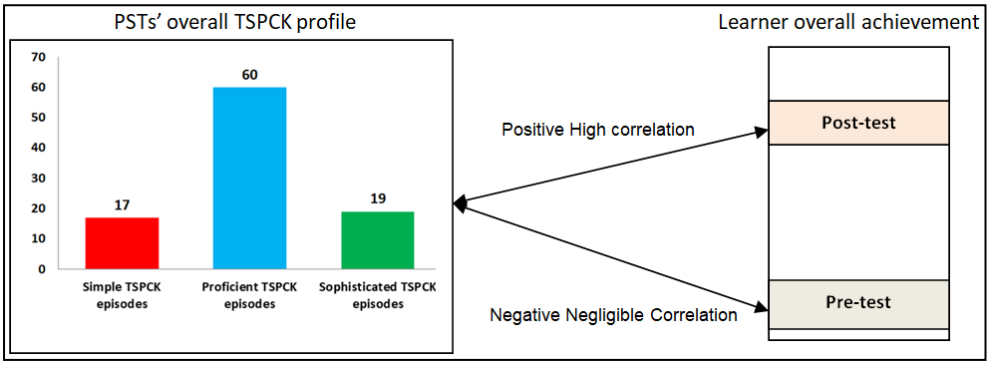


Figure 8.10: Correlation for overall PSTs' TSPCK versus learner performances

On the concepts of functional groups and IUPAC nomenclature of organic compounds, while the correlation could not be computed for Hope's TSPCK versus pre-test learner performances, the analysis revealed a negative negligible correlation for Ruth's TSPCK versus pre-test learner performances as shown in the Figure 8.11 below.

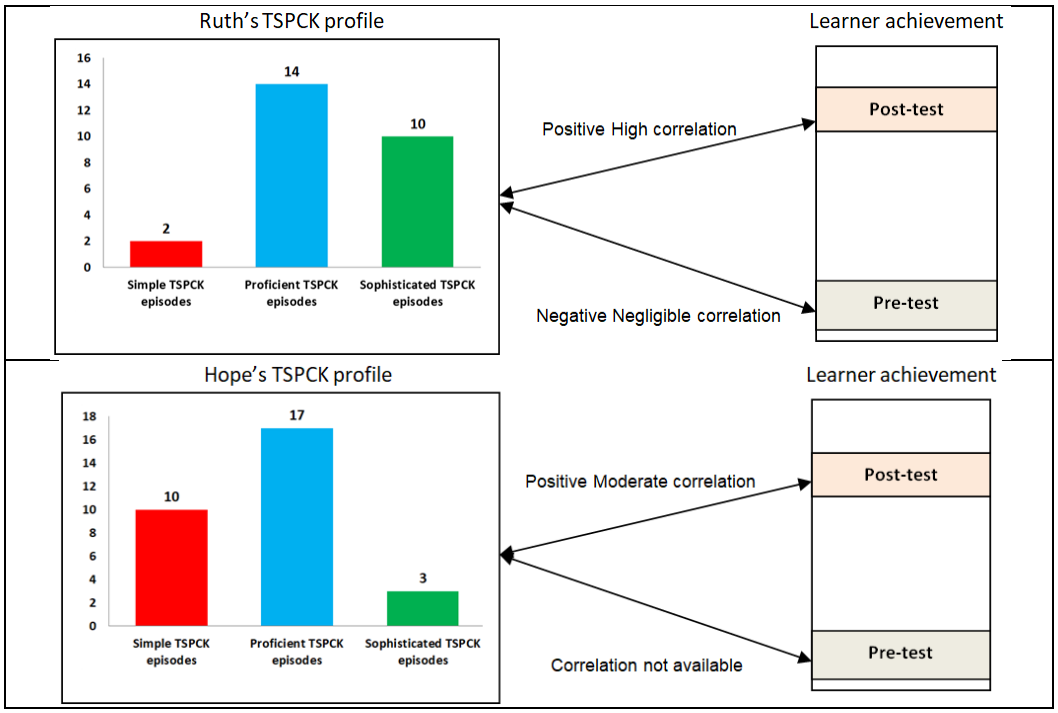


Figure 8.11: Correlation analysis on functional groups and IUPAC naming of organic compounds

As shown in the Figure 8.11 above, following the teaching, there was a positive correlation in the cases of Ruth's and Hope's TSPCK versus post-test learner performances. However, the correlation seemed to be high in the case of Ruth who had most high proficient and sophisticated TSPCK episodes rather than simple TSPCK episodes. Accordingly, the correlation appeared to be moderate in the case of Hope who had most high simple and proficient TSPCK episodes rather than sophisticated TSPCK episodes.

On the concepts of physical properties and structures of organic compounds, the analysis revealed both the negative and positive negligible correlation for Rose's TSPCK versus pre-test learner performances as shown in the Figure 8.12 below. A negative correlation was observed in the case of Mark's TSPCK versus pre-test learner performances.

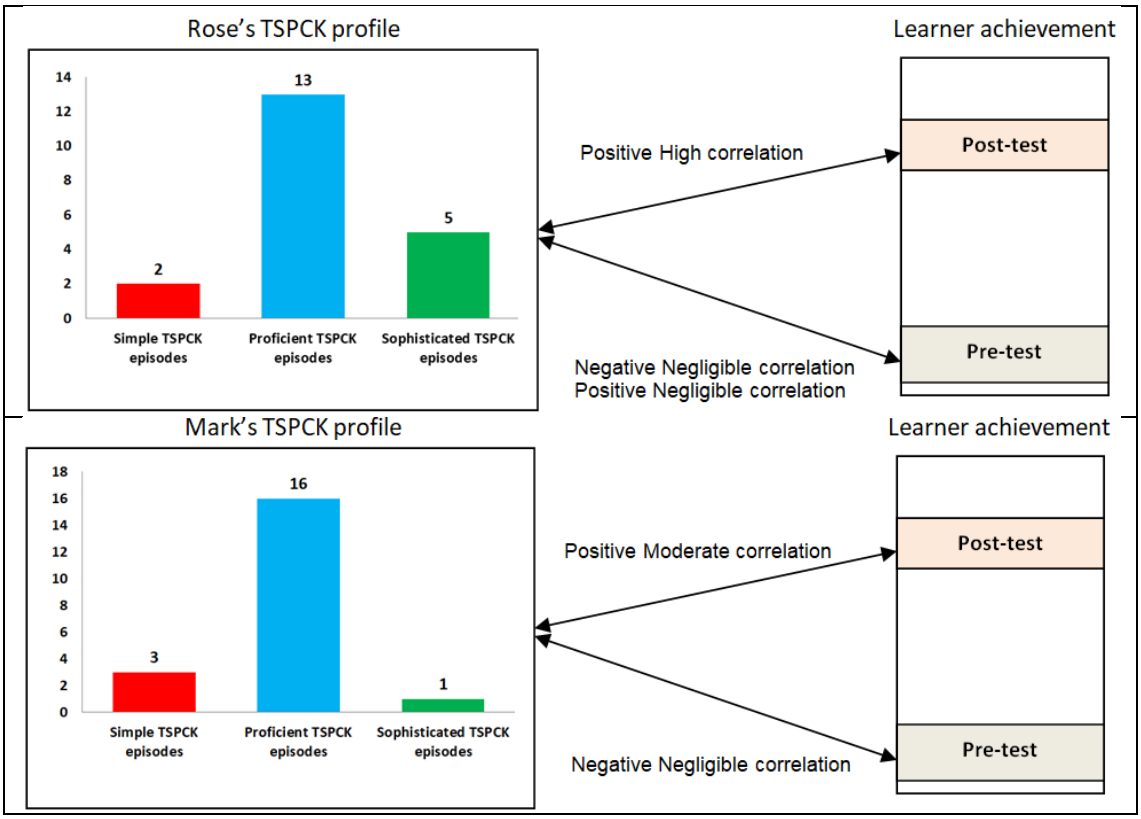


Figure 8.12: Correlation analysis on physical properties and structures of organic compounds

However, in both the cases of Rose's and Mark's TSPCK versus post-test learner performances, a positive correlation was observed. Noticeably, the correlation seemed to be high in the case of Rose who had most high proficient and sophisticated TSPCK episodes rather than simple TSPCK episodes. Accordingly, the correlation appeared to be moderate in the case of Mark who had most high simple and proficient TSPCK episodes rather than sophisticated TSPCK episodes.

The quantitative analyzes presented in the two Figures above aided the examination of pattern of correlation between the PSTs' eTSPCK and learner achievement in the presence of different categories of eTSPCK episodes thereby revealing the strength and direction of correlation. The qualitative examinations are further provided in the section below in order to provide additional insights into the weakness or strength of content-specific knowledge component interactions in TSPCK episodes that showed high or weak correlations to learner achievement. The qualitative examination is also needed in order to understand the quality of PSTs' TSPCK episodes with respect to the quality of learners' written responses in the pre-and post-achievement tests.

8.3.2 Collaborating qualitative examination of correlation between PSTs' eTSPCK and learner performances

The qualitative examination presented in this section focused on the PSTs' categories of TSPCK episodes in relation to the learner performances across the achievement test items. The analysis first examined the concepts of physical properties and structures followed by the concepts of functional groups and IUPAC nomenclature of organic compounds.

Part I: Concepts of physical properties and structures of organic compounds

In both the cases of Rose and Mark, the emerging TSPCK episodes which matched the achievement test items were identified. These are attached as Appendix XLIV and XLV for Rose and Mark respectively. The Table 8.5 below presents the achievement test items, the number of learners who responded correctly on each item in the pre-and post-test, the category of TSPCK episode emerging from the PST's explanations which directly matched the test item.

Table 8.5: Rose's and Mark's TSPCK episodes versus learners' item performances

Test item	Rose's learner performances			Rose's enacted TSPCK		Mark's learner performances			Mark's enacted TSPCK	
	Pre-test	Post-test	Gain	TSPCK episode	category	Pre-test	Post-test	Gain	TSPCK episode	category
item1	4	12	8	LP-RP/CS/CS	Sophisticated	4	11	7	RP/CS/CS	Proficient
item2	4	12	8	LP-RP/CS/CS	Sophisticated	3	8	5	RP/CS/CS	Proficient
item9	2	12	10	RP/CS/LP/CS	Sophisticated	6	8	2	LP-RP/CS	Proficient
item3	6	11	5	LP-CS/RP	Proficient	7	12	5	LP-RP/CS	Proficient
item5	4	11	7	LP-CS/RP	Proficient	3	8	5	LP-RP/CS	Proficient
item4	5	10	5	LP-CS/RP	Proficient	3	10	7	LP-RP/CS	Proficient
item7	3	10	7	LP-CS/RP	Proficient	3	7	4	LP-RP/CS	Proficient
item6	4	10	6	LP-CS/RP	Proficient	4	10	6	LP-RP/CS	Proficient
item10	1	10	9	RP/CS/LP/CS	Sophisticated	5	9	4	LP-RP/CS	Proficient
item8	3	9	6	LP-CS/RP	Proficient	5	9	4	LP-RP/CS	Proficient
item11	2	8	6	LP-RP/CS	Proficient	6	7	1	RP/CS	simple
item12	2	8	6	LP-RP/CS	Proficient	3	6	3	RP/CS	simple

Note: Items arranged in the decreasing order of Rose's learners gain correct responses

As shown in the Table 8.5 above, it could be observed that, the case of Rose's eTSPCK and her learners' item performance in the pre-test suggests a direct relationship between higher performances and lower category of TSPCK episodes and vice versa. For example, on the test item 3, the learner performance in the pre-test was 6 and this test item was linked to a proficient TSPCK episode (LP-CS/RP). On the other hand, the learner performance on test item 9 was 2 in the pre-test linked to a sophisticated TSPCK episode (RP/CS/LP/CS). Meanwhile, the case of Rose's eTSPCK and her learners' item performance in the post-test seemed to suggest a direct relationship between higher performances and higher category of TSPCK episodes and vice

versa. For example, on the test item 9, the learner performance in the post-test was 12 with performance gain of 10 and this test item was linked to a sophisticated TSPCK episode (RP/CS/LP/CS). However, on the test item 4, the learner performance in the post-test was 10 with performance gain of 5 and this item was linked a proficient TSPCK episode (LP-CS/RP).

Furthermore, it could be observed that, the case of Mark's eTSPCK and his learners' item performance in the pre-test suggests similar effect of different categories of TSPCK episodes on learner performances across all the test items. For example, learner performance on the test item 9 was 6 and this test item was linked to a proficient TSPCK episode (LP-RP/CS). Likewise, learner performance on the test item 11 was 6 and this test item was linked to a simple TSPCK episode (RP/CS). However, in case of Mark's eTSPCK and his learners' item performance in the post-test suggests a direct relationship between higher category of TSPCK episodes and higher item performances. For example, on the test item 3, the learner performance in the post-test was 12 with performance gain of 5 and this item was linked to a proficient TSPCK episode (LP-CS/RP). However, on the test item 12, the learner performance in the post-test was 6 with performance gain of 3 and this item was linked to a simple TSPCK episode (RP/CS).

A careful examination of Rose's and Mark's TSPCK episodes relating to the test items as shown in the Table 8.5 revealed that, while Rose demonstrated sophisticated and proficient TSPCK episodes, Mark had proficient and simple TSPCK episodes emerging from his teaching. It could also be observed that, following the teaching, learner item performances in the post-test seemed to be higher in positive direct proportion the case of Rose with sophisticated and proficient TSPCK episodes compared to the case of Mark who had proficient and simple TSPCK episodes. For example, on the test item 9 and 10, Rose's learner item performances improved from 4 in the pre-test to 12 post-test on the test item 9 and from 1 to 10 on the test item 10 where these two test items were linked to a Rose's sophisticated TSPCK episode (RP/CS/LP/CS) in each case. However, on the same test item 9 and 10, Mark's learner item performances improved from 6 in the pre-test to 8 post-test on the test item 9 and from 5 to 9 on the test item 10 where these two test items were linked to a Mark's proficient TSPCK episode (LP-RP/CS) in each case. Noticeably, on the test item 7 both Rose and Mark had a proficient TSPCK episode consisting of TSPCK components LP, CS and RP emerging from their teaching segment. However, Rose's learner performance on the test item 7 improved from 3 in the pre-test to 10 in the post-test with

the performance gain of 7. On the other hand, Mark's learner performance on the test item 7 improved 3 in the pre-test to 7 in the post-test with performance gain of 4. For a better insight into these trends observed in the Rose's and Mark's categories of TSPCK episodes and how they relate to the learners' conceptual performances in the pre-and post-test, the teaching segments with typical learners' written responses on the test item 9, 10 and 7 are further discussed below.

Rose's sophisticated TSPCK episodes versus Mark's proficient TSPCK episodes compared to learner performances on item 9 and 10

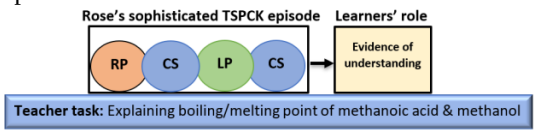
In the achievement test, item 9 is related to item 10 (See Chapter 3, section 3.4.2). While item 9 required the participant learners to state whether the boiling points of carboxylic acids would be higher than the boiling points of alcohols with the same number of carbon atoms, Item 10 asked them to explain their answer to Item 9. For learners to correctly answer these questions, they must have understood how the functional group in each of carboxylic acids and alcohols influences the intermolecular forces which in turn affect the boiling point of the organic molecules. For an illustration of Rose's and Mark's demonstration of TSPCK episodes and consequent learners' written responses in the achievement tests, the extract of teaching segments with learners' written responses are provided below.

(i) Rose's TSPCK episodes and learner performances on item 9 and 10

The extract of Rose's teaching segment on comparing the boiling point of a carboxylic acid (methanoic acid) to the boiling point of an alcohol (methanol) is presented in the Table 8.6 below. The Rose's precise explanation was provided in lesson 2 (27-31minutes). Prior to this time, between the lesson period of 24-27 minutes, using the structures methanoic acid and methanol drawn on the chalkboard, Rose probed learner prior knowledge by asking them which of the two organic molecules would have higher boiling/melting point. While two learners (SF5 and SM2) correctly pointed at methanoic acid, learner SF5's response revealed her misconception that, there are two hydrogen bonds in methanoic acid. In addressing SF5's misconception, Rose explained using the structures of the molecules what it means to have a hydrogen bond as an important aspect for learners to understand by indicating the occurrence of hydrogen bond whenever hydrogen atom is directly bonded to an oxygen atom. In her explanation, Rose demonstrated interactive use of content-specific knowledge components at a

proficient level of TSPCK episode (**RP/LP-CS**). Following this explanation was the Rose's further discussion on which of methanoic acid and methanol would have higher boiling point and melting point as presented in the Table 8.6 below.

Table 8.6: Rose's teaching segment on item 9 and 10

27-31min: Boiling/melting point of methanoic acid and methanol compared **Rose**: So now in here (*She pointed at the structure of methanol*) (**RP**), we've got one hydrogen bond, but take note guys, it's as a result of our hydroxyl group right, that's our functional group for identifying members of alcohol homologous series **(CS)** so no one should tell us that, ma'am carboxylic acids are weak acids, they dissociate and then we have H^+, it's hydrogen bond that we have here, consisting of one hydrogen bonded to oxygen, right it does not refer to hydrogen ion, no guys, **(LP)** that's an hydrogen ion, it's a different story so now as our methanoic acid, it's gonna have higher boiling point than methanol the reason being that, in the case of carboxylic acids, hydrogen bonding can occur between two molecules in the case of carboxylic acids alright, so when that happens, it forms a dimer, that's like similar molecules linked together, so it's the presence of dimers that normally increases the strength of the dispersion forces in carboxylic acids, that raises their boiling point making **(CS)** it to be higher than that of alcohols, hope my explanation is clear to someone? **Ss**:…..(Learners echoed 'yes') **SF2**: Please, can you come again? **Rose**: I need someone to repeat what I have just said if you've really understood my explanation? Yes, who's gonna help? **SF3**: She said the occurrence of hydrogen bonding in the molecules of carboxylic acids can produce dimers and the intermolecular forces will increase, it will then increase the boiling point. **Rose**: Exactly, the strength of intermolecular forces increases. Does anyone still needs clarification? **Ss**:…….(No response from learners)……	**Comment**: This teaching segment focused on comparing the boiling/melting point of methanol and methanoic acid. **In-depth Qualitative Analysis**: **Rose's role:** Using the structure of methanol (RP). Rose re-emphasized the presence of only one hydroxyl functional group in the molecule also used to identify all the members of alcohols, as an importance aspect for learners (CS). She then cautioned learners about a misconception that could emerged from the assumption that the H^+ produced by carboxylic acid when dissociate is also a hydrogen bond thereby demonstrating understanding of an aspect of learner prior knowledge (LP). She also explained the formation of dimers by carboxylic acids thereby increasing the strength of their intermolecular which raises their boiling point above that of alcohols as the second important aspect for learners to understand (CS). **Learners' role:** The evidence of understanding seemed to emerge as learner SF3 correctly paraphrased Rose's explanation as requested by another learner SF2. The Rose's interactive use of TSPCK components (RP/CS/LP/CS) at a sophisticated level with evidence of learners' understanding is given by the TSPCK map below. 

The extracts of Rose's learner Ro01's written work prior to and following Rose's teaching are provided as shown in the Figure 8.13 below.

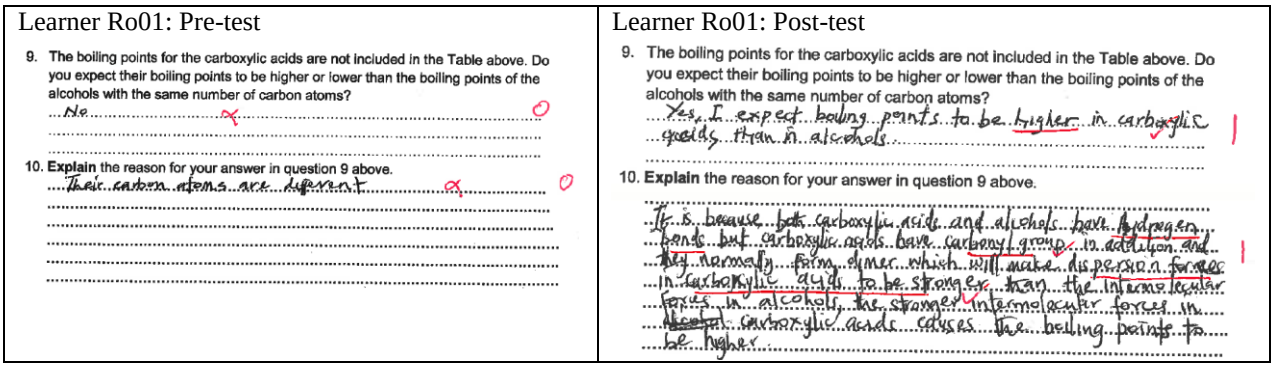


Figure 8.13: Extracts of Rose's learner Ro01's written work on test item 9 and 10

As shown in the Figure 8.13 above, learner Ro01's answer to question 9 in the pre-test was not clear as he only wrote 'no' instead of indicating whether the boiling points of carboxylic acids would be higher or lower than that of alcohols of the same number of carbon atoms. Likewise, his answer to item 10 question showed lack of understanding of same number of carbon atoms bonded in the two molecules as the question indicated. However, following Rose's teaching as learner responded in the post-test, he correctly indicated his expectation that, the boiling points of carboxylic acids should be higher than the boiling points of alcohols containing the same number of carbon atoms. While stating his reason in response to item question 10, he explained that, both carboxylic acids and alcohols have the hydroxyl group however, the formation of dimers by the hydrogen bond in carboxylic acids strengthens the intermolecular forces in carboxylic acids which in turn increases their boiling points. Learner Ro01's correct explanation in the post-test compared to his incorrect explanation in the pre-test showed an improvement in his conceptual understanding of the trend of boiling points in the carboxylic acids compared to the alcohols. A similar level of understanding was observed in the responses provided by another learner Ru02 whose extracts of written work are provided in the Figure 8.14 below.

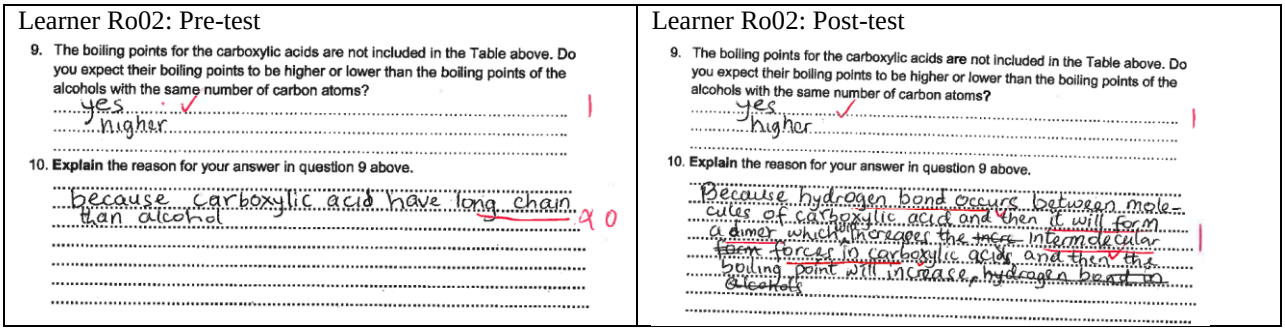


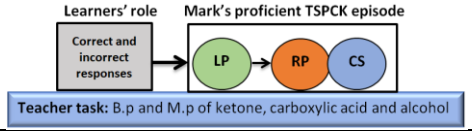
Figure 8.14: Extracts of Rose's learner Ro02's written work on test item 9 and 10

As shown in the Figure 8.14 above, learner Ro02 indicated in the both the pre-test and post-test that, the boiling points for carboxylic acids should be higher than the boiling points of alcohols of the same number of carbon atoms. This showed a good understanding prior to and following Rose's teaching. However, while answering question item 10 in the pre-test, Ro02 wrongly linked the reason for his expectation to the longer carbon chain in carboxylic acids than in alcohols. Meanwhile, following Rose's teaching as Ro02 responded to question item10 in the post-test, he referred to the occurrence of hydrogen bonds in carboxylic acids for dimers which increases their intermolecular forces making their boiling points to be higher than that of alcohols. This showed an improvement in the learners' conceptual understanding of the trend of boiling points in carboxylic acids compared to the alcohols.

(ii) Mark's TSPCK episodes and learner performances on item 9 and 10

On comparing the boiling point and melting point of carboxylic acids to that of alcohols, Mark had a related teaching segment which happened in lesson 2 (29-33minutes). Prior to this teaching segment, Mark had a moment of interaction with learners on the boiling point of carboxylic acids. Mark started by asking learners about the functional group for carboxylic acids. In response to that, Learner SF3 correctly mentioned RCOOH as the functional group for carboxylic acid. Taking SF3's correct response into consideration and with reference to the structure on the board, Mark emphasized the hydroxyl and carbonyl group in carboxylic acids and further explained as the carbon atoms increase, the molecules get bigger thereby increasing the boiling point thereby showing her understanding of what learners needed to know with the use of a symbolic representation. This discussion demonstrated Mark's interactive use of content-specific knowledge components (LP-CS/RP) at a proficient level of TSPCK episode. Following this explanation was Mark's further discussion during which the boiling point and melting point of carboxylic acids were compared to that of alcohols as presented in the Table 8.7 below.

Table 8.7: Mark's teaching segment on item 9 and 10

Teaching events in sequence (Lesson 2, 29-33minutes)	Comments/Qualitative in-depth analysis
Mark: So, now between ketone which has got a carbonyl functional group and in the case of carboxylic acid, which one is gonna have high boiling point and melting point? Ss: ketone….carboxylic acid….ketone (Chorus answers from learners) **Mark**: In deed, carboxylic acid is gonna have higher boiling point and melting point than ketone right **(LP)**, so now between alcohol and carboxylic acid which one is gonna have high boiling point and melting point? **SF6**: Alcohol **Mark**: I know you guys are smart, it's about hydrogen bond here, it's here in alcohol (*Mark pointed at the structure of ethanol on the board*), it's also here (*He pointed at the structure of ethanoic acid*) (**RP**) right but you see, carboxylic acid has also got a carbonyl group in addition to its hydroxyl group, whereas alcohols has only got hydroxyl group, so the boiling point of carboxylic acid is gonna be higher than that of alcohols, **(CS)** even more than ketones and aldehydes.	**Comment**: This section focused on comparing the boiling point and melting point of ketones, carboxylic acids and alcohols. **Mark's role**: In an attempt to establish the learners' prior knowledge, Mark asked them which of ketone and carboxylic acid would have higher boiling point and melting point. **Learners' role**: Learners gave a mix of correct and incorrect answers by referring to ketone as well carboxylic acid rather than mentioning only carboxylic acid, the understanding Mark expected them to have in place (**LP**). **Mark's role**: Mark acknowledged carboxylic acid as having high boiling point and melting point than ketone but without explaining why. He further asked learners which of carboxylic acid and alcohol would have high boiling point and melting point. **Learners' role**: A learner correctly referred to alcohol **Mark's role**: In explaining how the boiling point of carboxylic acids is higher than that of alcohols, using the structures of organic molecules (RP), Mark called learners' attention to the presence of presence of carbonyl group and hydroxyl group in carboxylic acid unlike in alcohols where only hydroxyl group is present. The type of functional groups demonstrated Mark's knowledge of what was important for learners to take note of, an element of curricular saliency (CS). Mark's interactive use of knowledge of TSPCK components (LP-CS/RP) at a proficient level in connection to the learners' correct and incorrect responses is given by the TSPCK map below. 

The extracts of Mark's learner Ma05's written responses on item 9 and 10 prior to and following Rose's teaching are provided as shown in the Figure 8.15 below.

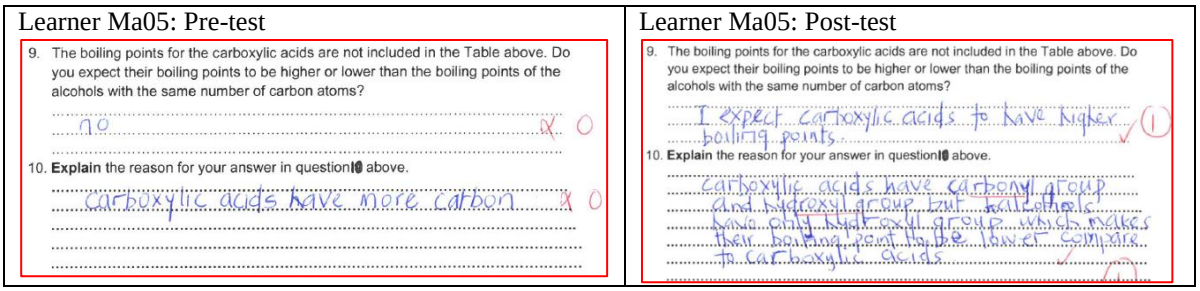


Figure 8.15: Extracts of Mark's learner Ma05's written work on test item 9 and 10

As shown in the Figure 8.15 above, the learner Ma05's responses on item 9 and 10 showed lack of understanding of the boiling points of carboxylic acids compared to that of alcohols. However, following Mark's teaching as Ma05 responded in the post-test, he correctly indicated his expectation that, the boiling points of carboxylic acids should be higher than the boiling points of alcohols containing the same number of carbon atoms. While stating his reason in response to question item 10, he stated that, both carboxylic acids have carbonyl group and hydroxyl group making their boiling points to be higher than alcohols of the same number of atoms. This response is similar to the explanation Mark provided in his teaching as shown in the Table 8.7 above. A similar level of understanding was observed in the written responses provided by another learner Ma07 whose extracts of written work are provided in the Figure 8.16 below.

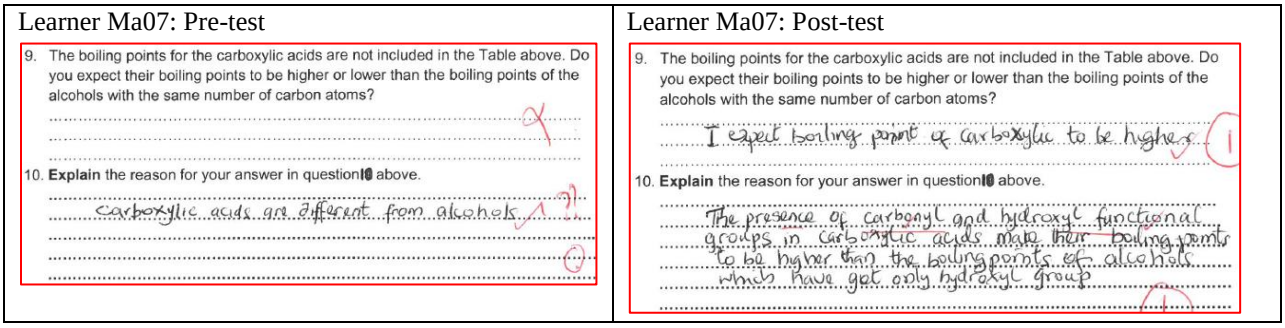


Figure 8.16: Extracts of Mark's learner Ma07's written work on test item 9 and 10

As shown in the Figure 8.16 above, learner Ma07 could not provide correct answers in the pre-test on item 9 and 10 which suggests lack of the required conceptual understanding. However, in the post-test, Ma07 correctly indicated that, the boiling points of carboxylic acids should be higher than that of alcohols. He further explained the reason for his answer in relation the presence of carbonyl and hydroxyl group in carboxylic acids which make their boiling points to be higher than that of alcohols consisting of only the hydroxyl group. This learner's written

response in the post-test is equally similar to the explanation Mark provided in his teaching as shown in the Table 8.7 above.

(iii) Similarity and differences in Rose's and Mark's TSPCK episodes versus learners' written responses on item 9 and 10

In the explanations provided by Rose and Mark, the understanding of three content-specific knowledge components were demonstrated but at different categories of TSPCK episodes. The knowledge components included: learner prior knowledge (LP); curricular saliency (CS); and symbolic representations (RP). However, there were noticeable differences. The first difference revolved around the identifying and addressing a learners' misconception relating to the concept. The second difference revolved around the category of TSPCK episode emerging from each PST's teaching segment.

The analysis of teaching segments revealed that, while Rose and Mark acknowledged learners' prior understanding (**LP**) necessary for the concept focused on, Rose further made effort to identify and address a learners' misconception in relation to hydrogen bond in carboxylic acids. Both Rose and Mark talked about hydroxyl group and carbonyl group in distinguishing carboxylic acids from alcohols. These two groups are important aspects of functional groups needed for learners to understand, an element of teachers' knowledge of curricular saliency (**CS**). Meanwhile, Rose in her own case further explained the formation of dimers by carboxylic acids in relation to the intermolecular forces. This represents another important aspect of organic reactions considered important for learners to know about, an element of teachers' knowledge of curricular saliency (**CS**). The knowledge component (CS) gives additional depth to the quality of explanation provided by Rose compared to that of Mark. There was also evidence of the use of symbolic representations (**RP**) in the cases of Rose and Mark. Considering the two teaching segments focusing on the same aspect of functional group, there was a sophisticated TSPCK episode (RP/CS/LP/CS) emerging from Rose's explanations whereas a proficient TSPCK episode (LP-CS/RP) emerged from Mark's explanations as shown in the Table 8.6 and Table 8.7 above respectively. Noticeably, the learners' responses following the Rose's explanations (emergence of TSPCK episode) reflect the evidence that, they understood the explanations provided. Apart from the category of emerging TSPCK episode, this evidence distinguishes the quality of Rose's explanations from that of Mark.

Subsequently, the Rose's learners' written responses in the post-test as shown in the Figure 8.13 and Figure 8.14 above revealed this extent of understanding compared to the limited written explanations provided by Mark's learners as shown in the Figure 8.15 and Figure 8.16 above. Likewise, as shown in the TSPCK map for Rose's teaching segment (see Table 8.6), learners' responded following Rose's explanations to show instant evidence that, they understood the concept. Such a moment was absent in the case of Mark's teaching segment. As shown in the Table 8.6 above, Rose's emergence of a sophisticated TSPCK episode on item 9 and 10 seemed to attract 12 and 11 learners' gain correct responses respectively following her teaching. On the other hand, Mark's emergence of a proficient TSPCK episode appeared to attract 5 and 4 learners' gain correct responses on item 9 and 12 respectively following his teaching.

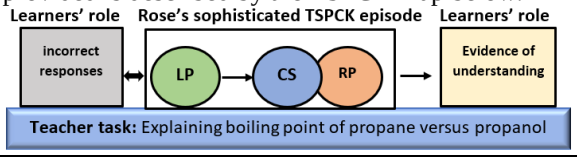
Rose's proficient TSPCK episodes versus Mark's proficient TSPCK episodes compared to learners' performances on item 7

Item 7 asked learners to explain why the boiling point for hexane is so much lower than the boiling point of hexan-1-ol as highlighted in Chapter 3 (section 3.4.2b). For learners to answer this question correctly, they should have understood the strength of the intermolecular forces in the two organic molecules as a result of their functional groups. For an illustration of Rose's and Mark's demonstration of TSPCK episodes and consequent learners' written responses in the achievement tests, the extract of teaching segments with learners' written responses are provided below.

(i) Rose's TSPCK episodes and learner performances on item 7

Rose had a teaching segment which focused on explaining how the melting point and boiling point of an alkane (propane) differ from the melting point and boiling point of an alcohol (propanol) as shown in the Table 8.8 below.

Table 8.8: Rose's teaching segment on propanol versus propane

Rose's segment of teaching focusing on the boiling point of alkanes compared to alcohols	
Extract from Lesson 1 (37-40min)	**In-depth Qualitative Analysis**
Rose: Let's go back to our discussions someone said that propanol is gonna have high boiling point compare to propane, (*she pointed to the learner SM5*) you said, it right? SM5: yes Rose: What was that your reason again? SM5: Propanol has got weak intermolecular forces Rose: Than propane right? SM5: yes Rose: Ok guys, does anyone have any comment on that please? *There was no response from learners.* **Rose**: He's saying propanol has got weak intermolecular forces and that's why it's gonna have a low melting point and boiling point than propane which has got strong intermolecular forces (**LP**). One thing you must first consider what is the type of intermolecular forces in each compound and then, what is the strength of that intermolecular forces, that's important (**CS**) as I earlier said so if you look at propane here (*she pointed at the molecular structure on the chalk board*), (**RP**) it's our alkane right, alkanes are non-polar because they have got van der Waals dispersion forces and then our propanol here (*she pointed at the molecular structure of propanol on the chalk board*), it's got the hydroxyl group OH which means it's got hydrogen bond but you see by nature, hydrogen bonds are stronger than van der Waal's forces so now, which one among propane and propanol is gonna have high boiling point and melting point? Yes anyone? **SF1**: propanol **Rose**: why? **SF1:** it has got hydrogen bond which is stronger than van der waal's force in propane **Rose**: Good, so why would that make the boiling point and melting point to be higher? Yes, someone should help. **SM1**: There's more energy required to break a strong bond, so more energy will be needed in the case of propanol, it's boiling point will increase because of that.	**Rose's role**: Rose first confirmed with learner SM5 about his response that propanol has got weak intermolecular forces compared to propane. **Learners' role**: Learner SM5 referred to propanol as having weak intermolecular forces compared to pentane. **Rose's role:** Rose re-stated the SM5's reference to propanol as having weak intermolecular forces and thus, low melting point and boiling point compared to propane considered to have strong intermolecular forces (**LP**). As an important aspect for learners to understand when comparing alkanes to alcohols in terms of the boiling point and melting point, Rose indicated the need to first identify the type of intermolecular forces and the strength of such intermolecular forces present in the compound. This is an element of Rose's knowledge of curricular saliency (**CS**). She identified van der Waal's dispersion forces as the weak intermolecular forces in propane compared to the hydrogen bond which is the strong intermolecular forces in propane using the molecular structures drawn on the chalk board (**RP**). Having differentiated between the type and strength of intermolecular forces, she asked learners which of the two compounds would have high melting and boiling point. She further asked to explain the reasons. **Learners' role**: Learner SF1, through her response, showed the understanding that propanol would have higher boiling point and melting point because of the hydrogen bond. Likewise, learner SM1 showed the understanding of what it means to have higher boiling point. These learners' responses seemed to point at the evidence that, they understood Rose's explanations. Rose's interactive use of TSPCK components (LP-CS/RP) at a proficient level in connection to a learner's incorrect response and pointing at the evidence that learners' understood the explanation provided is described by the TSPCK map below. 

In her explanation as shown in the Table 8.8 above, Rose demonstrated the understanding of interactive of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode with the emerging evidence of learners' understanding. The extracts of two learners' written responses in the pre-and post-achievement tests are given in the Figure 8.17 below.

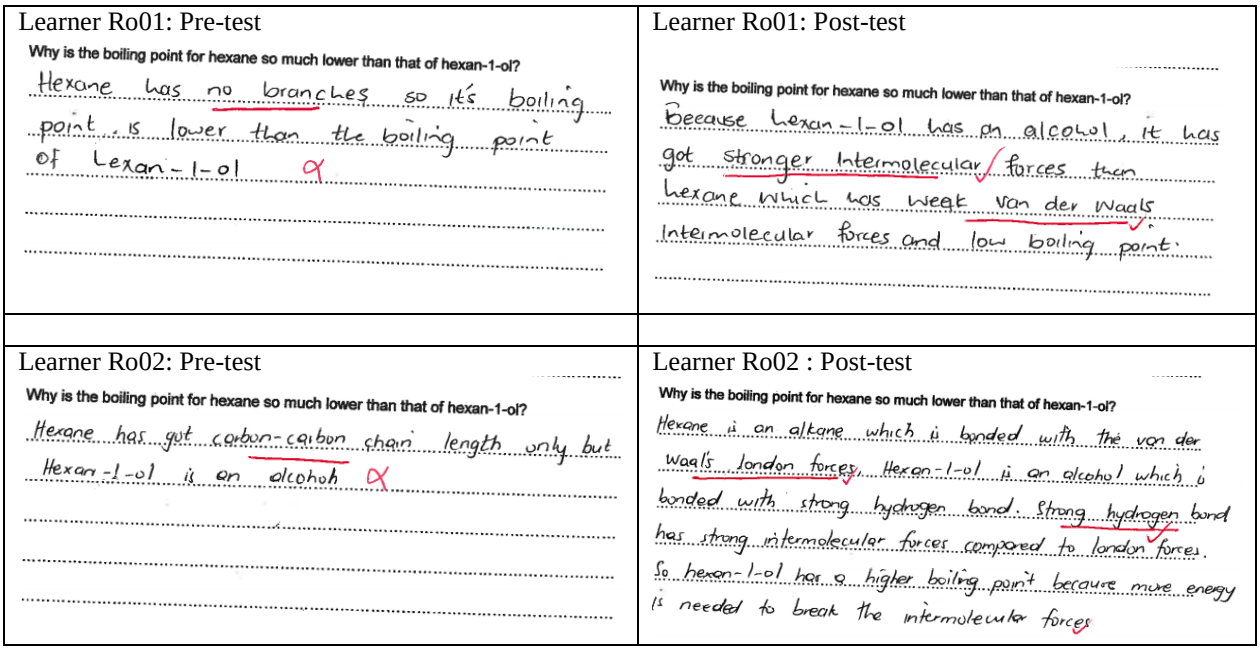


Figure 8.17: Extracts of Rose's learners' pre-and post-test written responses on item 7

As shown in the Figure 8.17 above, learner Ro01's written response in the pre-test showed no good understanding of why the boiling point of hexane is much lower than the boiling point of hexan-1-ol. However, in the post-test, Ro01 correctly referred to weak van der Waal's forces in hexane compared to the strong intermolecular forces in hexan-1-ol. While the Ro01's written response in the post-test showed a good understanding, the explanation did not specifically identify the type of intermolecular forces (hydrogen bond) in hexan-1-ol as a result of the hydroxyl functional group.

In the case of learner Ro02, her pre-test written response revealed her understanding that, Hexane consists of carbon to carbon covalent bond and hexan-1-ol as an alcohol. Nevertheless, the response does not correctly answer the question asked. In the post-test, Ro02 correctly identified weak van der Waal's London forces in hexane compared to strong hydrogen bond in hexan-1-ol as a result of the hydroxyl group. The learner also revealed the understanding of how such strong intermolecular forces in hexan-1-ol requires more energy for breaking bonds which eventually leads to the higher boiling point.

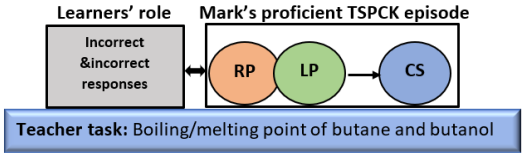
The possible effect of Rose's explanations on the learners' understanding could be observed qualitatively in terms of the depth of the learners' answers in the post-test compared to the pre-

test. It could also been seen to have influenced learners' understanding quantitative in terms of increasing the number of learners who responded correctly in post-test compared to the pre-test.

(ii) Mark's TSPCK episodes and learner performances on item 7

Mark also had a teaching segment which focused on explaining how the melting point and boiling point of an alkane (butane) differ from the melting point and boiling point of an alcohol (butanol) as shown in the Table 8.9 below.

Table 8.9: Mark's teaching segment on butane versus butanol (test item 7)

Lesson 2, 18-23minutes	**In-depth Qualitative Analysis**
Mark: Now, each of those homologous series is identified by a functional group. Let's say (*In the molecular structure of butane on the chalk board, Mark replaced H on the first carbon with OH such that butane becomes butanol*) yeah, now let's compare it to the butane here (*He drew the molecular structure of butane again*) (**RP**), so is this gonna affect the melting point and boiling point? What can we say about the melting point and boiling point of butanol and butane here? SM8: Butane is stronger than butanol so it's gonna have higher melting point and boiling point. Mark: What do we mean by butane is stronger? ***There was no response from SM8….*** **SM9**: I think the melting point and the boiling point of butanol are gonna be higher than that of butane **Mark**: the melting point and the boiling point of butanol are gonna be higher than butane according to him, the reason being? SM9: Butanol has got strong intermolecular forces **Mark**: Indeed, butanol is gonna have high melting point and boiling point because it has strong intermolecular forces ok (**LP**). The hydroxyl functional group is the key, it's our OH (*He pointed at the molecular structure on the board*) commonly identified with the alcohols homologous series, **(CS)** so butanol has melting and boiling point stronger than butane.	**Mark's role**: With reference to the structures of butane and butanol on the board (**RP**), Mark asked learners if the hydroxyl group in butanol was going to make its boiling point and melting point different from that of butane. **Learners' role**: Learner SM8 wrongly stated that, butane is stronger than butanol and hence, butane would have high melting point and boiling point. However, Learner SM9 correctly responded by stating higher melting point and boiling point in butanol than in butane. The learner also added that, butanol has stronger intermolecular forces than butane, the reason for the difference in melting point and boiling point (**LP**). **Mark's role:** Mark further confirmed the learner's correct prior understanding by re-stating the learner's response. With reference to the molecular structure of butanol, Mark referred learners to the presence of hydroxyl which is known to be the functional group of all alcohols. This seems to describe Mark's understanding of hydroxyl functional as an important aspect of alcohols. This is an element of curricular saliency (CS). The Mark's interactive use of TSPCK components (RP/LP-CS), in connection to learner' correct and incorrect responses, is given by the TSPCK map below. 

In his explanation as shown in the Table 8.9 above, Mark demonstrated the understanding of the interactive use of TSPCK components (RP/LP-CS) at a proficient level of TSPCK episode. The extracts of two Mark's learners' written responses in the pre-and post-achievement tests are given in the Figure 8.18 below.

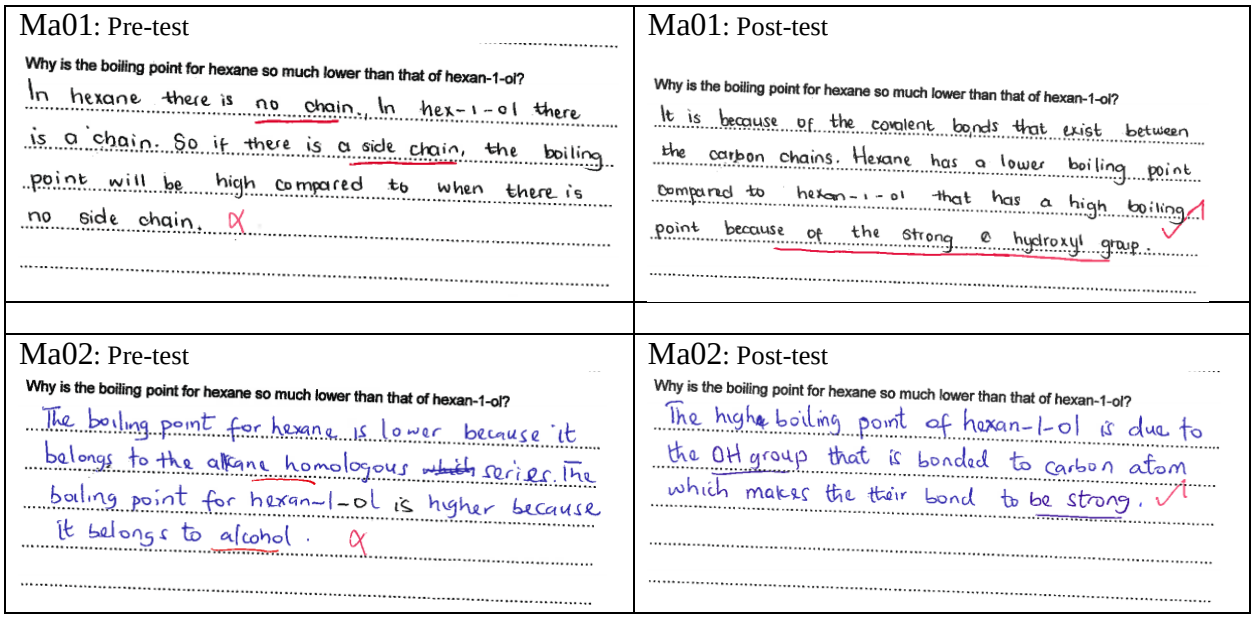


Figure 8.18: Extracts of Mark's learners' pre-and post-test written responses on item 7

As shown in the Figure 8.18 above, Ma01 showed no good understanding for why the boiling point of hexane is lower than the boiling of hexan-1-ol as he referred the side chain in hexanol and no side chain in hexane. However, the learner's understanding seemed to have improved in the post-test as he only referred to hexanol having high boiling because of the hydroxyl group. What appeared to be lacking in his post-test written response was the understanding that, hydrogen bond is stronger in hexanol due to the presence of hydroxyl group. He rather referred to hydroxyl group as being strong.

In the case of learner Ma02, the learner's written response in the pre-test showed she understood hexane belonging to the alkane homologous series and hexan-1-ol belonging to the alcohol homologous series. However, the difference in the boiling point of the two organic molecules mentioned was not clear in the learner's explanation. In the post-test, Ma02 specifically referred to the higher boiling point of hexan-1-ol due to the presence of hydroxyl group which is not presence in hexane. Notwithstanding, the explanation in the post-test does not revealed the type of intermolecular forces present in each organic molecule and how they strength differs. It could be observed that, learners were not really able to provide more than the information acquired during Mark's teaching. However, to some extent, learners improved in their conceptual performance following the teaching.

(i) Similarity and differences in Rose's and Mark's TSPCK episodes versus learners' written responses on item 7

There were a few similarities and differences observed between the Rose's and Mark's teaching on the boiling point of alkanes versus alcohols. First, common to Rose's and Mark's teaching, majority of the learners who responded to which of the alkanes and alcohols would have high boiling point and melting point got it wrong by referring to the alkanes except in the case of one Mark's learner. This learners' misunderstanding was connected to the assumption that, the intermolecular forces in the alkanes are stronger than the intermolecular forces in the alcohols. In her reaction to this, Rose specifically mentioned the van der Waal's dispersion forces as the weak intermolecular forces present in alkanes compared the strong hydrogen bond in alcohols as a result of the hydroxyl functional group in alcohols. However, while Mark indicated to the learners that, alcohols would have high melting point and boiling point due to their strong intermolecular forces with reference to the hydroxyl functional group, he did not explain what type of intermolecular forces are found in alcohols which distinguish them from alkanes. Second, from both the Rose's and Mark's explanations, there was a proficient TSPCK episode emerging which consists of the TSPCK components, *learner prior knowledge* (LP), *curricular saliency* (CS), and *symbolic representations* (RP). However, unlike what was observed in Mark's teaching, Rose seemed to have a deeper interaction with learners such that, the learners' conversations following the Rose's explanations signaled instant evidence that they understood the explanations Rose provided. There was no such instant evidence of understanding in the case of Mark's learners.

Part II: Concepts of functional groups and IUPAC nomenclature of organic compounds

In both the cases of Ruth and Hope, the emerging TSPCK episodes which matched the achievement test items were identified. These are attached as Appendix XLVI and XLVII for Ruth and Hope respectively. The Table 8.10 below presents the achievement test items, the number of learners who responded correctly on each item in the pre-and post-test, the category of TSPCK episode emerging from the PST's explanations which directly matched the test item.

Table 8.10: Ruth's and Hope's TSPCK episodes against learners' item performances

Test item	Ruth's learner performances			Ruth's enacted TSPCK		Hope's learner performances			Hope's enacted TSPCK	
	Pre-test	Post-test	Gain	TSPCK episode	category	Pre-test	Post-test	Gain	TSPCK episode	category
item1	5	29	24	RP/LP-CS/CS	Sophisticated	0	16	16	LP-CS/RP	proficient
item2	13	28	20	RP/LP-CS/CS	Sophisticated	0	12	12	CS/RP	simple
item3	6	28	22	LP-RP/CT/WD	Sophisticated	0	14	14	CS/RP/LP	proficient
item4	8	28	20	RP/LP-CT/CS	Sophisticated	0	16	16	LP-RP/CS	proficient
item9	11	27	16	LP-RP/CT/WD	Sophisticated	0	10	10	CS/RP	simple
item10	11	27	16	LP-RP/CT/WD	Sophisticated	0	11	11	CS/RP/LP	proficient
item7	9	26	17	RP/LP-CS	proficient	0	15	15	CS/RP/LP	proficient
item8	9	26	17	LP-CS/RP	proficient	0	10	10	CS/RP	simple
item5	12	26	17	RP/LP-CS	proficient	0	14	14	LP-CS/RP	proficient
item11	7	26	19	RP/LP-CS	proficient	0	14	14	LP-CS/RP	proficient
item16	7	26	19	LP-CS/RP	proficient	0	12	12	CS/RP	simple
item14	10	25	15	RP/LP-CS	proficient	0	15	15	LP-CS/RP	proficient
item17	11	26	15	LP-RP/CS	proficient	0	9	9	LP-CS/RP	proficient
item6	14	23	9	CS/RP	simple	0	13	13	LP-CS/RP	proficient

Note: Items arranged in the decreasing order of Ruth's learners gain correct responses

As shown in the Table 8.10 above, it could be observed that, the case of Ruth's eTSPCK and her learners' pre-test item performances seemed to suggest higher category of TSPCK episodes linked to lower learner pre-test item performances and lower category of TSPCK linked to higher learner pre-test item performances. For example, on the test item 6, the test item performance was 14 in the pre-test and this test item was linked to a simple TSPCK episode (CS/RP). On the test item 5, the test item performance was 12 in the pre-test and this test item was linked to a proficient TSPCK episode (RP/LP-CS). On the test item 3, the test item performance was 6 in the pre-test and this test item was linked to a sophisticated TSPCK episode (LP-RP/CT/WD).

Meanwhile, the case of Ruth's eTSPCK and her learners' post-test item performances seemed to suggest a direct relationship between higher performances and higher category of TSPCK episodes and vice versa. For example, on the test item 1, the learner performance in the post-test was 29 with performance gain of 24 and this test item was linked to a sophisticated TSPCK episode (RP/LP-CS/CS). On the test item 7, the learner performance in the post-test was 26 with performance gain of 17 and this item was linked a proficient TSPCK episode (RP/LP-CS). On the test item 6, the learner performance in the post-test was 23 with performance gain of 9 and this item was linked a proficient TSPCK episode (CS/RP).

Furthermore, it could be observed that, the case of Hope's eTSPCK and her learners' item pre-test performances seemed to suggest similar effect of different categories of TSPCK episodes on learner performances across all the test items since learners got zero in the test due to their lack

of conceptual knowledge of organic chemistry prior to Hope's teaching. However, the case of Hope's eTSPCK and her learners' item performance in the post-test suggests a direct relationship between higher category of TSPCK episodes and higher item performances. For example, on the test item 1, the learner performance in the post-test was 16 with performance gain of 6 and this item was linked to a proficient TSPCK episode (LP-CS/RP). On the test item 2, the learner performance in the post-test was 12 with performance gain of 12 and this item was linked to a simple TSPCK episode (CS/RP).

A careful examination of Ruth's and Hope's TSPCK episodes relating to the test items as shown in the Table 8.10 revealed that, while Ruth demonstrated 6, 7 and 1 sophisticated, proficient and simple TSPCK episodes respectively, Hope had 10 and 4 proficient and simple TSPCK episodes respectively emerging from his teaching. It could also be observed that, following the teaching, learner item performances in the post-test seemed to be higher in positive direct proportion in the case of Rose with high sophisticated and proficient TSPCK episodes rather than simple TSPCK episodes compared to the case of Mark who had high proficient and simple TSPCK episodes rather than sophisticated TSPCK episodes. For example, on the test item 1, Ruth's learner item performances improved from 5 in the pre-test to 29 in the post-test and this test item was linked to the Ruth's sophisticated TSPCK episode (RP/LP-CS/CS). In the case of Hope, on the same test item 1, her learner item performances improved from 0 in the pre-test to 16 in the post-test with performance gain of 16 and this item was linked to Hope's proficient TSPCK episode (LP-CS/RP). For a better insight into these trends observed in the Ruth's and Hope's categories of TSPCK episodes and how they relate to the learner performances in the pre-and post-test, the teaching segments with typical learners' written responses on the test item 1 are discussed below.

Ruth's sophisticated TSPCK episodes versus Hope's proficient TSPCK episodes compared to learners' performances on learners' performances on item 1

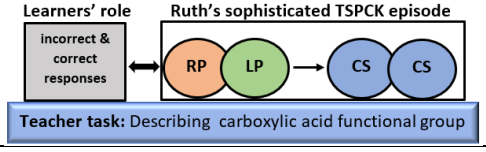
As alluded to in Chapter 3 (Table 3.5), item 1 required the participant learners to identify the functional group on a given structure of ethanoic acid. For learners to answer this question correctly, they must have understood the constituent atoms that make up the carboxylic acid functional group. Meanwhile, the Table 8.10 above shows that, while Ruth demonstrated a sophisticated TSPCK episode and learners' gain was 24, Hope demonstrated a proficient TSPCK

episode and attracted learners' gain of 16 following the teaching. For an illustration of these two PSTs' demonstration of TSPCK episodes and consequent learners' written responses in the achievement tests, the extract of teaching segments with learners' written responses are provided below.

(i) Ruth's teaching segment with learners' written responses on item 1

The Table 8.11 below presents the extract of Ruth's teaching segment focusing on the carboxylic functional group which corresponds to the item 1 in the achievement test.

Table 8.11: Ruth's teaching segment on carboxylic acid functional group

Extract from Lesson 1	Comments/Qualitative in-depth analysis
20-23min: Describing Carboxylic functional group **Ruth**: Now, let's see the next one (*she put the structure of carboxylic acid functional group on the chalk board*) **(RP)**, we can simple write it as RCOOH), yeah so which organic compound does this functional group represent? Ss: …. (No response from learners)…. **Ruth**: What does this R represent guys? SM10: Alkyl group **Ruth**: That's like CH_3 right? SM10: yes **Ruth**: (She pointed at the C=O portion), what's this? SF8: it's like carbon monoxide Ss: …..(Learners laugh)…… **Ruth**: Carbon monoxide is a gas remember, it's an inorganic compound, **(LP)** please not that here *(she pointed at the structure on the chalk board)* it's our C=O is a carbonyl group, we've got carbon double bonded to oxygen, it's a functional group in organic chemistry, **(CS)** so now how about this (*she pointed at the OH portion*)? SF9: hydroxyl functional group Ruth: Functional group for SF9: Alcohols **Ruth**: So, we're saying here is our hydroxyl group OH, the functional group of alcohols homologous as we discussed before, so here our OH and C=O form the carboxylic functional group, we can write it as (she wrote COOH on the board) or (*she wrote C(=O)OH on the board*), we've got a carbon double bonded to an oxygen, it's also bonded to one hydroxyl group and on the other side, to an alkyl group, yeah, with this functional group we can identify and name all the compounds in the carboxylic acid homologous series like using oic for methanoic acid, ethanoic acid, propanoic acid and so, you can see the trend right, so because they've got the same functional group, they undergo same organic reactions, **(CS)** is that understood now? Ss: yes	**Comment**: The discussion here focused on describing the carboxylic acid functional group where Ruth asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of carboxylic acid functional group drawn on the board (RP), Ruth asked learners the organic compound represented by the structure **Learners' role**: Learners provided no answer in response to what organic compounds are represented by the functional group. However, SM10 and SM9 correctly identified R as the Alkyl and OH as the hydroxyl group for alcohols respectively. SF8 wrongly referred to C=O as carbon monoxide (LP). **Ruth's role:** Taking all learners' responses into consideration, Ruth first indicated the hydroxyl and carbonyl group as the constituents of carboxylic functional group used for identifying and naming all carboxylic acids. This suggests an aspect important for learners to know thereby describing Ruth's knowledge of curricular saliency (**CS**). Another important aspect describing Ruth's knowledge of curricular saliency was the effect of all members having the same functional group as seen through similar organic reactions they undergo (**CS**). Ruth's interactive use of TSPCK components (RP/LP-CS/CS) at a sophisticated level of TSPCK episode in connection to the learners' incorrect and correct responses is given by the TSPCK map below. 

As illustrated in the Table 8.11 above, emerging from Ruth's explanations was a sophisticated TSPCK episode consisting of three content-specific knowledge components (LP, RP and CS) where CS repeated. The extracts of two learners' written responses in the completed pre-and post-achievement tests are provided in the Figure 8.19 below.

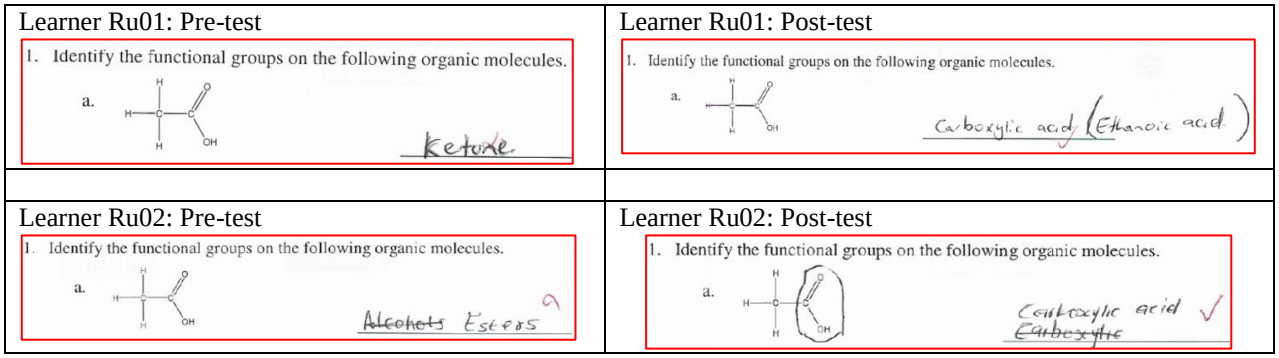


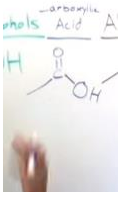
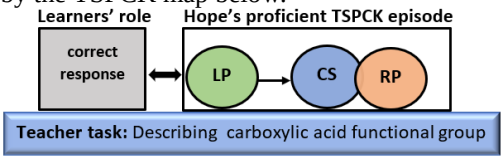
Figure 8.19: Extracts of Ruth's learners' written responses on carboxylic functional group

As provided in the Figure 8.19 above, the learner Ru01 and Ru02's written responses in the pre-test indicate that, they had no good knowledge of carboxylic acid functional group but they were familiar with organic compounds like ketone and ester prior to Ruth's teaching. However, following Ruth's teaching, they were able to correctly identify carboxylic acid functional group in the structural molecule of ethanoic acid. The possible effect of Ruth's explanations seemed to have reflected quantitatively by causing an increase in the number of learners who were able to identify carboxylic acid functional group in the post-test compared to the pre-test.

(ii) Hope's teaching segment with learners' written responses on item 1

On the same carboxylic acid functional group, Hope had a similar teaching segment as presented in the Table 8.12 below.

Table 8.12: Hope's teaching segment on carboxylic acid functional groups

Hope's segment of teaching focusing on carboxylic acid functional group	
Extract of from Lesson 1 (21-25min)	**In-depth Qualitative Analysis**
Hope: So, the next one we gonna discuss is carboxylic acid functional group. Have you guys heard of acids? Ss:….(Learners echoed 'yes')….. SF8: acids and bases **Hope**: Exactly, we have got acids and bases in organic chemistry in inorganic chemistry right (**LP**). In organic chemistry we also have carboxylic acids, here you think of a kind of fusion between particularly between the our hydroxyl group and carbonyl group (**CS**), here is our carboxylic acid functional group (*she drew the molecular structure for the carboxylic acid functional group on the chalk board*), (**RP**) we just put one hydroxyl group here and then I bring in the carbonyl group which is the carbon bonded to oxygen, you see can how I brought the carbonyl and OH right? Ss: yes **Hope**: That's our carboxylic functional group 	**Hope's role**: As a starting point, Hope asked learners if they had heard of carboxylic acid functional group before knowing that, carboxylic acid refers to an acidic compound and learners must have already learnt about acids in the previous Grade. **Learners' role**: Learner SF8 referred to acids and bases as what he knew about acids. This shows the learner prior knowledge which Mark expected all learners to bring into the discussion (**LP**) **Hope's role**: Hope acknowledged the acids and bases that SF8 mentioned in relation to inorganic chemistry in order to confirm the correct prior knowledge. She referred to the fusion between the hydroxyl group and a carbonyl group as representing the carboxylic acid functional group. This is an element of curricular saliency (CS), the knowledge of what is important for learners to know. She drew the molecular structure of carboxylic acid functional group to support her explanation thereby suggesting her knowledge of the use of a symbolic representation (RP). Hope's use of TSPCK components (LP-CS/RP) in connection to a learner's correct response is given by the TSPCK map below. 

As illustrated in the Table 8.12 above, emerging from Hope's explanations was a proficient TSPCK episode consisting of three content-specific knowledge components (LP, RP and CS). The extracts of two learners' written responses in the completed pre-and post-achievement tests are provided in the Figure 8.20 below.

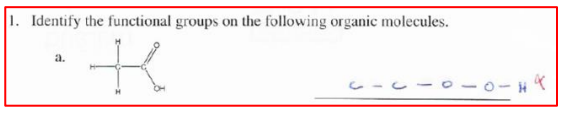
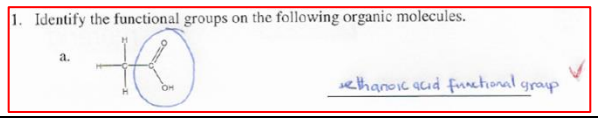
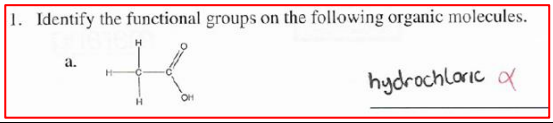
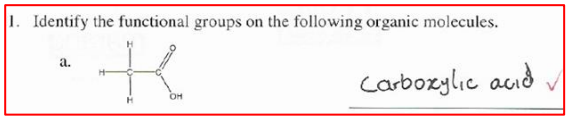
Learner Ho01: Pre-test	Learner Ho01: Post-test
	
Learner Ho02: Pre-test	Learner Ho02: Post-test
	

Figure 8.20: Hope's learners' written responses on carboxylic functional group

As provided in the Figure 8.20 above, the learner Ho01 and Ho02's written responses in the pre-test indicate that, they had no good knowledge of carboxylic acid functional group However, following Hope's teaching, they were able to correctly identify carboxylic acid functional group in the structural molecule of ethanoic acid. The possible effect of Hope's explanations seemed to have reflected quantitatively by causing an increase in the number of learners who were able to identify carboxylic acid functional group in the post-test compared to the pre-test.

(iii) Similarities and differences observed in the Ruth's and Hope's teaching segments on item 1

There were a few differences noticed in the Ruth's and Hope's presentations that could possibly have suggested higher gain in the Ruth's learners' conceptual performances than Hope's learners' conceptual performances following the teaching. First, a deeper extent of interaction was observed as Ruth presented carboxylic acid functional group with learners than in the case of Hope. Ruth's use of symbolic representations began at the very point of asking learners questions in order to establish their prior knowledge about atoms that constitute carboxylic acid functional group. Unlike in the case of Hope where the use of symbolic representation came to play while explaining how carboxylic acid looks like, Ruth's use of a symbolic representation surfaced at the point of investigating learner prior knowledge and also while providing standardized explanations in relation to the learners' responses. This seemed to have assisted Ruth to discover a learner's misconception revolving around taking carbonyl group (C=O) as a carbon monoxide (CO). Likewise, Ruth's effort made in asking her learners about R (alkyl group) and OH (hydroxyl group) in the give molecular structure seemed to describe an attempt to link what she had been previously discussed with the learners about the alkyl group and hydroxyl group. This was associated with making effort to ensure that, the learners were able to apply the acquired knowledge from the preceding discussions in correctly recognizing the two functional groups in the structure of carboxylic acid functional group drawn for them. Second, aside discussing what atoms constitute carboxylic acid functional group as observed in both the Ruth's and Hope's teaching, Ruth further explained how carboxylic acids undergo same organic reactions due to the same functional group present in all their molecules. This understanding of what could be considered a post-concept facilitated the emergence of a sophisticated TSPCK episode (RP/LP-CS/CS) from Ruth's explanations higher than the proficient TSPCK episode (LP-RP/CS) emerging from Hope's explanations.

8.4 Concluding remarks

This chapter focused on determining the correlation between the PSTs' eTSPCK and learner achievement in organic chemistry. This was guided by the third research question for this study which asks "How does the quality of pre-service teachers' TSPCK seen in the actual classroom teaching of organic chemistry influence the learner achievement in organic chemistry?". As highlighted in the introductory section in this chapter, there is the acknowledgement of the complexity of teaching and learning process mediated by myriad of factors and hence, the difficulty in accurately linking one particular factor (e.g. teachers' PCK) to learner outcomes. The findings emerging from this Chapter are of the recognition that, the observed learner achievement are directly influenced by various factors associated with the process of classroom teaching and learning including the PSTs' eTSPCK. One attempt made to sift out the effect of PSTs' eTSPCK and minimize the effects of other factors was to analyse only for the eTSPCK episodes as defined above in isolation to other types of teacher knowledge and classroom factors. Furthermore, all the test items which were not covered by the PSTs in their teachings were excluded from the correlation analysis. These represented the levels of refinement of data which added credibility to the emerging findings from the correlation analysis. They assisted in ensuring that, TSPCK episodes could be singly worked with as one significant factor while examining how to improve learners' conceptual performances. Having taken these steps in an attempt to singly work with TSPCK and then minimise the effects of other factors, there were two key findings emerging from the analyzes presented in this chapter.

First, it was found out that, there was a negative negligible and statistically insignificant correlation between the PSTs' overall TSPCK episodes versus pre-test learner performances prior to the teaching. A 'negative correlation' suggests an inverse relationship between PSTs' eTSPCK and pre-test learner performances prior to the teaching. The 'negligible statistically insignificant correlation' implies that, there was *no considerable relationship* between PSTs' eTSPCK and pre-test learner performances as expected since the learners were only exposed to the teaching by the PSTs only in this study. This points to the reliability of the data. The correlation could not be computed for the relationship between Hope's eTSPCK and pre-test learner performances because of the poor learner performances in the test. However, there was a positive and statistically significant correlation between the PSTs' overall TSPCK episodes and

post-test learner performances. This practically means that, an increase in the PSTs' eTSPCK in organic chemistry is directly associated with an increase in the learner achievement in the topic.

Second, it was discovered that, the positive correlation between the PSTs' eTSPCK and post-test learner performances increases in positive strength with most high quantity of proficient and sophisticated TSPCK episodes compared to simple TSPCK episodes. This was observed in the analysis using the overall TSPCK episodes. For example, there was a most high positive significant correlation between eTSPCK and post-test learner performances in the cases of Ruth and Rose who demonstrated most high quantity of proficient and sophisticated TSPCK episodes compared to simple TSPCK episodes in their teachings. Accordingly, there was a moderate positive significant correlation between eTSPCK and post-test learner performances in the cases of Hope and Mark who demonstrated most high quantity of simple and proficient TSPCK episodes compared to sophisticated TSPCK episodes in their teachings. These two examples reflect the pattern of the gradient correlation in cognisance of the respective different quality-kinds of TSPCK episodes. This finding practically suggests that, as the quality of PSTs' eTSPCK increases in the classroom teaching of organic chemistry, the learner achievement in the topic increase as well.

In the case of PSTs' overall TSPCK episodes versus pre-test learner performances, there was a negative negligible correlation between the PSTs' eTSPCK and pre-test learner performances prior to the teaching. This suggests that, there was an inverse but ignorable relationship between the PSTs' eTSPCK and pre-test learner performances prior to the teaching as expected since learners were being taught by the PSTs in this study for the first time. However, in the case of PSTs' overall TSPCK episodes versus post-test learner performances, there was a high positive and statistically significant correlation between the PSTs' eTSPCK and post-test learner performances following the teaching. This suggests that, there was a direct and statistically significant relationship between the PSTs' eTSPCK and post-test learner performances following the teachings. Having the overall TSPCK episodes directly and strongly related to the increase in the post-test learner performances contributes to the reliability of the correlation analysis and TSPCK as one important factor that could be referred to when examining learner achievement.

The use of a mixed methods design has been of great value in this chapter. First, the quantitative examination revealed the strength and direction between the PSTs' eTSPCK and learner performances. By the magnitude of correlation, the association between the PSTs' eTSPCK and learner performances was specifically found to be either negligible, moderate or high. By the direction of correlation (negative or positive), the association between the PSTs' eTSPCK and learner performances was found to be negative (inversely related) or positive (directly related). The quantitative patterns were complimented by the qualitative examination which revealed how the emergence of TSPCK content-specific knowledge components, consitituting the PSTs' explanations, contributed to the difference in the quality of learners' written responses in the post-test compared to the pre-test. The principal content-specific knowledge components of TSPCK interactively involved in the PSTs' TSPCK episodes were identified through qualitative analysis which reflected the popularity of: learner prior knowledge (LP); curricular saliency (CS); and symbolic representations (RP). In other words, the qualitative analysis brought to view in qualitative terms, the weakness or strength of component interactions in TSPCK episodes that showed high or weak correlations to the learners' conceptual performances. This is considered an important convergent point where mixing qualitative and quantitative research methods occurred to wholistically provide an understanding required. Another identified convergent point was seen in the representation of in-depth qualitative descriptions of TSPCK episodes using quantitative rubric scores and most importantly, the conversion of these scores into statistical values for correlation analysis. Thus, the convergence of quantitative and qualitative analysis in this chapter points to the benefit of use of a mixed methods research design for revealing patterns of correlation between the PSTs' eTSPCK and learner performances in a wholistic manner. It has been of great value in gaining insights into how and by what extent eTSPCK relates to learner achievement in the topic of organic chemistry. The next chapter presents the analyzes of the learners' views about the possible classroom factors which, from the learners' perspectives, might have promoted or hindered their understanding of the concepts of organic chemistry covered by the PSTs.

CHAPTER NINE

9. ANALYSIS OF LEARNERS' VIEWS

In Chapter 5 and 6 there were examinations of the quality of PSTs' planned TSPCK and enacted TSPCK in organic chemistry respectively. Chapter 7 and Chapter 8 explored learner achievement in organic chemistry prior to and following the PSTs' teachings in relation to the categories of PSTs' TSPCK episodes. The current chapter focused on examining learner views about the PSTs' teachings. The chapter presents another perspective of looking at the correlation between PSTs' eTSPCK and learner outcomes. It closes by summarizing the key findings emerging from the examinations.

9.1 Introduction

The purpose of this chapter is to present the examination of learners' views about aspects of the PSTs' teachings which seemed to have promoted or hindered their conceptual understanding of organic chemistry. As alluded to in Chapter 2, this study acknowledges the complexity of classroom instruction and learning due to myriad of influences and hence, the difficulty in accurately establishing the link between teachers' PCK and learner outcomes (Gess-Newsome *et al*., 2017; Cross & Lepareur, 2015). As a result, the overall target in this study was to explore the connections in the anticipated TSPCK development projectile from cTSPCK, through planned TSPCK and eTSPCK to learner outcomes measured as the learner achievement and views. In Chapter 5, the analysis revealed a significant improvement in the PSTs' quality of TSPCK in organic chemistry following the intervention. The analysis in Chapter 6 further revealed the PSTs' demonstration of a varied mix of simple, proficient and sophisticated TSPCK episodes in the classroom teaching of organic chemistry. In Chapter 7, it was observed that, the participant learners improved significantly in their conceptual understanding of organic chemistry following the PSTs' teachings. The observed learner achievement following the PSTs' teachings was noticed to be positively correlated with the PSTs' eTSPCK as analyzed in Chapter 8. In the current Chapter, the same correlation is explored from gauging the learners' perspectives of what aspects of teachers' knowledge demonstrated during teaching had helped them learn the presented topic of organic chemistry. In this line of thought, Broadhead (1996) highlighted that a way of improving science teaching and learning is to encourage learners to indicate what makes science difficult for them to learn and how teaching such scientific concepts can be improved. In this way, collecting such learners' views would enable teachers to

appreciate the perceived instructional influences on learners' learning and conceptual understanding (Halim *et al*., 2014). As a result, the participant learners' views about the PSTs' teachings in this study were collected in order to gain insights into the aspects of PSTs' knowledge and instructional practices which promoted or hindered learners' conceptual understanding of organic chemistry. Thus, this chapter is presented in two sections. The first section comprises a recap of the methodology employed. The second section presents the findings from the participant learners' views about the PSTs' teachings. The chapter closes with the summary of the findings.

9.2 A recap of the methodology used in this Chapter

The participants in this chapter comprised 88 physical science high school learners whose conceptual achievement was analyzed Chapter 7 and also, a group of 4 PSTs whose eTSPCK was captured and portrayed in Chapter 6. The main source of data for this chapter consists of the learners' written responses to the open-ended questions which asked them about the PSTs' lessons. The detailed discussions on the participant learners, PSTs, focus of the lessons, learner view questions, method of analyzing and validating the analyzed learners' written responses are all presented in Chapter 3 (section 3.3.2, section 3.4.2b, section 3.5 and section 3.6.2). The results are presented in the next section below.

9.3 Results

The findings from the learners' views about the PSTs' teachings are presented in two parts. The first part presents the Ruth's and Hope's learners' views about the PSTs' teachings focusing on functional groups and IUPAC nomenclature of organic compounds. The second part presents the Rose's and Mark's learners' views about the PSTs' teachings focusing on physical properties and structures of organic compounds. In each case, the PST's eTSPCK profile (Chapter 6) versus learner achievement (Chapter 7) were first re-presented in order to provide a recap of the PST's TSPCK enacted in the classroom teaching and the corresponding learner performances prior to and following the teachings.

Part I: Learners' views about teaching focusing on functional groups and IUPAC nomenclature of organic compounds

The case of Ruth's learners

The Figure 9.1 below re-presents Ruth's overall TSPCK profile analyzed in Chapter 6 and her learner achievement as analyzed in Chapter 7.

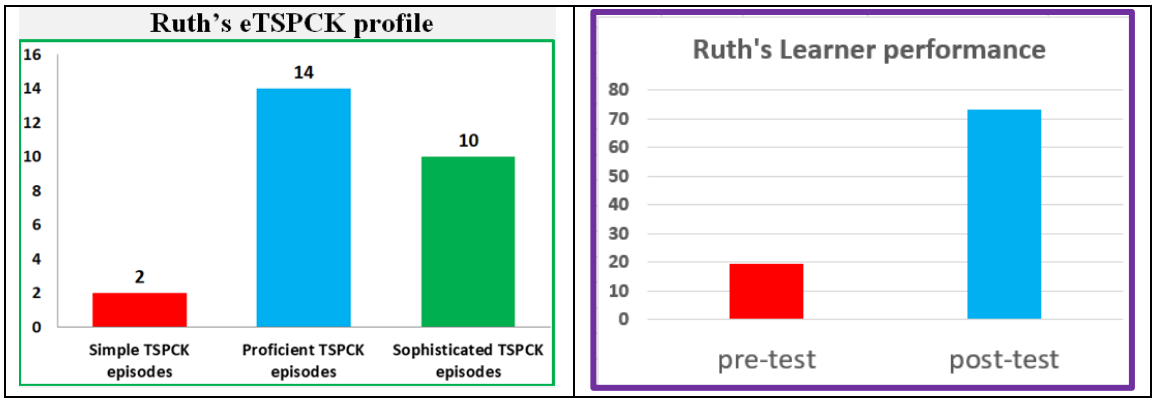


Figure 9.1: Ruth's eTSPCK profile and learner achievement

As shown in the Figure 9.1, Ruth demonstrated 2 simple TSPCK episodes, 14 proficient TSPCK episodes and 10 sophisticated TSPCK episodes in her teaching. It is important to highlight that, as analyzed in Chapter 6, in addition to other knowledge components of TSPCK, three content-specific knowledge components which principally informed Ruth's eTSPCK included: learner prior knowledge including misconceptions (LP); curricular saliency (CS); and use of symbolic representations (RP). As shown in the Figure 9.1 above, Ruth's learners conceptually improved from 19.61% in the pre-test to 73.14% in the post-test which is well above 60% mark considered the comfortable level of achievement in this study.

The first question item in the learners' views asked the participant learners to state what Ruth did in her teaching that helped them to understand the concepts. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.1 below.

Table 9.1: Things done during teaching that helped Ruth's learners understand the concepts

Key phrases	Frequency	Percentage
Emphasis on concepts /repetition of explanations	10	33.3
Use of structures/ diagrams in explaining concepts	8	26.7
Use of familiar examples in explaining concepts	6	20.0
Asking questions to ensure understanding of concepts	4	13.3
No response	2	6.7
Total	30	100.0

As shown in the Table 9.1 above, the important factors indicated by Ruth's learners to have contributed to their understanding of the lesson included: emphasis made during teaching on concepts (or repetition of explanations); use of structures (or diagrams) in explaining concepts; use of familiar examples in explaining concepts; and asking questions during the lesson to ensure learners' understanding. There were no responses from 2 learners on this question item. Relating to TSPCK construct, emphasis on important concepts is an element of curricular saliency (CS), use of structures in explaining concepts is an element of symbolic representations (RP) and use of familiar examples takes learner prior knowledge (LP) into consideration. Asking learners questions to check their understanding of the concepts describes an aspect of the teachers' general pedagogical knowledge.

The second question item in the learners' views asked the participant learners to indicate what was done by Ruth that they liked most. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.2 below.

Table 9.2: Things done during teaching that Ruth's learners liked most

Key phrases	Frequency	Percentage
Use of structures/diagrams in explaining concepts	10	33.3
Teacher personality (e.g. friendliness)	9	30.0
Language use	6	20.0
Asking questions to ensure understanding of concepts	5	16.7
Total	30	100.0

As shown in the Table 9.2 above, the largest percentage (33.3%) of learners referred to the Ruth's use of structures or diagrams in her teaching followed by the 30.0% of the learners who talked about Ruth's personality such as friendliness. Likewise, 20.0% of the learners talked about Ruth's good use of language in explaining concepts and 16.7% of the learners referred to

Ruth asking them questions in order to check their understanding of the concepts. While Ruth's use of structures/diagrams referred to her knowledge of representation as a content-specific knowledge component, other factors except her personality describe her general pedagogical knowledge.

The third question item in the learners' views asked the participant learners to highlight was done by Ruth during her teaching that they did not like. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.3 below.

Table 9.3: Things done by Ruth that her learners did not like

Key phrases	Frequency	Percentage
Nothing	10	33.3
No response	10	33.3
All well done	7	23.3
Teacher talked too fast	3	10.0
Total	30	100.0

As shown in the Table 9.3 above, while 33.3% of the learners indicated that Ruth did nothing which they did not like, there were no responses on this item from 33.3% of the learners, 23.3% of the learners stated that Ruth did everything well. However, while 10.0% of the learners highlighted that, Ruth talked too fast.

The fourth question item in the learners' views asked the participant learners to indicate what they thought would help them to understand the concepts better. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.4 below.

Table 9.4: Things Ruth's learners thought would make them understand the concepts better

Key phrases	Frequency	Percentage
Laboratory experiments on the concepts covered	14	46.7
Self-study/solving past questions	10	33.3
Nothing but to listen to her teach more lessons	3	10.0
Getting take home exercises on the concepts covered	3	10.0
Total	30	100.0

As given in the Table 9.4 above, the largest percentage (46.7%) of Ruth's learners believed that performing laboratory experiments would enhance their understanding of the concepts.

Although Ruth had simple demonstrations which involved the use of symbolic representations and models, there is a hint for hunger for practical work where learners normally take active part. 33.3% of the learners indicated that engaging in self-study or solving past questions would make them understand the concepts better. 10.0% of the learners indicated that they would prefer listening to Ruth teach more lessons. 10.0% of the learners stated that, getting take home exercises on the concepts covered would enhance their understanding. One important aspect of representations as a content-specific knowledge component is engaging learners at the macroscopic level of representations in explaining concepts. This was completely absent in the Ruth's teaching, there was no evidence of engaging learners' in experimental activities. The aspects of self-study and getting take home exercises also talked to possible confidence that learners developed through Ruth's teachings. The aspect of listening to Ruth to teach more lessons could reasonably be interpreted as learners' interest in Ruth's teaching.

The case of Hope's learners

The Figure 9.2 below presents Hope's overall eTSPCK profile analyzed in Chapter 6 and her learner achievement as analyzed in Chapter 7.

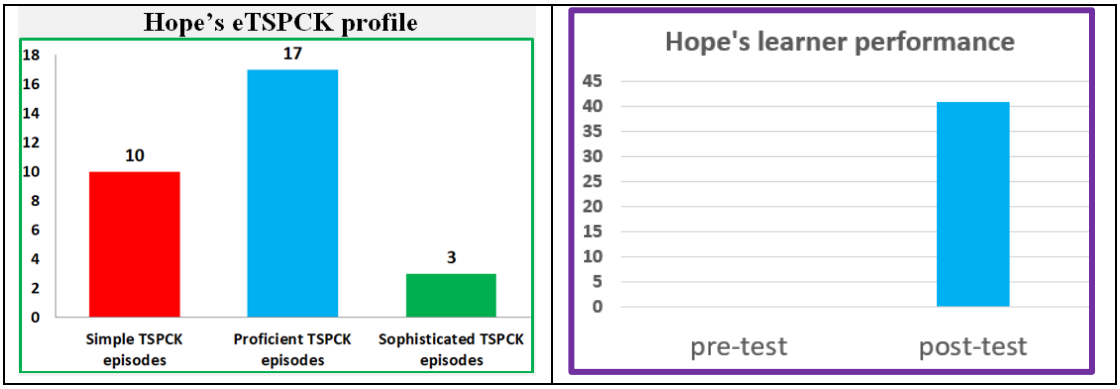


Figure 9.2: Hope's eTSPCK profile and learner achievement

As shown in the Figure 9.2, Hope demonstrated 10 simple TSPCK episodes, 17 proficient TSPCK episodes and 3 sophisticated TSPCK episodes in her teaching of the concepts of functional groups and IUPAC nomenclature of organic compounds. The demonstration of these three categories of TSPCK episodes was similar to that of Ruth except that Ruth had high proficient and sophisticated TSPCK episodes than simple TSPCK episodes unlike Hope with high simple and proficient TSPCK episodes than sophisticated TSPCK episodes. Similar to Ruth's eTSPCK, three content-specific knowledge components which principally informed

Hope's eTSPCK as analyzed in Chapter 6. These included: learner prior knowledge including misconceptions; curricular saliency; and use of symbolic representations. Moreover, as shown in the Figure 9.2 above, Hope's learners conceptually improved from 0.0% in the pre-test to 40.98% in the post-test although the performance following the teaching did not reach 60% mark considered the comfortable level of achievement in this study.

The first question item in the learners' views asked the participant learners to state what Hope did in her teaching that helped them to understand the concepts. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.5 below.

Table 9.5: Things done that helped Hope's learners to understand the concepts

Key phrases	Frequency	Percentage
Use of structures/ diagrams in explaining concepts	14	46.7
No response	7	23.3
Opportunity to write directly on the chalkboard	4	13.3
Asking questions to ensure understanding of concepts	3	10.0
Use of familiar examples in explaining concepts	2	6.7
Total	30	100.0

As shown in the Table 9.5 above, the important factors indicated by Hope's learners to have contributed to their understanding of the lessons included: the use of structures (or diagrams) in explaining concepts; opportunities given to learners to write on the chalkboard in response to the questions asked; asking questions during the lesson to ensure learners' understanding; and use of familiar examples in explaining concepts. There were no responses from 23.3% of the participant learners on this item. Relating to TSPCK construct, the use of structures in explaining concepts is an element of symbolic representations and use of familiar examples takes learner prior knowledge into consideration. Asking learners questions to check their understanding of the concepts describes an aspect of the Hope's general pedagogical knowledge.

The second question item in the learners' views asked the participant learners to indicate what was done by Hope that they liked most. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.6 below.

Table 9.6: Things done during teaching that Hope's learners liked most

Key phrases	Frequency	Percentage
Opportunity to write directly on the chalkboard	9	30.1
Use of structures/ diagrams in explaining concepts	6	20.1
Teacher personality	5	16.6
Asking questions to ensure understanding of concepts	5	16.6
No response	5	16.6
Total	30	100.0

As shown in the Table 9.6 above, the largest percentage (30.1%) of learners referred to the opportunity they had to write directly on the chalkboard as what they liked most followed by 20.1% of the learners who mentioned Hope's use of structures or diagrams in her teaching. 16.6% of the learners who talked about Hope's good personality as what they liked most. 16.6% of the learners referred to Hope asking them questions in order to check their understanding of the concepts. There were no responses from 16.6% of the learners regarding what they liked most about Hope's teaching. While Hope's use of structures/diagrams referred to her knowledge of representation as a content-specific knowledge component, other factors except her personality describe her general pedagogical knowledge.

The third question item in the learners' views asked the participant learners to highlight was done by Hope during her teaching that they did not like. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.7 below.

Table 9.7: Things done by Hope that her learners did not like

Key phrases	Frequency	Percentage
No enough explanations	8	26.7
Illegible board work	6	20.0
All well done	6	20.0
Teacher talked too fast	5	16.7
Nothing	5	16.7
Total	30	100.0

As shown in the Table 9.7 above, while 26.7% of the learners complained about Hope not explaining enough as what they did not like, 20.0% of the learners referred to her illegible board work. 16.7% of the learners complained about Hope talking too fast as what they did not like. However, 20.0% of the learners indicated that Hope did everything well while 16.7% did not

respond to this question. In relation to TSPCK construct, not giving enough explanation could mean Hope did not make enough emphasis on important concepts or lack of repetition where necessary towards enhancing learners' understanding.

The fourth question item in the learners' views asked the participant learners to indicate what they thought would help them to understand the concepts better. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.8 below.

Table 9.8: Things Hope's learners thought would make them understand the concepts better

Key phrases	Frequency	Percentage
Further explanations on the concepts	13	43.3
Laboratory experiments on the concepts covered	10	33.4
More examples relating to common experiences	7	23.3
Total	30	100.0

As given in the Table 9.8 above, the largest percentage (43.3%) of Hope's learners believed that further explanations would enhance their understanding of the concepts. 33.4% of the learners indicated that giving them the opportunity to perform laboratory experiments on the concepts learnt would deepen their understanding. 23.3% of the learners believed that providing them with more examples relating to common experiences would make them to understand the concepts better. In relation to TSPCK construct, further explanations could mean making enough emphasis on important concepts where necessary which suggest Hope's more of knowledge of curricula saliency towards enhancing learners' understanding. The laboratory experiments also call for engaging learners in the macroscopic form of representing concepts. A request for more examples relating to common experiences could be describing aspects drawing more on the Hope's understanding of learner prior knowledge.

Part II: Learners' views about teaching focusing on physical properties and structures of organic compounds

The case of Rose's learners

The Figure 9.3 below presents Rose's overall eTSPCK profile analyzed in Chapter 6 and her learner achievement as analyzed in Chapter 7.

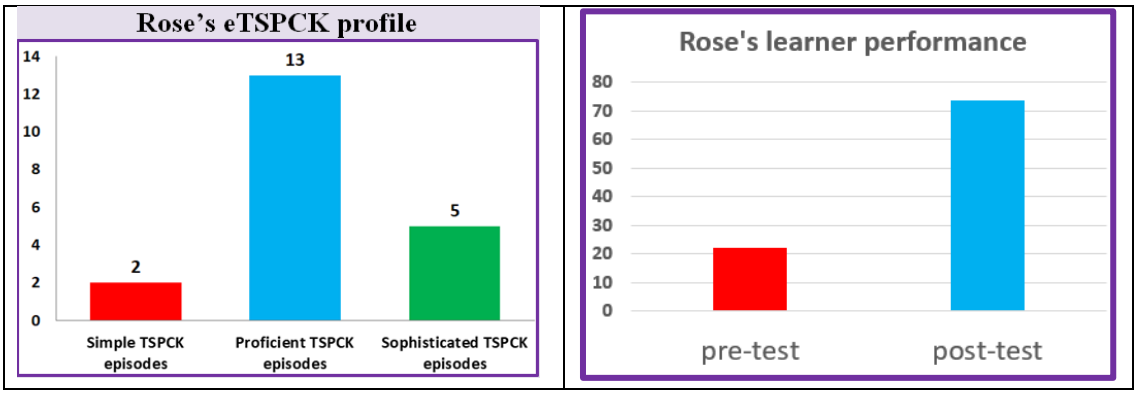


Figure 9.3: Rose's eTSPCK profile and learner achievement

As shown in the Figure 9.3, Rose demonstrated 2 simple TSPCK episodes, 13 proficient TSPCK episodes and 5 sophisticated TSPCK episodes in her teaching of the concepts of physical properties and structures of organic compounds. As analyzed in Chapter 6, in addition to other knowledge components, three content-specific knowledge components which principally informed Rose's eTSPCK included: learner prior knowledge including misconceptions; curricular saliency; and use of symbolic representations. Likewise as shown in the Figure 9.3 above, Rose's learners conceptually improved from 21.9% in the pre-test to 73.5% in the post-test which is well above 60% mark considered the comfortable level of achievement in this study.

The first question item in the learners' views asked the participant learners to state what Rose did in her teaching that helped them to understand the concepts. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.9 below.

Table 9.9: Things done that helped Rose's learners to understand the concepts

Key phrases	Frequency	Percentage
Use of structures/diagrams in explaining concepts	5	35.7
Emphasis on concepts/repetition of explanations	3	21.4
Use of familiar examples in explaining concepts	3	21.4
Asking questions to ensure understanding of concepts	3	21.4
Total	14	100.0

As shown in the Table 9.9 above, the important factors indicated by Rose's learners to have contributed to their understanding of the lessons included: the use of structures (or diagrams) in explaining concepts; emphasis made on concepts; use of familiar examples in explaining

concepts; and asking questions during the lesson to ensure learners' understanding. There were no responses from 21.4% of the participant learners. Relating to TSPCK construct, the use of structures in explaining concepts is an element of symbolic representations and use of familiar examples takes learner prior knowledge into consideration. Also, emphasis on important concepts describes Rose's knowledge of curricular saliency. Asking learners questions to check their understanding of the concepts describes an aspect of the Rose's general pedagogical knowledge.

The second question item in the learners' views asked the participant learners to indicate what was done by Rose that they liked most. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.10 below.

Table 9.10: Things done during Rose's teaching that learners liked most

Key phrases	Frequency	Percentage
Asking questions to ensure understanding of concepts	4	28.6
Use of structures/ diagrams in explaining concepts	3	21.4
Good explanations provided	3	21.4
Giving familiar examples	2	14.3
Teacher personality	2	14.3
Total	14	100.0

As shown in the Table 9.10 above, 28.6% of the learners talked about Rose asking them questions in order to check their understanding as what they liked most. 21.4% of learners referred to the Rose's use of structures/diagrams in explaining concepts as what they liked most. 21.4% of the learners referred to Rose's good explanations provided as what they liked most. 14.3% of the learners mentioned Rose's use of familiar examples in explaining concepts as what they liked most. 14.3% of the learners referred to Rose's personality. In relation to TSPCK construct, Rose's use of structures describes his knowledge of symbolic representations and giving familiar examples refers to her understanding of an aspect of learner prior knowledge. Asking the learners questions describes an aspect of Rose's general pedagogical knowledge.

The third question item in the learners' views asked the participant learners to highlight was done by Rose during her teaching that they did not like. The keywords emerging from the

learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.11 below.

Table 9.11: Things done by Rose that her learners did not like

Key phrases	Frequency	Percentage
Nothing	8	26.7
All well done	6	20.0
Total	14	100.0

As shown in the Table 9.11 above, 26.7% of the learners indicated that there was nothing Rose did that they did not like. Likewise, 20.0% of the learners stated that, Rose did everything well.

The fourth question item in the learners' views asked the participant learners to indicate what they thought would help them to understand the concepts better. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.12 below.

Table 9.12: Things Rose's learners thought would make them understand concepts better

Key phrases	Frequency	Percentage
Laboratory experiments on the concepts covered	9	64.3
Self-study/solving past-questions	3	21.4
Nothing but to listen to her teach more lessons	2	14.3
Total	14	100.0

As given in the Table 9.12 above, 64.3% of the learners believed that performing laboratory experiments would enhance their understanding of the concepts. While 21.4% of the learners believed that self-study and solving past questions would deepen their understanding of the concepts, 14.3% of the learners stated that they would prefer listening to Rose teach more lessons. In relation to TSPCK construct, laboratory experiments talk to more of Rose's knowledge of the use of macroscopic representation in explaining concepts. Self-study and solving past questions describe confidence that learners might probably have developed due to their understanding of the concepts covered by Rose during her teaching. Listening to Rose teach more lessons talks to the interest learners develop in Rose's teaching.

The case of Mark's learners

The Figure 9.4 below presents Mark's overall TSPCK profile analyzed in Chapter 6 and her learner achievement as analyzed in Chapter 7.

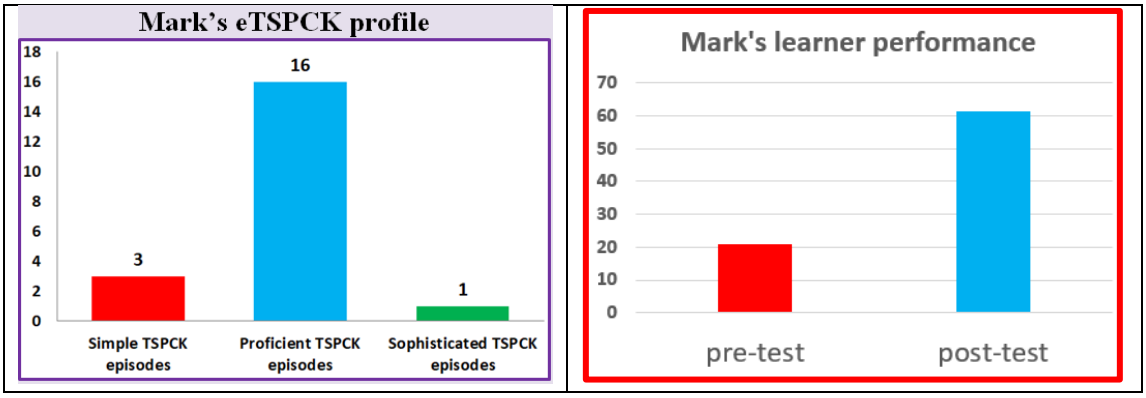


Figure 9.4: Mark's eTSPCK profile and learner achievement

As shown in the Figure 9.4, Mark demonstrated 3 simple TSPCK episodes, 16 proficient TSPCK episodes and 1 sophisticated TSPCK episode in his teaching of the concepts of physical properties and structures of organic compounds. As analyzed in Chapter 6, three content-specific knowledge components which principally informed Mark's eTSPCK: learner prior knowledge including misconceptions; curricular saliency; and use of symbolic representations. Likewise as shown in the Figure 9.4 above, Mark's learners conceptually improved from 20.9% in the pre-test to 61.2% in the post-test.

The first question item in the learners' views asked the participant learners to state what Mark did in his teaching that helped them to understand the concepts. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.13 below.

Table 9.13: Things done that helped Mark's learners to understand the concepts

Key phrases	Frequency	Percentage
Use of structures/ diagrams in explaining concepts	6	42.9
Emphasis on concepts /repetition of explanations	4	28.6
Good use of language	2	14.3
No response	2	14.3
Total	14	100.0

As shown in the Table 9.13 above, the important factors indicated by Mark's learners to have contributed to their understanding of the lessons included: the use of structures (or diagrams) in

explaining concepts; emphasis made on important concepts explained; and good use of language. There were no responses from 14.3% of the participant learners. Relating to TSPCK construct, the use of structures in explaining concepts is an element of symbolic representations and use of familiar examples takes learner prior knowledge into consideration.

The second question item in the learners' views asked the participant learners to indicate what was done by Mark that they liked most. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.14 below.

Table 9.14: Things done during Mark's teaching that learners liked most

Key phrases	Frequency	Percentage
Use of structures/ diagrams in explaining concepts	5	35.7
Asking questions to ensure understanding of concepts	4	28.6
No response	3	21.4
Giving familiar examples	2	14.3
Total	14	100.0

As shown in the Table 9.14 above, 35.7% of learners referred to Mark's use of structures/diagrams in explaining concepts as what they liked most. 28.6% of the learners referred to Mark asking them questions in order to check their understanding of the concepts. 21.4% of the learners did not respond to this question. 14.3% of the learners referred to Mark using familiar examples in his explanations as what they liked most. In relation to TSPCK construct, Mark's use of structures describes his knowledge of symbolic representations and giving familiar examples refers to his understanding of an aspect of learner prior knowledge. Asking the learners questions describes an aspect of Mark's general pedagogical knowledge.

The third question item in the learners' views asked the participant learners to highlight was done by Mark during his teaching that they did not like. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.15 below.

Table 9.15: Things done by Mark that his learners did not like

Key phrases	Frequency	Percentage
No enough explanations	4	28.6
All well done	4	28.6
Teacher talked too fast	3	21.4
Nothing	3	21.4
Total	14	100.0

As shown in the Table 9.15 above, while 28.6% of the learners complained about Mark not providing enough explanations during his teaching as what they did not like, 21.4% of the learners mentioned that Mark talked too fast. However, 28.6% of the learners stated that Mark did everything well while 3% of the learners highlighted there was nothing done by Mark that they did not like.

The fourth question item in the learners' views asked the participant learners to indicate what they thought would help them to understand the concepts better. The keywords emerging from the learners' written responses and the corresponding number of learners expressed in frequency and percentages are presented in the Table 9.16 below.

Table 9.16: Things Mark's learners thought would make them understand the concepts better

Key phrases	Frequency	Percentage
Laboratory experiments on the concepts covered	6	42.9
More explanations needed on the concepts covered	5	35.7
More examples relating to common experiences	3	21.4
Total	14	100.0

As given in the Table 9.16 above, the largest percentage (42.9%) of the Mark's learners believed that performing laboratory experiments would enhance their understanding of the concepts. 35.7% of the learners indicated that they would need more explanations on the concepts covered for them to have a better understanding while 21.4% of the learners mentioned that they would need more examples relating to their daily experiences. In relation to TSPCK construct, laboratory experiments talk to more of Mark's knowledge of the use of macroscopic representation in explaining concepts. Also, more explanations on the concepts refer to more of Mark's knowledge of curricular saliency which involves emphasizing important aspects to learners. More examples relating to common experiences equally refer to more of Mark's understanding of an aspect of learner prior knowledge.

9.4 Summary

The current chapter focussed on examining the learners' views about aspects of the PSTs' knowledge and instructional practices which promoted or hindered their conceptual understanding of organic chemistry concepts. It was found out that, in the cases of the 4 participant PSTs, majority of the learners indicated that, the use of structures (or diagrams) and explanations which emphasized important concepts assited them in understanding the concepts. These two aspects described the PSTs' understanding of the content-specific knowledge components of curricular saliency and symbolic representations. This aspect of learners' views served as additional evidence to substantiate the PSTs' interactive use of curricular saliency, representations and learner prior knwledge as the dominating content specific knowledge components which principally shaped their eTSPCK in the classroom teaching of organic chemistry as analyzed in Chapter 6. Equally, these were the dominating knowledge components which consitituted the PSTs' eTSPCK that positively correlated with improvement in post-test learner performances as analyzed in the previous chapter, Chapter 8.

Furthermore, the analysis of learners' views revealed that, in the cases of Ruth and Rose who demonstrated high quantity of proficient and sophsicated TSPCK episodes compared to simple TSPCK episodes and whose eTSPCK correlation was highly correlated with post-test learners' conceptual performances, the participant learners believed that, getting take home exercises and self-study would deepen their understanding of the concepts. However, in the cases of Hope and Mark who demonstrated high quantity of simple and proficient TSPCK episodes compared to sophisticated TSPCK episodes and whose eTSPCK was moderately correlated with post-test learner performances, the participant learners required more explanations with familiar examples on the concepts covered. This suggests that the PSTs should have more interactive use of content-specific knowledge components which inform their quality of TSPCK in order to facilate science learning among learners. In other words, the learners' views of what would make them understad the concepts better could help to promote the development of PSTs' TSPCK in the topic of organic chemistry. As argued by Park and Oliver (2008), when teachers of sciences get sensitized to the needs of learners, only then can they think of improving the quality of their instructions. This seems to imply that, while possessing the different components of TSPCK is essential, it is equally important for teachers to develop the understanding of interactive use of

knowledge components in planning and enacting instructions (Aydin *et al*., 2015). Noticeably, in the cases of the 4 PSTs, the participant learners believed that, performing laboratory experiements would deepen their conceptual understanding. This suggests that, more of the PSTs' application of macroscopic levels of representations in presenting organic chemistry concepts to learners was needed. The overall findings in this chapter correlate with the findings emerging from the previous chapters (Chapter 8). The next chapter pulls together all the findings emerging from this study guided by the theoretical framework with the purpose of answering the research questions guiding this study.

CHAPTER TEN

10. DISCUSSIONS AND IMPLICATIONS

The current chapter presents discussions of research findings reported in the previous chapters in relation to the purpose of the study and the formulated research questions guiding this study. The contributions to new knowledge, reflections on the methodology employed and implications of the study are discussed. The chapter closes by highlighting the limitations of the study and future research.

10.1 Introduction

The purpose of this study was to explore the link between the PSTs' eTSPCK and learner outcomes in the topic of organic chemistry. This study was grounded on two important conceptualizations in the PCK literature. First, it was based on the Shulman's (1987) argument that, "comprehended ideas must be transformed in some manner if they are to be taught" (p. 16). Second, it was grounded on the understanding that the value of 'pedagogically transformed content understanding' lies in its desired effect to enhancing learner achievement (Rollnick & Mavhunga, 2015). Despite these conceptualizations, investigating how PCK relates to learner outcomes is considered an unanswered question in the PCK literature (Akin & Uzuntiryaki-Kondakci, 2018) because "very little, if anything at all is known about the link between PCK and student learning" (Cross & Lepareur, 2015, p. 47). Where knowledge exists, the PCK-learner outcomes link shows contradictory findings leaving the issue highly unresolved as hinted in the rationale for conducting this study and review of literature (Chapter 2). Such an exploration is particularly important in the educational system of a developing country like South Africa with continued learners' poor academic performances in sciences and mathematics against international benchmarks (Taylor *et al.*, 2019) linked to the teachers' weak PCK (Rollnick & Mavhunga, 2015). Accordingly, this study sought to explore and establish understanding of the nature of the relationship between PCK and learner outcomes, measured as both the learner achievement and learner views. The exploration of PCK-learner outcomes link was guided by the Refined Consensus Model of PCK (Carlson & Daehler, 2019) and TSPCK construct (Mavhunga & Rollnick, 2013) in examining the theoretical framework of PCK. The RCM of PCK exemplifies complex knowledge and experiences in complex layers that shape teachers' practice and facilitate learner outcomes. The researchers' effort to develop RCM of PCK

responds to criticisms levelled at PCK research for its focus on exploring what a teacher knows, without relating it to what the teacher actually does and how it influences learner outcomes (Park & Suh, 2019). The criticism voices the same sentiment expressed by Lee Shulman in his review on PCK, that PCK should not only be viewed as a cognitive construct that exists in the teachers' heads, but as a dynamic construct which explains the complex processes teachers engaging in and apply during actual teaching (Shulman, 2015). On this note, RCM of PCK attempts to represent pictorially the multi-dimensions of PCK, its projected development in teachers and its influence on what the teacher does and the subsequent impact on learner outcomes. As explained in the Literature Review chapter (Chapter 2), the RCM recognizes TSPCK as one of the grain sizes of PCK, along with discipline -and concept-specific reflecting the different levels in which teachers' knowledge operates (Carlson & Daehler, 2019). The RCM of PCK further recognizes the different dimensions or teaching realms in which PCK is visible. Three distinct realms of PCK have been identified and named as: collective PCK (cPCK); personal PCK (pPCK); and enacted PCK (ePCK) with learner outcomes as a key downstream product. At the topic specific level, these three realms have been referred to as cTSPCK, pTSPCK and eTSPCK. These three realms of PCK were of interest in this study as they display the developmental trajectory through which the TSPCK-learner outcomes link could be explored. In this study, the PSTs went through an intervention based on cTSPCK, specific for the topic of organic chemistry; they drew and developed from the intervention their pTSPCK in personalized ways which they demonstrated in their planning (Chapter 5) as planned TSPCK and in actual teaching as eTSPCK (Chapter 6). The argument was that, to be able to sufficiently describe the nature of teachers' PCK in a given topic and its link to learner outcomes, following the teachers' cTSPCK, pTSPCK and eTSPCK represent holistically the distinct realms through which a specific grainsize of PCK, TSPCK in this case, progressively develops (Chan & Hume, 2019). Considering the significance of PCK as part of the teacher professional knowledge, "student outcomes are one way of determining the effectiveness of a teachers' instruction; therefore one way to assess the usefulness of a construct, such as PCK, is to determine if that construct predicts student learning outcomes" (Carlson & Daehler, 2019, p. 83). This chapter presents discussions and implications of the emerging findings from this study in a systematic order, starting with the need for establishing a credible baseline.

10.2 Establishing a credible baseline for the study: Developing PSTs' planned TSPCK by focusing on cTSPCK

Several studies have empirically proven the effectiveness of specific interventions in developing PSTs' planned TSPCK in core science topics such as chemical equilibrium (Mavhunga & Rollnick, 2013), electric circuits (Mavhunga *et al*., 2016), particulate nature of matter (Pitjeng-Mosabala & Rollnick, 2018; Mavhunga, 2016) and so on. These intervention based studies reported an improvement in the quality of participants' planned TSPCK following explicitly discussions which focused on TSPCK construct. The intervention procedures have been termed a signature intervention (Mavhunga & Rollnick, 2017) and hence, repeating such procedures to eventually realize an improvement in the participants' quality of TSPCK cannot be considered new knowledge. However, this understanding served as the needed credible baseline to build on in exploring the TSPCK-learner outcomes link by following the PSTs' TSPCK development through the cPCK-pPCK-ePCK trajectory and its ultimate influence on learner achievement. To date, the construct of TSPCK has not been used to such an extent of investigation. Meanwhile, the important argument raised by the interventions conducted using TSPCK construct was that, while TSPCK is not transferable from one topic to another, the explicit discussions of its knowledge components enhances the development of pedagogical transformation competence which can be applied in a new topic to generate TSPCK for the topic (Mavhunga, 2016; Rollnick & Mavhunga, 2015). Mavhunga (2016) described the pedagogical transformation competence as the understanding to interactively use content-specific knowledge components in pedagogically transforming the content knowledge of a given topic. Having this in mind, efforts were made in this study to first expose a group of PSTs to explicit discussions on the understanding of individual content-specific knowledge components and then, their interactive usage, a path way to developing PCK in a given topic (Park & Chen, 2012). Similar to the previous studies in this line of research, the same TSPCK intervention procedures were replicated in this study but in the topic of organic chemistry in order to first confirm the development of planned TSPCK with this specific cohort of PSTs (Chapter 5). While commenting on the issues relating to replicating previous studies, Schneider (2004) indicates that, "a major problem in educational research is that investigators find it difficult or are unable to replicate their work or that of their peers" (p. 1472). Whereas replicating studies contributes to the essence of the scientific method which can be repeated and verified by others (American Psychological Association, 2010), the lack of

replication of previous studies undermines "the community's ability to accumulate knowledge" (Schneider, 2004, p. 1473). By focusing on collective TSPCK (cTSPCK), this study was grounded on the understanding that PCK is topic specific (Gess-Newsome, 2015) and emphasizing its topic specificity is effective in assisting PSTs to learn about the complexity of teaching and learning process (Mavhunga, 2019; Aydin *et al*., 2015). The results of the intervention conducted in this study (Chapter 5) revealed two key findings. First, there was a significant conceptual improvement in the PSTs' quality of planned TSPCK in organic chemistry, the chemistry topic focused on during the intervention. Second, there was the evidence of successful application of the pedagogical transformation competence learnt by the PSTs in providing explanations of the same quality in their completed post-TSPCK tool and complementary Content Representations (CoRe). These are two different tools measuring the same construct. These key findings served as a credible baseline for this study in a few exciting ways.

First, it is important to highlight that, chemistry is traditionally known as a difficult subject to teach and learn at both the high school and higher institution levels making the situation of PSTs in this study of no exception (Upahi & Ramnarain, 2019; Treagust, Nieswandt, & Duit, 2000). Particularly, organic chemistry concepts are known to be highly demanding cognitively making its learning over-whelming for learners who only operates at the concrete stage of cognitive ability (O'Dwyer & Childs, 2017). The conceptual improvement observed in the participant PSTs in this study reflects good comprehension of organic chemistry from the perspective of thinking about teaching. In agreement with the results of previous studies (e.g. Mavhunga & Rollnick, 2013), the quality of participant PSTs' planned TSPCK in this study was found to improve from a lower category referred to as 'Limited TSPCK' to a higher category denoted by 'Developing TSPCK' in organic chemistry. There was a positive shift of two quality categories. The close qualitative analysis of the PSTs' written responses across the pre- and post-TSPCK tests indicated a visible depth in thought in the post-TSPCK test. The generated rank order of item difficulty by the Rasch Analysis Model (see Chapter 5, Table 5.3) is an indicator of the process of engaging with the content-specific knowledge components experienced at varying difficulty extents by the participant PSTs which goes beyond just regurgitating the precise discussions held during the intervention despite the fact that, there were explicit discussions during the intervention. The improvement portrays enabled pedagogical transformation

competence of drawing on multiple content-specific knowledge components at a developing level in formulating written explanations to teacher tasks, hence illustrating their improved quality of TSPCK for organic chemistry. It was directly linked to the explicit discussions these PSTs were exposed to during the intervention considering the fact that, their scores from post-TSPCK test were stronger than the weak scores in the pre-TSPCK test. This was also confirmed by the participant PSTs who provided reflections on what made a difference in their pedagogical reasoning prior to and following the intervention. For example, while Hope was commenting on her pre-and post-TSPCK test written responses during the stimulated recall interview, she highlighted how difficult it was for her to formulate a written good explanation to teacher tasks in the pre-TSPCK test due to lack of teaching experience. However, she attributed her improved explanations in the post-TSPCK test to the discussions of TSPCK components and their interactive use provided during the intervention. While the focus of the intervention was not on explicit discussions of the content of organic chemistry, the participant PSTs developed the understanding that, effective teachability of the topic organic chemistry has to be reasoned from the perspective of pedagogical transformation which positions learners at the centre of learning. This is knowledge that practicing teachers develop over years of interaction with learners and thus, it was encouraging to see PSTs developing such understanding following a few weeks of the intervention.

Second, it was interesting to observe a congruency between the quality of explanations provided by the PSTs in both the post-TSPCK test tool and their explanations on the CoRe tool**.** It is important to note that these two tools capture TSPCK from different methodological foundations. The CoRe as a tool captures TSPCK, holistically from an in-depth qualitative perspective where the participants freely demonstrates what they know about planning for teaching, while in the TSPCK tool, their demonstration is limited to the knowledge asked of them. This complementary quality of explanations was noticed in terms of the similarity in the successful application of pedagogical transformation competence that the PSTs learnt during the intervention drawing mostly on the interactive use of four out of five content-specific knowledge components. These were: learner prior knowledge, curricular saliency, representations and what is difficult to teach or understand. The first three knowledge components emerged as the easiest in the quantitative analysis of Item order of difficulty as revealed by the Rasch Analysis. While the observed improvement in the PSTs' quality of planned TSPCK following the intervention

was expected, it was essential to establish this expectation, as it is the base from further findings are interpreted. It therefore follows that the confirmation indicative of the trustworthiness of the baseline from which PSTs' TSPCK-learner outcomes link could be explored. Likewise, the acceptable agreement of a Cohen kappa value of 0.86 (see Appendix XXI) between the raters who scored the completed pre-and post-TSPCK tools was acceptable. Both the TSPCK tool and the CoRe gave the same quality of PSTs' planned TSPCK following the intervention and that validates the finding regarding the influence of the intervention.

On another note, the repeated findings from the signature intervention, provides additional evidence which supports the call for the nationalization of the explicit TSPCK intervention as the means to operationalize TSPCK in science teacher education (Mavhunga, 2017). The discussions below provide the emerging findings that are key contributions to new knowledge in the PCK literature in science education.

10.3 The empirical findings that contribute to new knowledge

The RCM of PCK was formulated from piecemeal studies that were on one realm and not the other or in one grain size and not the other. In addition, the link to learner outcomes is an informed extrapolated proposition which has not be explored empirically fully. This study contributes towards closing this paucity through three key findings which are: (i) the empirical confirmation of the theoretical proposition that undergirds the Refined Consensus Model of PCK (RCM) which describes PCK as a theoretical framework. This refers to an empirical demonstration of the cPCK-pPCK-ePCK continuum link to learner outcomes; (ii) the nature of the correlation between PSTs' eTSPCK and learner outcomes; and (iii) the exposure of the elements that are perceived to reflect the quality of the PSTs' TSPCK from the learners' perspective. These key findings have emerged from a focus on TSPCK explored across the three realms of PCK as a progressive continuum, with the same cohort of PSTs in the same topic of organic chemistry. The discussions on each of these key findings are provided below.

10.3.1 Empirical demonstration of the cPCK-pPCK-ePCK continuum link to learner outcomes

As highlighted in the RCM, the understanding of three distinct realms of PCK is necessary in developing and investigating the nature of teachers' PCK. This study provides insights into the relationship between cTSPCK, pTSPCK and eTSPCK linked to learner outcomes by investigating the development of the PSTs' PCK in organic chemistry, from an intervention into its demonstration in both the planning and actual classroom contexts. The discussions held with the participant PSTs focused on TSPCK construct and hence, cTSPCK representing, the understanding of individual content-specific knowledge components and then, their interactive usage in making content of organic chemistry understandable. It was found out that, there were congruencies between the discussions held with the PSTs during the intervention, the pedagogical transformation competence demonstrated by the PSTs following the intervention and in the actual classroom teaching. It would be recalled that, the pedagogical transformation competence is the understanding of interactive use of two or more content-specific knowledge components of TSPCK in making the content of a given topic understandable (Mavhunga, 2016). As analyzed in Chapter 5 and alluded to the section above, the participant PSTs' quality of planned TSPCK following the intervention was found in the category of Developing TSPCK according the planned TSPCK rubric used in scoring their written responses. In this category of TSPCK, the PSTs were able to: identify a possible learners' misconception and provide correct explanations to address the identified misconception; identify key concepts in a topic with appropriate emphasis to enhance learners' understanding; identify potentially difficult aspects by stating the particular gate keeping concepts which are problematic; explain concepts using more than one level of representations; and provide teaching strategies that draw on interactive use of two or more knowledge components. Furthermore, the in-depth qualitative analysis of PSTs' teachings presented in Chapter 6 revealed the emergence of eTSPCK profiles which were of a combination of simple, proficient and sophisticated TSPCK episodes albeit to varying extents (see Figure 6.2 and Figure 6.3). A careful examination of the overall emerging TSPCK episodes (see Chapter 6, Figure 6.29) revealed that, in the cases of the 4 participant PSTs, there were more proficient TSPCK episodes (n=60) than simple TSPCK episodes (n=17) and sophisticated TSPCK episodes (n=19). The demonstration of proficient TSPCK episodes, like the *Developing* category for planned TSPCK, implied the interactive use of three TSPCK knowledge

components (e.g. LP/CS/RP) or two knowledge components of TSPCK where one knowledge component repeated (e.g. LP/CS/CS) in explaining concepts. As shown in the Table 6.2 (Chapter 6), the dominating TSPCK components which principally informed the PSTs' quality of eTSPCK included: Learner Prior Knowledge (LP); Curricular saliency (CS) and Representations (RP). The overall emergence of Developing TSPCK and proficient TSPCK episodes as the captured quality of PSTs' planned TSPCK and eTSPCK respectively suggests a noticeable similarity in the quality of personal TSPCK (pTSPCK) demonstrated by the PSTs in both the context of planning and actual classroom teaching of organic chemistry. Moreover, as reported in Chapter 8 (see Table 8.5 and Table 8.10), the PSTs' eTSPCK (particularly proficient and sophisticated TSPCK episodes) was observed to be positively associated with higher post-test learner performances and commonly involved in the TSPCK episodes were the TSPCK components LP, CS and RP. This showed the similarity between the cTSPCK that the PSTs were exposed to in the context of learning to teach (see Chapter 4), the planned TSPCK they demonstrated following the intervention (see Chapter 5), the enacted TSPCK they manifested in the actual classroom teaching (see Chapter 6) and its relationship to the post-test learner performances following the teaching (see Chapter 8). The pedagogical transformation competence was observed to be similar across these three realms of PCK (cTSPCK-pTSPCK-eTSPCK) at a topic specific level (organic chemistry). A practical example of the PST 'Ruth' is further discussed below.

Ruth's cTSPCK-pTSPCK-eTSPCK continuum link to learner outcomes

cTSPCK (collective TSPCK): It would be recalled that, the explicit discussions held with the PSTs during the intervention emphasized individual understanding of TSPCK components and most importantly, the interaction among these knowledge components in pedagogically transforming the content knowledge of organic chemistry as fully discussed in Chapter 4. For example, there were discussions with the PSTs on the *Conceptual teaching strategies* (CT) as one important aspect of cTSPCK (see Chapter 4, section 4.3.6). These encouraged transforming content knowledge of organic chemistry through investigating learners' existing misconceptions and addressing the misconceptions by emphasizing what is important for learners using representations in order to prevent of the occurrence such existing misconceptions in the course of teaching concepts that are considered difficult and confusing. The discussions also introduced

the PSTs to the variation theory, a science teaching strategy of discussing two concepts side by side in order to make learners understand the difference or similarity between the concepts (Bussey *et al*., 2013).

pTSPCK (planned TSPCK component): As analyzed in Chapter 5, for example, the question item 1 in the administered TSPCK tool required the participant PSTs to provide explanations on a learner's choice of alcohols from a list of organic and inorganic compounds that contain oxygen and hydrogen atoms (see Chapter 5, section 5.3.2i). The important PSTs' ability being probed by this question item was whether they could recognize the misconception and then provide explanations which would move the learner to the correct conceptual knowledge. A typical example of the PSTs' written responses which showed an improvement from Limited TSPCK in the pre-test to Developing TSPCK in the post-test was that of Ruth (see Figure 5.4, in Chapter 5). The Ruth's written explanation in the pre-TSPCK test showed her intention to explain the hydroxyl group bonded to a carbon atom as a way of classifying alcohols. While mentioning hydroxyl group describes the knowledge of a functional group as an important concept (**CS**), the explanation was inadequate due to its in-explicitness in specifically highlighting and addressing the learner's misconception. However, in the post-TSPCK test, she highlighted her intention to begin by naming of all functional groups consisting of oxygen and hydrogen atoms because the particular learner in question could not distinguish alcohols from other compounds containing these atoms. The IUAPC naming of organic compounds was one of the key concepts discussed with the PSTs during the intervention focusing on curricular saliency as one important element of cTSPCK (see Chapter 4, section 4.3.3). The statement in her post-TSPCK written work in this regard describes her understanding of IUPAC naming system as a key concept representing an element of curricular saliency (**CS**). She further added that "*…because from the given problem, the learner cannot distinguish alcohols from other compounds containing oxygen and hydrogen (e.g. NaOH) but which are not alcohols…*" (See Chapter 5, Figure 5.4). This statement also reflects her understanding of the specific learner's misconception to associate all compounds with O and H atoms in the formula as indicators of the alcohol group (**LP**). Following this was her plan to work with the learners in "*distinguishing the key characteristic of each functional group*" and by drawing "…*structural formula of these functional groups using different homologous series*" (See Chapter 5, Figure 5.4). In addition to portraying the knowledge of curricular saliency by referring to distinguishing key characteristic

of each functional group, she also indicated the intermitted use of structures in explaining concepts similar to the discussions had during the intervention (See Chapter 4, section 4.3.5), reflecting her understanding of symbolic representations (**RP**). She ended her explanation with a statement given as "…*from there, I expect learners to select 1 and 4 as alcohols, state the functional group of 2 as carboxylic acid, 3 as aldehyde, 7 as an inorganic compound, sodium hydroxide…*" (See Chapter 5, Figure 5.4). This statement outlined her intention to assess learners' understanding of her explanations by asking them to select alcohols from the mix of inorganic and organic compounds with the expectation that, they would be able to able to identify alcohols based on the knowledge of hydroxyl functional group. Her explanations in the post-TSPCK test compared to the pre-TSPCK test described her developed thoughts about addressing an identified learner's misconception progressing from the individual demonstration of only one TSPCK component 'curricular saliency' (**CS**) in the pre-test to the interactive use of three TSPCK components curricular saliency, learner prior knowledge and representations (**CS/LP/RP)** in the post-test. This improvement seemed to reflect the impact of the emphasis put on the interactive use of TSPCK components as discussed during the intervention and alluded to in the paragraph above focusing on cTSPCK. Furthermore, the understanding of interactive use of TSPCK components seen through the Ruth's post-TSPCK test written response was further confirmed as she commented on her pedagogical reasoning during the post-intervention interview (see Chapter 5, section 5.3.2 i). She indicated as follows "*I could say I have now understood better how these things of TSPCK work yeah….. my initial thought was it's fine to just point out to the learners that the hydroxyl group should be attached to a carbon atom and end it there, but having learned about TSPCK, by the time I wrote the second test, I understood how such an explanation make learners understand important aspects like IUPAC naming of compounds……*" In her response, she linked her improved written explanations in the post-TSPCK test compared to the pre-TSPCK test to the understanding of TSPCK construct learnt during the intervention. The statements revealed her understanding of what aspects (e.g. IUPAC naming and identifying functional groups) are important to explain to learners with the use of symbolic representations. These are elements of curricular saliency and representations. She also pointed out the learners' inability to distinguish the hydroxide ion in inorganic compounds from the hydroxyl group in organic compounds thereby demonstrating understanding of a possible learners' misconception, an element of learner prior knowledge (LP). She indicated the

place of having good content knowledge in correctly explaining scientific concepts. These knowledge components shaped the quality of her personal TSPCK (pTSPCK) demonstrated as planned TSPCK while learning to teach organic chemistry.

pTSPCK (enacted TSPCK component)*:* As presented in Chapter 6, Ruth's actual teaching focused on functional groups and IUPAC nomenclature of organic compounds following the intervention. During the pre-lesson interview conducted with her, she talked about her envisaged learners' misconception relating to the common assumption that, all compounds of carbon are organic compounds. As discussed during the intervention and similar to her post-TSPCK test written work, during the pre-lesson interview, she again referred to learners' confusion relating to the symbolic representation of hydroxide ion and hydroxyl group in distinguishing between alcohols and inorganic compounds like sodium hydroxide. In addressing the misconception, she indicated the use of questioning in first eliciting learner prior knowledge and then, the use of structural representations of organic molecules in explaining concepts. Likewise, she repeated the same issue in her reasoning in lesson planning, stating the learners' misconception relating to the assumption that, by representation, hydroxyl group (OH) could be taken for hydroxide ions (OH^-) in organic compounds which makes it difficult to distinguish an organic compound like methanol from an inorganic compound like sodium hydroxide. Then, during her actual classroom teaching, she discussed the alcohol functional group by first drawing the learners' attention to the symbolic formula for alcohol functional group (R-OH) written on the chalkboard. Through questioning and by using the molecular formula, she confirmed the learners' ability to correctly identify alkyl and hydroxyl group (see Chapter 6, Table 6.1, 16-18 minutes) as a strategy they were encouraged to incorporate in investigating and establishing learner prior knowledge during the intervention focusing on cTSPCK (see Chapter 4, section 4.3.2). Then, in her explanation of what constitutes alcohol functional group, she called the learners' attention to the possible misconception that might emanate from taking OH (hydroxyl group) for OH^- (hydroxide ion) in organic molecules. Her explanations were similar to the discussions held during the intervention on the related aspect of organic chemistry and it was also similar to her post-TSPCK test written response. The statement revealed her understanding of the interactive use of a symbolic representation (**RP**) and learner prior knowledge (**LP**). Then, with reference made to the symbolic representation on the chalk board, she placed the organic molecule containing OH (i.e. ethanol) side-by-side with an inorganic molecule containing OH^- (i.e. sodium

hydroxide) in an attempt to make the learners understand the similarity and difference between them (see Chapter 6, Table 6.1, 16-18 minutes). This described her knowledge of a conceptual teaching strategy (**CT**), an aspect of variation theory explicitly discussed during the intervention (see Chapter 4, section 4.3.6). She further explained the reactions which alcohols undergo as a result of the hydroxyl functional group which distinguishes them from other organic compounds. This is an element of curricular saliency (**CS**) and it reflects her knowledge of organic reactions, one of the Big Ideas discussed during the intervention (see Chapter 4, section 4.3.3). Subsequently, emerging from her teaching segment on alcohol functional group was a sophisticated TSPCK episode (**RP/LP-CT/CS**) describing her interactive use of TSPCK components representation, learner prior knowledge, conceptual teaching strategy and curricular saliency. Noticeably, the interactive use of content-specific knowledge components observed in her actual teaching suggests a reflection of the emphasis placed on the interactions among knowledge components of TSPCK in pedagogically transforming the content knowledge of organic chemistry during the intervention as alluded to in the paragraph for cTSPCK component above. Moreover, the constituting content-specific knowledge components which informed her emerging TSPCK episode in the actual teaching (eTSPCK) were similar to the knowledge components that constituted her TSPCK episode in post-TSPCK episode (planned TSPCK) as illustrated in the paragraph above. Furthermore, there was a teaching segment which seemed to have responded to the Ruth's expectation stated in the post-TSPCK test as highlighted in the paragraph on pTSPCK (planned TSPCK component) above. Specifically after Ruth had ended teaching the learners the functional groups of organic molecules (see Chapter 6, Table 6.1, 18-33minutes), the learners' ability to correctly answer the questions posed showed evidence that they understood her explanations. This understanding demonstrated by Ruth's learners during the actual teaching appeared to have positively responded to the Ruth's expectation about the outcomes of her explanations as part of what described improvement in the quality of her planned TSPCK following the intervention. These similar noticeable observations appeared to describe the continuum nature of **cTSPCK-pTSPCK-eTSPCK** focusing on organic chemistry.

Link to learner outcomes: The analysis of learners' pre-and post-achievement tests revealed a significant improvement in learner performances following the PSTs' teachings (See Chapter 7, Table 7.1). Likewise, the analysis of correlation revealed an existence of a positive significant relationship only between the PSTs' eTSPCK and post-test learner performances (See Chapter 8,

Figure 8.9 and Figure 8.10). The Table 8.10 in Chapter 8 showed that, on the achievement test item 4 which required the learners to identify the functional group on the given molecule of butanol, the Ruth's learners' item performance by persons improved from 8 (learners) in the pre-test to 28 (learners) in the post-test. This learners' item performance was observed to be associated with the Ruth's teaching segment from which a sophisticated TSPCK episode emerged (RP/LP-CT/CS) as discussed in the eTSPCK paragraph above and analyzed in Chapter 8 (see Table 8.10). More cPCK-pPCK-ePCK link to learner performances has been highlighted for Ruth and for the other PSTs in Chapter 8 (See Table 8.5 and Table 8.10).

The illustrations provided in the paragraphs above discussed the empirical demonstration of the cPCK-pPCK-ePCK continuum link to learner outcomes in the topic of organic chemistry. Based on the discussions, the finding from this study expands the existing understanding in the literature on the interactions among TSPCK components which are most considered crucial to the quality and development of PCK in a given topic than the strength of an individual knowledge components (Nilsson & Karlsson, 2019; Park & Chen, 2012). While there is the awareness that, the understanding about teachers' PCK progresses from preparation through actual teaching seems to be essential for creating effective learning occasions (Adadan & Oner, 2014), this study has been able to provide empirical evidence of the link between the knowledge demonstrated at each stage. This evidence supports the understanding in the literature that, focusing on what teachers know is important in teacher education programmes but that knowledge on its own is not sufficient to ensure capability for development in PSTs without simultaneously paying attention to what the PSTs eventually do in the classroom (Ball & Forzani, 2009; Mathewson & Reid, 2017). PCK and in association, TSPCK is known to be tacit knowledge that teachers gain in the actual classroom teaching and thus difficult to pass on to others (Rollnick & Mavhunga, 2015; Kind, 2009). Most importantly, PCK is known to be topic specific (Gess-Newsome, 2015). One common issue raised among science PCK researchers while deliberating on the teacher professional knowledge was whether learned PCK (planned PCK) is transferable to actual classroom teaching (Gess-Newsome, 2015; Park & Oliver, 2008). The idea of talking about the transferability of PCK, the domain of teacher knowledge known to be topic specific, sounds contradictory (Rollnick & Mavhunga, 2015). However, this study has empirically provided the understanding that, the pedagogical transformation competence learnt to generate planned TSPCK through exposure to cTSPCK in planning context of a given topic is

continuously transferable to the classroom teaching of the topic to generate eTSPCK. The finding in this study is consistent with previous studies which reported a similarity between PCK demonstrated by PSTs in planning and that manifested in the actual classroom teaching (Guzey & Roehrig, 2009; Rollnick & Mavhunga, 2014). Unlike the study conducted by Mazibe et al. (2018) in which teachers' planned PCK (reported PCK) was not necessarily a reflection of the teachers' ePCK, this study has further provided empirical evidence of seeing the same quality PSTs' planned TSPCK demonstrated as in eTSPCK by the same PSTs in the actual classroom teaching of a given topic. Moreover, beyond the congruent translations through the cPCK-pPCK-ePCK continuum, the findings further confirmed an extended link to learner outcomes in the same topic and with the same participants. Having different contexts and data sources such as written explanations, post-intervention interviews, classroom teachings, lesson plans, pre and post-lesson interviews to collectively describe **cPCK-pPCK-ePCK link to learner outcomes** added trustworthiness to this finding. Likewise, the acceptable agreement of Cohen kappa inter-rater values of 0.86 (See Appendix XXI) and 0.92 (See Appendix XXVI) between the raters who scored the completed pre-and post-TSPCK tools and identified TSPCK episodes from teaching segments respectively added to the credibility of the finding. This finding is considered original as most of the known foundational studies have explored PCK in either a single realm (e.g. Park & Chen, 2012 in a classroom context) or at most across two of the PCK realms, for example, Mavhunga and Rollnick (2013) across the cPCK-pPCK; and the study by Alonzo et al. (2019) between ePCK and pPCK and vice versa. The finding is considered an important and a new contribution to the PCK literature, particularly for providing the needed empirical evidence that confirms the theoretical propositions which informed the RCM of PCK, thereby validating it as a useful conceptual framework to explore the progressive development nature of teachers' PCK. The finding is also a response to the main research question guiding this study, see discussions later below.

10.3.2 The nature of correlation between the PSTs' eTSPCK and learner achievement

(i) Reflections on the learner achievement

One main purpose of this study was to explore the TSPCK-learner outcomes link by investigating whether there exists or not a relationship between the PSTs' eTSPCK and learner

performances in organic chemistry. For this reason, a pre-and post-achievement tests were first conducted with the respective participant learners prior to and following the PSTs' teachings as reported in Chapter 7. Across the pre-and post-test scores, the participant learners significantly improved from an overall average performance of 15.6% in the pre-test to an overall average performance of 62.2% in the post-test following the lessons delivered by the participant PSTs (See Figure 7.17). The analyses revealed that, all the participant learners improved significantly as a collective class in their conceptual performances following the PSTs' teaching. In this study, the performance of 60% in a subject (chemistry) was considered a minimum level that a learner has to achieve in order to be considered knowledgeable enough in that subject. The performance of 60% is also regarded as the minimum qualifying mark for entry into several Higher Education institutions in South Africa to study Bachelor of Science degree in Chemistry. It was observed that, except in the case of Hope's learners, all the participant learners taught by Ruth, Rose and Mark reached the desirable 60% achievement mark in the post-test in topic of the intervention (organic chemistry). It would be recalled that, while Ruth, Rose and Mark taught Grade 12 physical science learners, Hope taught Grade 11 physical science learners. Organic chemistry is only taught in Grade 12 according to the South African physical science curriculum as alluded to in Chapter 3. Meanwhile, the high school record showed that, the participant Grade 12 learners in this study had covered immediate concepts such as chemical bonding, intermolecular forces and chemistry of carbon as an element which made them cognitively suitable to be taught organic chemistry as at the time this study was conducted. Nevertheless, the post-test Rasch person measures showed that despite Hope's learners being in Grade 11, their performance gain of 3.06 was similar to performance gain of 3.92 and 3.31 obtained by Ruth's and Rose's learners in Grade 12 respectively but lower than Mark's learner performance of 1.99 who were equally in Grade 12 (See Chapter 7, Figure 7.18). Thus, the post-test performances of Hope's learners below the acceptable mark of 60% brings to view the idea of cumulative learning in developing knowledge and skills. For learner to adequately learn newly introduced concepts, according to cumulative learning theory, they must develop the ability to link such concepts to the previously acquired knowledge and the concepts must be returned to some other time with emphasis and then, adding-on more advanced elements (Maton, 2009; Muklis *et al*., 2018). While the participant Ruth's, Rose's and Mark's learners had the privilege of having the new concepts of functional groups and other organic chemistry concepts covered by the PSTs

built on their prior knowledge of hydrocarbons, Hope's learners were introduced to these same concepts of organic chemistry for the first time. Overall, the general improvement in the participant learner performances in the cases of the 4 PSTs is considered good news because the post-test was written immediately on completion of the PSTs' teachings. This seems to imply that, the participant learners learnt the concepts of organic chemistry presented to them by the PSTs in line with the South African Physical science curriculum. Unlike the related study by Liepertz and Borowski (2019) where the general learners' learning gains were low with no significant difference, the learners' significant improvement observed in this study was consistent with some other previous studies in sciences (e.g. Gess-Newsome *et al*., 2019; Lange *et al*., 2011; Sadler *et al*., 2013) and mathematics (e.g. Callingham *et al*., 2016; Luna & Aclan, 2015). Furthermore, it is important to highlight that the learner performances following the PSTs' teachings could be considered inclusive of all the factors that were at play in the lessons. These included the possible influence of PSTs' beliefs of their roles as science teachers; their own understanding of content knowledge of the topic (CK); their pedagogical knowledge (PK) and also their topic specific pedagogical content knowledge (TSPCK). However, since this study focussed succintly on the influence of the PSTs' personal TSPCK in enactment, it was thus important to minimize the effect of the other factors and try to filter-out selectively that of their eTSPCK. This process is discussed in the next section below.

(ii) Reflections on the methodological followed in calculating correlation between PSTs' eTSPCK and learner achievement

The methodological process followed to establish the TSPCK-learner outcomes link in this study examined the correlation between the PSTs' TSPCK episodes versus learner performances and (See Chapter 8). As highlighted in the literature review chapter (Chapter 2), this study acknowledges the complexity of teaching and learning mediated by myriad of factors and hence, the difficulty in accurately linking one particular factor (e.g. teachers' PCK) to learner outcomes. The findings in this study regarding the TSPCK-learner outcomes link are cautiously interpreted with the recognition that, the learner achievement observed in Chapter 7 is directly influenced by various factors associated with teaching and learning process including the PSTs' eTSPCK. So, an attempt made to sift out the effect of PSTs' eTSPCK and minimize the effects of other factors was to analyse only for the eTSPCK episodes as defined above in isolation to other types of

teacher knowledge and classroom factors. Furthermore, all the test items which were not covered by the PSTs in their teachings were excluded from the correlation analysis presented in Chapter 8. While the PSTs had the awareness that, there was going to be pre-and post achievment test conducted with learners, the content of the test was concealed from them. To some extents, taking such step assisted in preventing them from focusing on the test at the expense of the learners' conceptual understanding. So, removing all test items not covered by the PSTs represented one level of refinement of data which added credibility to the emerging findings from the correlation analysis. These levels of minimizing the noise of other factors in the classroom assisted in ensuring that, TSPCK episodes could be singly worked with as one significant factor in the course of examining how to improve learner achievement.

The above methodological process has uniquely provided an opportunity, in addition to establishing the correlation, to further develop new insights into the nature of eTSPCK and the explored correlation with learner outcomes. The magic in this method lied in capturing verbatim and qualitatively describing each of the identified TSPCK episodes observed in classroom enactment. It was important to note that, those lesson segments displaying evidence of TSPCK episodes according to our operational definition (Chapter 3, secton 3.6.2) were distinguishable in the recorded lesson, and could be identified from other activities in the lesson with reliability (See Appendix XXVI). So, the methodological process inherently contributed towards filtering other factors that may have been at play in the lessons. Armed with a set of identified TSPCK episodes, an observation was further made. The correlation analysis focused on the PSTs' overall TSPCK episodes versus the learner performances in the pre-and post-achievement tests. The overall TSPCK episodes consisted of clusters of different categories of TSPCK episodes which collaboratively built up towards making the content understandable to learners. This observations has been made due to the choice of the in-depth qualitative method used in this study in preparing for the calculation of the correlation in question for establishing TSPCK-learner outcomes link. This supports the understanding that, the TSPCK episodes, emerging from teaching segments, do not occur in isolation but they are clustered in such a way that, they jointly work towards pedagogically transforming the content knowledge of a given topic (Mavhunga, 2018). Hence, the consideration given to the overall TSPCK episodes emerging from the PSTs' teaching in the correlation analysis assisted in acknowledging the overall efforts made by the PSTs during teaching. Furthermore, the statistical correlation for establishing a

relationship between two variables (e.g. eTSPCK versus learner performances) is conventionally defined for paired observations, but not for unpaired observations consisting of two variables with different sizes (Greasley, 2007). However, there is the understanding that, in the cases of unpaired observations (variables), samples could be randomly selected strategically in order to satisfy the underlying principle of pairing variables in a correlation analysis (Lorenz *et al*., 2018; McMillan & Schumacher, 2014). Therefore, the correlation analyses focusing on the PSTs' TSPCK episodes versus learner performances were done in two batches so as to satisfy the underlying principle of pairing these two set of variables. In order to avoid bias involved in such random sampling as Lorenz et al. (2018) cautioned, it was ensured that, all the data in the first batch, which were not included in the strategic random selection done and used for the first correlation analysis, were considered part of the second batch for a further correlation analysis. Likewise, two other TSPCK researchers joined me in this entire correlation analysis including the identification of TSPCK episodes, matching of TSPCK episodes to the corresponding test items in the learners' achievement tests and strategic random selection of TSPCK episodes and learners' conceptual performances for correlation analysis. We repeated the same procedures until we had thoroughly re-examined the in-depth qualitative analysis versus the test items and then, we got the acceptable agreement of a Cohen kappa value of 0.96 (see Appendix XLII) which added to the credibility of the findings from the correlation analysis done. Having taken the steps discusssed above in an attempt to singly work with TSPCK and then minimise the effects of other factors, the results of the correlation analysis are discussed in the next section below.

(iii) Reflections on the results of correlation analysis between PSTs' eTSPCK and learner performances

The overall correlation analyzes revealed two key findings revolving around the direction and strength of correlation coefficients calculated. First, when the 4 PSTs' overall TSPCK episodes were analyzed with pre-test learner overall performances for correlation, the correlation coefficient was found to be $r = -0.178$ ($p = 0.097$) which was insignificant as its p value was very much higher than the significant level, $\alpha = 0.05$ (See Chapter 8, Figure 8.9). This implies the existence of a negative negligible and statistically insignificant correlation between PSTs' overall TSPCK episodes and learner overall performances prior the PSTs' teaching. In other

words, while there appeared to be an inverse relationship between PSTs' eTSPCK and pre-test learner performances, the relationship is negligible. This was expected because the participant learners were taught organic chemistry concepts for the first time in this study. However, the correlation coefficients for the analysis of PSTs' overall TSPCK episodes versus overall post-test learner performances were $r = 0.765$ ($p = 0.001$) and 0.761 ($p = 0.005$) at a significant level $\alpha = 0.05$ (See Chapter 8, Figure 8.9). This suggests the existence of a positive high and statistically significant correlation. This finding practically implies that, there was a direct relationship between PSTs' eTSPCK and post-test learner achievement such that, an increase in PSTs' eTSPCK was strongly connected to an increase in learner performances in organic chemistry following the PSTs' teachings. Second, it was discovered that, the positive correlation between the PSTs' eTSPCK and post-test learner performances increases in positive strength with high quantity of proficient and sophisticated TSPCK episodes compared to simple TSPCK episodes. For example, there was a most high positive significant correlation between eTSPCK and post-test learner performances in the cases of Ruth and Rose who demonstrated most high quantity of proficient and sophisticated TSPCK episodes compared to simple TSPCK episodes in their teachings (See Chapter 8, Figure 8.11 and Figure 8.12). Accordingly, there was a moderate positive significant correlation between eTSPCK and post-test learner performances in the cases of Hope and Mark who demonstrated most high quantity of simple and proficient TSPCK episodes compared to sophisticated TSPCK episodes in their teachings (See Chapter 8, Figure 8.11 and Figure 8.12). These two examples (i.e. high correlation versus moderate correlation) reflect the pattern of the gradient correlation in cognisance of the respective different quality-kinds of TSPCK episodes. Based on the eTSPCK rubric (Miheso, 2018) used in categorisng the PSTs' TSPCK episodes, a combination of higher quantity of proficient and sophisticated TSPCK episodes describes a more developed TSPCK than a combination of higher simple and proficient TSPCK episodes. Thus, the result of this correation analysis suggests that, more developed TSPCK was strongly related to higher post-test learner achievement following the PSTs' teachings in organic chemistry.

In summary, the calculated correlation coefficients displayed significant correlation between the PSTs' eTSPCK and post-test learner outcomes, where the strength of correlation increased with increasing quantity of high quality TSPCK episodes (proficient and sophisticated TSPCK episodes rather than simple category of TSPCK episodes). The quantitative examination

revealed the strength and direction between the PSTs' eTSPCK and learner performances. By the magnitude of correlation, the association between PSTs' eTSPCK and learner performances was specifically found to be negligible in the pre-test, but moderate and high in the post-test. By the direction of correlation, the association between the PSTs' eTSPCK and learner performances was found to be negative (inversely related) in the pre-test but positive (directly related) in the post-test. In other words, an increase in the quality of PSTs' eTSPCK is directly associated with an increase in the post-test learner performances. Having the overall TSPCK episodes in the cases of the 4 PSTs directly and strongly related to the increase in the post-test learner performances contributes to the reliability of the correlation analysis thereby suggesting TSPCK as one important factor that could be referred to when examining learner performances.

The link between teachers' PCK and learner outcomes has been reported in the literature with mixed findings, leaving the issue highly unresolved as hinted in the rationale for conducting this study. The positive finding in this study is consistent with the results of previous studies reported in the topic of states of matter (Lange *et al*., 2011), optics (Alonzo, et al., 2012), neurobiology (Fortsch et al., 2016) and in the subject of physical science (Sadler *et al*., 2013) where the observed teachers' broad PCK was positively correlated to learner performances. Nevertheless, the findings in this study are inconsistent with the findings of some other studies (e.g. Liepertz & Borowski, 2019; Gess-Newsome *et al*., 2019). Gess-Newsome et al. (2019) found lack of correlation between the observed teachers' broad PCK and learner achievement contrary to their qualitative analysis which revealed a strong positive association between learners' learning and teachers' perceptions about changes in their teaching practice. Likewise, Liepertz and Borowski (2019) stated the assumption that, teachers who possess higher professional knowledge (CK, PK and PCK) better apply their knowledge in the classroom teaching and thus, provide a worthwhile learning environment which initiates learners' understanding. However, the analysis of their data revealed a negative correlation between the observed teachers' PCK and learner achievement. These inconsistent findings have naturally sent a mixed signal to the PCK community. Several reasons could be assigned to the contradiction in the literature. It may be as a result of different operational definition of PCK and methodological strategies employed in examining the correlation. The link between teachers' PCK and learner outcomes has been reported in the literature with mixed findings, leaving the issue highly unresolved as hinted in the rationale for conducting this study.

Difference in the conceptualization

While Liepertz and Borowski's (2019) conceptualization of PCK revolves around 'special amalgam of content and pedagogy' (Shulman, 1987, p. 8) for teaching physics, Gess-Newsome et al. (2019) assumed that within PCK, there exists content knowledge, pedagogical knowledge and contextual knowledge for teaching photosynthesis and cell transport mechanisms in Biology. In hindsight, with the RCM in place, we now know that these studies used a different grainsize of PCK, a discipline conceptualization while working with topics. In this study, PCK was conceptualized and operationalized as being topic specific (Gess-Newsome, 2015), thus referring to the grainsize of topic specific PCK and accordingly using only content specific components rather than reference to components that are generic and subject specific. Furthermore, the evidence of PCK has been consistently being associated with visible interactive use of these content-specific knowledge components to pedagogically transform the content knowledge in all the contexts (planning and in classroom enactment) (Mavhunga, 2018).

Difference in the method of measurement

Liepertz and Borowski's (2019) used paper-and-pencil tests to measure both the professional knowledge (i.e. CK, PCK and PK) of teachers and the learners' achievement**.** In terms of the RCM, we now know that the PCK measured could have been in the realm of planning to teach. In the case of Gess-Newsome et al. (2019), PCK was measured through written reflections, interviews and observations of classroom practice using a PCK rubric and learner achievement test drawn from a large bank of question items. However, in this study, in an effort of minimizing the effect of all other factors, careful filtering of only the PSTs' TSPCK episodes that had a link with test items was followed using the in-depth qualitative method of identifying (Park & Chen, 2012). These different operational definitions of PCK and methods employed could have resulted in the different results.

The value of the findings in this study

In this study, there were insights provided about the nature of TSPCK-learner outcomes link investigated. The Figure 10.1 below summarizes the key aspects of this study relating to the emerging findings and based on which the overall conclusion has been drawn.

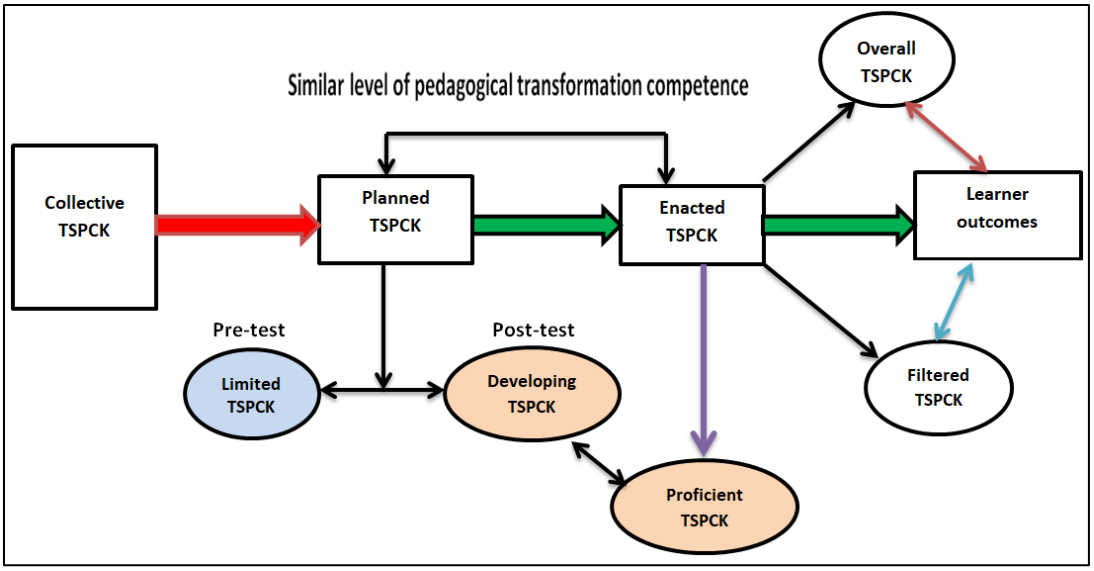


Figure 10.1: Key aspects of this study

As shown in the Figure 10.1, this study was conducted in the cTSPCK-pTSPCK-eTSPCK trajectory as discussed in the paragraphs above. The fixed criterion used in assessing the quality of PSTs' TSPCK at each stage was the extent of understanding of interactive use of content-specific knowledge components on which cTSPCK, discussed explicitly during the intervention, focused. This understanding has also been described as the pedagogical transformation competence which was examined through planning, actual classroom teaching and in relation to learner outcomes. With the similarity observed between cTSPCK, the quality of PSTs' planned TSPCK and their overall quality of eTSPCK, the cTSPCK-pTSPCK-eTSPCK link was established focusing on the extent of interactive use of TSPCK components as the fixed criterion. Building on the trajectory followed and established, the result of correlation analysis focusing on the PSTs' overall TSPCK episodes reflected a positive association with the post-test learner achievement following the teaching. It is understood in this study that, correlations do not imply causal relationships (McMillan & Schumacher, 2014). Nevertheless, the value of this study is tightly connected to the cTSPCK-pTSPCK-eTSPCK trajectory followed with a fixed criterion used in describing the quality of PSTs' TSPCK at each stage. Supporting this value is also the effort made to refine data by sifting out the effect of TSPCK and minimizing other factors that influence classroom teaching as discussed in the above paragraphs. Thus, the correlation result in this study suggests a cause and effect link which may not be direct however; there is high probability that, TSPCK represented a possible important influence on the observed post-test learner achievement following the PSTs' teachings. The observed positive correlation between

PSTs' eTSPCK and post-test learner performances practically suggests that, efforts put into improving the PSTs' quality of TSPCK are promising in ultimately improving learner achievement in a core science topic. This finding in a way supports Richardson et al.'s (2018) opinion that highly developed PCK would produce superior instructional experiences for learners and hence, increase learning. The higher categories of TSPCK episodes (i.e. a combination of proficient and sophisticated TSPCK episodes) in this study demonstrated deeper content-specific knowledge component interactions to provide rich teacher explanations that had meaning for learners. These episodes displayed a close connection to a deeper extent of interactions with learners in an attempt to make them understand the concepts. The deeper extent of teacher-learner interactions observed in this study was manifested in the PSTs' engagement with learners in a questioning and dialoguing process in order to establish the learner prior knowledge before providing the expected explanations and also, having the learners commenting on the explanations provided with evidence of instant learning. As presented in Chapter 6, section 6.4 (Finding 3), Ruth and Rose had 2 and 6 instances of such deeper teacher-learner interactions respectively accompanied the learners' responses that revealed evidence of instant understanding of the explanations provided by the PSTs whereas Hope and Mark had none of such instances. This finding has provided empirical evidence to support the argument that "teacher-student interactions are fundamental to learning outcomes" (Tan *et al*., 2019, p. 169) which supports previous research that reported that, such interactions contribute to enhancing learner outcomes (Ajjawi & Boud, 2017; Boud & Molloy, 2013). Through such deep interactions, Ruth and Rose were able to identify learners' misconceptions and addressed them accordingly. Likewise, this supports the understanding in the literature that, pedagogical reasoning skills which enable teachers to explicate particular concepts and highlight misconceptions is reflective of teaching and learning of good quality (Richardson *et al*., 2018). While there have been arguments and confusion in the literature that, how PCK relates to learners' understanding remains an unanswered question in PCK studies (Akin & Uzuntiryaki-Kondakci, 2018; Abell, 2008), this study has empirically provided evidence of a positive relationship between overall eTSPCK and post-learner performances in the topic of organic chemistry as analyzed in Chapter 8. Thus, the finding in this study brings to the contested table a solid and original declaration about the nature of the correlation between PSTs' TSPCK and learner outcomes. It is the result from a quantitatively calculated positive link between PSTs' TSPCK and learner performances with an

extended insight into the interactions among content-specific knowledge components of TSPCK in relation to learners' written responses arrived at through qualitative means. The finding is considered an important and a new contribution to the PCK literature, particularly for providing the needed empirical evidence that confirms theoretical propositions informing the RCM of PCK and hence, validating it as a useful conceptual model describing the theoretical framework of PCK for exploring the link between teachers' eTSPCK and learner outcomes within a specific topic.

10.3.3 The exposure of the elements perceived to reflect the quality of the PSTs' TSPCK from the learners' perspective.

As presented in Chapter 9, there were insights provided by the learners' views about aspects of the PSTs' knowledge and instructional practices which promoted or hindered their conceptual understanding of organic chemistry concepts. It was found out that, in the cases of the four participant PSTs, majority of the learners indicated that, the use of structures (or diagrams) intermitted with explanations which emphasized important concepts assisted them in understanding organic chemistry concepts. These two aspects described the PSTs' understanding of the content-specific knowledge components of curricular saliency and symbolic representations. This aspect of learners' views served as additional evidence to substantiate the PSTs' interactive use of curricular saliency, representations and learner prior knowledge as the dominating content specific knowledge components which principally shaped their eTSPCK in the classroom teaching of organic chemistry as analyzed in Chapter 6. Equally, these were the dominating knowledge components which consitituted the PSTs' eTSPCK that positively correlated with an improvement in the learner performances as analyzed in Chapter 8.

Furthermore, the analysis of learners' views revealed that, in the cases of Ruth and Rose who demonstrated most high quantity of proficient and sophisticated_TSPCK episodes compared to simple TSPCK episodes and whose eTSPCK correlation was highly correlated with post-test learner performances, the participant learners believed that, getting take home exercises and self-study would deepen their conceptual understandings. However, in the cases of Hope and Mark who demonstrated most high simple and proficient TSPCK episodes compared to sophisticated TSPCK episodes and whose eTSPCK was moderately correlated with post-test learner

performances, in contrast, the participant learners called for more explanations with familiar examples on the concepts of organic chemistry covered. This suggests that learners are, in their own way, able to tell when rich, meaningful teacher's explanations are lacking or present in a lesson. These, as seen in the case of Ruth and Rose, are forms of teachers' explanations that draw interactively on more TSPCK content specific knowledge components. Learners have an expectation for teachers to provide meaningful explanations that facilitate their learning. This supports the understanding in the literature that learners themselves are active participants in their own learning (Lee & Branch, 2018). In line with the observations made in the study, the participant learners, using their personal vocabularies (e.g. objects, diagrams, strcutures, repeatitions), identified the components of representations and explanations that emphasized important meaning (curricular saliency) as useful in their construction of learning. As argued by Park and Oliver (2008) , teachers of sciences have to get sensitized to the needs of learners, only then can they think of improving the quality of their instructions. This seems to imply that, while the possession of different components of TSPCK is essential, it is equally important for teachers to develop the understanding of interactive use of knowledge components in planning and enacting instructions (Aydin *et al*., 2015).

Moreover, in the cases of the four PSTs, the participant learners believed that, performing laboratory experiements would deepen their conceptual understanding of the aspects of organic chemistry covered. Although the PSTs engaged learners in simple demonstrations using models as a form of macroscopic representation, there was the lack of opportunities for doing laboratory experiments in the PSTs' teachings. This finding is consistent with the previous study by Halim et al. (2014) where lack of laboratory experiments in the science teachers' teaching reinforces the passive learning environment commonly seen in the Malaysian classrooms where the study was conducted. This suggests the need for more of the PSTs' application of macroscopic levels of representations in presenting organic chemistry concepts to learners. Overall, the emerging finding from the examination of learners' views in this study revealed the elements perceived to reflect the quality of the PSTs' eTSPCK from the learners' perspective. This finding is considered a new contribution to the PCK literature as it confirms the learners' ability to identify quality in teachers' eTSPCK.

10.4 Other empirical findings confirming existing findings in the PCK literature

In addition to the findings that contributed to new knowledge in the literature, there were additional findings in this study, emerging from the analysis of PSTs' actual teachings, which confirmed major understandings in the PCK literature. The first major finding is about the translations of pPCK to ePCK. The second major finding is related to what makes the realm of pPCK, personal. Each of these findings is discussed below.

Translation of pTSPCK to eTSPCK

One noticeable feature of the RCM of PCK is the clear illustration of ePCK, demonstrated in the actual classroom teaching, as the application of teachers' pPCK manifested during a pedagogical cycle involving planning (Carlson & Daehler, 2019). As analyzed in Chapter 6, it was found out in this study that, the learners' responses during the PSTs' teachings prompted the translation of PSTs' lower quality of pTSPCK (planned TSPCK), manifested as simple TSPCK episodes in lesson planning, to a higher quality of eTSPCK (enacted TSPCK) demonstrated as proficient and sophisticated TSPCK episodes in the actual classroom teaching. For example, five aspects of the template used by the PSTs for lesson planning (see Appendix IV) required them to provide explanations relating to the teachability of organic chemistry concepts focused on. Such explanations were all considered opportunities in this study for the participant PSTs to demonstrate their understanding of interactive use of TSPCK content-specific knowledge components in planning. The five aspects focused on identifying and explaining immediate concepts necessary for the content of the lesson; summarizing important content knowledge; identifying learners' common misconceptions with reasons; identifying possible areas of difficulty associated with the content; and explaining the proposed teaching strategies. The analysis of the PSTs' lesson plans (see Chapter 6, section 6.4, finding 2) showed that there were mostly simple TSPCK episodes emerging from the written explanations provided by the PSTs on the five aspects. The TSPCK episodes were commonly characterized by the PSTs' understanding of key concepts that must be emphasized (CS) in teaching organic chemistry, possible misconceptions (LP) relating to the concepts, areas of potential difficulties (WD) and use of symbolic representations (RP) (e.g. see Figure 6.3). For example, as an immediate concept for physical properties and structures of organic compounds, Rose highlighted in her

lesson plan (see Figure 6.10) that, the learners' prior knowledge of different types of intermolecular forces would be necessary for understanding the influence of intermolecular forces on the boiling point and melting point of organic compounds. In addition, she highlighted the strength of intermolecular forces, an aspect considered important (CS). She also explained how difficult it might be for learners to understand the related organic chemistry lesson without good mastery of the strength of intermolecular forces (WD). In planning for teaching, a simple (basic) TSPCK episode consisting of the interactive use of CS and WD in the form CS/WD seemed to have emerged from Rose's written explanation. In her actual classroom teaching, one of her teaching segments (Lesson 1, 31-35 minutes) appeared to specifically focus on the intermolecular forces in relation to the concepts of organic chemistry (see Appendix XXIX). During this teaching segment, Rose presented the structure of propane and propanol to her learners and asked them which of the two organic molecules would have a high boiling point. Learner SM5 (pseudonym) correctly referred to propanol but wrongly mentioned weak intramolecular forces as the reason. Through other learners' responses, there was interchangeably use of intramolecular forces for intermolecular forces and vice versa. Taking learners' responses into consideration, Rose explained how intermolecular forces are similar to and different from intramolecular forces with reference made to the chemical formula of sodium chloride drawn on the chalkboard for learners to see. While her understanding of learner prior knowledge (LP) came to play as she investigated and confirmed learners' existing knowledge, her use of chemical formula describes the knowledge of a symbolic representation (RP). Also, showing side-by-side the difference and similarity between intramolecular forces and intermolecular describes Rose's knowledge of a conceptual teaching strategy of sciences (CT). There was a proficient TSPCK episode (LP-CT/RP) emerging from Rose's explanations in the actual teaching prompted by the learners' mix of correct and incorrect responses to the question asked to evaluate their prior knowledge. Following this was Rose's teaching segment (Lesson 1, 35-37 minutes) which focused on intermolecular forces in relation to the physical properties of organic compounds generally. Through questioning and dialoguing, she first confirmed the learners' existing knowledge of hydrogen bonds, van der Waal's forces as examples of intermolecular forces. In relation to kinetic theory, she explained how the strength of intermolecular forces in organic compounds affects the physical properties (e.g. boiling point) of such compounds. She pointed out to the learners how inability to identify what intermolecular

forces are present in an organic molecule might hinder understanding of the trend of physical properties. Emerging from her explanations was another proficient TSPCK episode (LP-CS/WD). While the first TSPCK episode (LP-CT/RP) was prompted by learners' mix of correct and incorrect responses, the second TSPCK episode was facilitated by the learners' correct responses, ability to correctly identify intermolecular forces based on prior knowledge. In this case, Rose's pTSPCK characterized by a simple TSPCK episode in planning translated into eTSPCK which was characterized by two higher categories of TSPCK episodes at a proficient level prompted by the mix of learners' correct and incorrect responses. More instances of translation of PSTs' pTSPCK to eTSPCK prompted by the learners' responses have been for Rose and for other PSTs in Chapter 6 (see section 6.4, finding 2). This finding is in agreement with Shulman's (1987) argument that the transformation of content knowledge starts in planning, a stage preceding the actual teaching and which is equally important as the actual teaching itself. Although Mavhunga (2018) categorized the PSTs' lesson planning as well-reasoned due to the emergence of TSPCK episodes, this study has further provided the empirical evidence of that, such TSPCK episodes in planning could translate into more complicated TSPCK episodes in the actual classroom teaching. This finding has provided empirical evidence supporting the suggestion that, when PSTs are involved in the actual classroom teaching, their available PCK possibly comes into play in the course of their interactions with learners (Adadan & Oner, 2014). Having simple TSPCK episodes translating into more complex TSPCK episodes implied deep engagement with learners and better explanations that could enhance learners' understanding. This provides an insight into the complexity of the instructional teaching and learning process in the actual classroom context.

Empirical evidence supporting the nature of realm of pPCK

As highlighted in the RCM of PCK, the manifestation of teachers' pPCK in the actual classroom describes the nature of teachers' ePCK. The finding in this study revealed the complexity and idiosyncratic nature of the interactions among TSPCK content-specific components which shaped the PSTs' pPCK portrayed as ePCK in the actual classroom teaching of organic chemistry. As illustrated in Chapter 6 (see Table 6.3), the observed complexity of knowledge components interactions in the detailed analysis of PSTs' teachings occurred in the form of a linear standalone sequence (e.g. LP-CS), interwoven structural arrangement (CS/LP/CT) and

combination of both linear and interwoven emergence (RP/LP-CS-CS, LP-CT/RP). These were similar in terms of the knowledge components found interacting but differ in terms of the quantity of knowledge components and sequence in which the knowledge components emerged. There were cases where a single knowledge component CS (curricular saliency) was repeated in a given TSPCK episode (e.g. RP/CS/CS) reflecting additional depth added to the PSTs' explanations from which such TSPCK episodes emerged. To varying degrees, the 4 participant PSTs in this study had teaching segments from which simple TSPCK episodes (e.g. CS/RP), proficient TSPCK episodes (e.g. LP-CS/RP) and sophisticated TSPCK episodes (e.g. RP/LP-CS/WD) emerged. This further contributes to the understanding in the literature that, PCK and in association, TSPCK is not the ordinary sum of linear individual components but rather constitutes interactions among its knowledge components (Abell, 2008; Park & Chen, 2012).

Also, the idiosyncratic nature of knowledge components interactions happened across the concepts involved in the PSTs' teaching (see Chapter 6, Table 6.2). For example, when Ruth was discussing saturated hydrocarbons with the learners (see Chapter 6, Table 6.1, 6-7minutes), a simple TSPCK episode (CS/RP) emerged from her explanations. Preceding this particular Ruth's explanation was her discussion with learners on hydrocarbons (4-6 minutes) from which a proficient TSPCK episode (LP-CS/RP) emerged. Again, following her explanation on saturated hydrocarbons was her discussions with learners on unsaturated hydrocarbons (7-8minutes) from which a proficient TSPCK episode (CS/CT/RP) emerged. On a different concept, aldehyde functional group (29-33 minutes) as presented in the Table 6.4, a sophisticated TSPCK episode (LP-RP/CT/WD) emerged. During this teaching segment, she was noticed confirming learner prior knowledge (LP), using symbolic representations (RP), putting aldehyde functional group and ketone functional group side-by-side to explain their difference and similarity (CT) and highlighting a possible difficulty that might experience understanding this due to the presence of carbonyl group in the two functional groups (WD). Meanwhile, from Hope's teaching segment focusing on the same aldehyde functional group, there were the understandings of what was important to emphasized (CS), use of symbolic representations (RP) and a learner's possible misconception identified (LP). This explanation revealed the emergence of a proficient TSPCK episode (RP/CS/LP) from Hope's teaching segment on aldehyde functional group whereas a sophisticated TSPCK episode (LP-RP/CT/WD) emerged while Ruth was found explaining the same concept.

Although the findings in this study as illustrated above are consistent with the previous studies which focused mostly on experienced teachers (e.g. Akin & Uzuntiryaki-Kondakci, 2018; Aydin & Boz, 2013; Park & Chen, 2012), it was interesting to know that such observation could be noticed in the PSTs who are commonly known to have weak PCK due to lack of consistent interactions with learners. More so, with the RCM in place, it is now understood that, these previous studies used a discipline grain size of PCK while investigating the teachers' nature of pPCK in science topics. However, the examination of the complex and idiosyncratic nature of PCK in this study has been conducted on the grain size of its topic specificity rather than reference to the interaction of knowledge components that are generic and subject specific. This provides insights into the similarity between TSPCK construct and broader PCK without losing the epistemological disparity of TSPCK being located at topic-specific level compared to the broader (discipline) PCK. The similarity of these two levels of PCK is embedded in the understanding that both of them emerge from the interaction of the constituent knowledge components reported to be complex and idiosyncratic particular in the complexity of teaching and learning process. This finding expands the existing understanding in the literature on the coherent interactions among TSPCK components which are most considered crucial to the quality and development of PCK in a given topic than the strength of an individual knowledge components (Nilsson & Karlsson, 2019; Park & Chen, 2012) especially in the case of PSTs' actual classroom teaching. This finding also confirms the argument that the topic specificity of PCK can be linked to not only which components compose teachers' PCK for a specific topic but how and to what degree those components interact with each other (Akin & Uzuntiryaki-Kondacki, 2018; Park & Chen, 2012).

10.5 Summary of research questions

The overarching research question guiding this study was stated as: "How does the competence to pedagogically transform content knowledge of organic chemistry learned by pre-service teachers influence their quality of TSPCK seen in planning for teaching and actual classroom teaching of organic chemistry in relation to learner achievement?" Considering the benefits attached to PCK with regards to the teachers' ability to reason soundly in lesson planning and enactment of instructions, it was important to establish the PCK-learner outcomes link, a noticeable gap identified in the literature. Due to the researchers' diversity of understanding

about what constitutes PCK, it was essential in this study to clearly explain what conceptualization of PCK has been adopted and a theoretical framework to investigate the identified problem as explicitly discussed in Chapter 2. Likewise, it was pertinent to clearly explain the research design employed in this study which enabled the mixed-methods technique of collecting and analysing the data as elucidated in Chapter 3. Hence, the overarching research question guiding this study was further re-structured into three sub-questions revolving around how pedagogical transformation competence based on how cTSPCK influences planned TSPCK and quality of eTSPCK in relation to the learner performances in organic chemistry. The three sub-research questions formulated were considered sufficient to cover aspects of the overarching research questions in an attempt to contribute to addressing the identified gap in the PCK literature. A review of the findings emerging from this study in relation to the sub-research questions are discussed below.

Sub-research question 1: The first sub-research question examined how explicit discussions provided during the intervention, focusing on developing pedagogical transformation of content knowledge of organic chemistry, influenced the quality of PSTs' planned TSPCK in the topic. Within this sub-research question was a credible baseline established towards investigating and interpreting the quality of eTSPCK eventually seen in the actual classroom teaching and how it relates to learner achievement. This kicked off by exposing the participant PSTs to the cTSPCK, through explicit discussions on the individual content-specific knowledge components and their interactive use in pedagogically transforming the content knowledge of organic chemistry as discussed in Chapter 4. As revealed in Chapter 5, there was a statistically significant improvement in the quality of participant PSTs' planned TSPCK from a lower category of Limited TSPCK in the pre-TSPCK test to a Developing category of TSPCK in the post-TSPCK test. The successful application of the pedagogical transformation competence learned by the PSTs during the intervention was also observed in a complementary developing level of interactive use of content-specific knowledge components on their written explanations provided in the completed post-TSPCK tool and CoRe tool.

The direct response drawn from these key empirical findings is that, the intervention positively influenced the quality of PSTs' planned TSPCK in organic chemistry with the evidence of

interactive multiple use of content-specific components at a developing level of TSPCK following the intervention.

Sub-research question 2: The second sub-research question examined how the pedagogical transformation competence learned by the PSTs during the intervention influenced the quality of eTSPCK seen in their actual classroom teachings of organic chemistry. The examination required the use of TSPCK construct discussed with the PSTs during the intervention as the lens to investigate the nature and quality of their eTSPCK in the actual classroom teaching as it was presented in Chapter 6. The nature and quality of eTSPCK was captured and portrayed through an in-depth qualitative analysis of identifying TSPCK episodes and using the eTSPCK rubric to categorize the identified TSPCK episodes. First, it was revealed that, the PSTs' eTSPCK demonstrated complex and idiosyncratic nature of interactions among content-specific knowledge components. There were simple, proficient and sophisticated TSPCK episodes emerging from the PSTs' teachings albeit to varying extents. The emerging TSPCK episodes from the PSTs' teachings were largely at the proficient category which was similar in quality to the developing level that described the PSTs' planned TSPCK. Both the developing level of TSPCK and proficient TSPCK episodes consist of the knowledge of interactive use of three content-specific knowledge components or two content-specific knowledge components where one repeated. Second, there were translations of simple TSPCK episodes identified in the PSTs' lesson plans into proficient and sophisticated TSPCK episodes in the actual classroom teaching prompted by the learners' responses during the teachings. Third, there was congruence between the discussions held with the PSTs during the intervention, the pedagogical transformation competence acquired by the PSTs following the intervention and the pedagogical transformation competence demonstrated in the actual classroom teaching.

The direct response drawn from these key empirical findings is that, the competence to pedagogically transform content knowledge of organic chemistry learned by the PSTs positively influenced the quality of eTSPCK seen in their actual classroom teachings with evidence of interactive use of content-specific knowledge components predominantly at a proficient level of TSPCK episodes.

Sub-research question 3: The third sub-research question examined how the quality of pre-service teachers' TSPCK seen in the actual classroom teaching of organic chemistry influenced learner performances in organic chemistry. For this examination, the learner performances prior to and following the PSTs' teachings were first established. This was followed by determining the correlation between the PSTs' eTSPCK and the observed learner performances in the administered pre-and post tests. Summarily, there were three key findings emerging from this examination. First, it was found out that, all the participant learners improved significantly as a collective class in their conceptual performances following the PSTs' teachings and except in the case of Hope's learners, the learners individually reached the desirable 60% achievement mark in the post-test in topic of the intervention (organic chemistry). Second, it was revealed that, there was a positive significant correlation between the PSTs' eTSPCK and post-test learner performances in organic chemistry following the PSTs' teachings. Third, it was found out that, the positive correlation between the PSTs' eTSPCK and post-test learner performances in organic chemistry increases in positive strength with higher categories of TSPCK episodes. This study acknowledges the fact that, a correlation between two variables (e.g. TSPCK and learner achievement) does not imply a causal relationship (McMillan & Schumacher, 2014). However, based on the cTSPCK-pTSPCK-eTSPCK trajectory followed in this study with attempts made in sifting out the effects of TSPCK and minimizing the noise of other factors, the correlation estimated in this study seemed to have a cause and effect link which may not be direct but there is high probability that, the PSTs' TSPCK focused on had a positive influence on learner achievement.

The direct response drawn from these key empirical findings is that, the quality of PSTs' eTSPCK seen in the actual classroom teaching of organic chemistry positively influenced learner achievement in organic chemistry to varying extents.

The response to the Overall Research Question

The above three sub-research questions have provided sufficient empirical findings facilitating the formulation of a possible response to the overarching research question that sought the establishment of the cPCK-pPCK-ePCK-learner outcomes continuum link, as guiding this study as follows:

The competence to pedagogically transform content knowledge of organic chemistry learned by the PSTs during the intervention positively influenced the quality of their planned TSPCK by catapulting it from Limited TSPCK prior to the intervention to Developing TSPCK following the intervention. It also positively influenced the quality of PSTs' eTSPCK in the actual classroom teachings with evidence of interactive use of content-specific knowledge components predominantly at a proficient level of TSPCK episodes. Overall, the positive correlation between the PSTs' eTSPCK and post-test learner performances suggests high probability of the positive influence of TSPCK as the cause of learner achievement which improved from an overall average performance of 15.6% in the pre-test to an overall average performance of 62.2% in the post-test.

10.6 Conclusion

This study attempted to address a gap in the PCK literature revolving around how TSPCK developed in PSTs, in the context of learning to teach, translates into actual classroom teaching and influences learner achievement. The examination emanated from the perspective that, PCK is one important domain of teacher knowledge for planning and enacting classroom instructions of specific topics most significantly (Mavhunga, 2018; Pitjeng-Mosabala & Rollnick, 2018; Aydin, et al. 2015). This study was intrinsically connected to the persistent issue of the theory-practice gap which has been challenging in educational research (Barradell & Kennedy-Jones, 2015; Tang & Choi, 2005). At the center of this matter is the acknowledgement of dissonance coming in-between knowledge acquired while learning to teach content and knowledge enacted in the actual classroom teaching of content. Such disagreement describes the disconnection between the two kinds of knowledge referred to as 'episteme' and 'phronesis' conceptualized by Aristotle (Eisner, 2002; Kinsella & Pitman, 2012). While Greek philosophers refer to 'episteme' as true and certain knowledge which is synonymous to theoretical knowledge possessed about concepts (Eisner, 2002), 'phronesis' is the practical knowledge visible in particular situations (Kinsella & Pitman, 2012). In such cases, becoming a custodian of one of these two kinds of knowledge over the other tends to complicate the theory-practice gap rather than bridging the gap. Such a commonly noticeable pattern is not different from the occurrence in science teaching and learning. Particularly, PSTs are always confronted with the challenge of overcoming the gap between the acquired theoretical knowledge and application of the

knowledge in practical learning in order to enhance learners' conceptual understand (Stürmer & Seidel, 2017). The findings in this study have empirically proven the significance of focusing on PCK within topics as a theoretical framework which science teacher-educators, science educational researchers and practitioners in science teaching and learning may consider as a weapon for bridging the theory-practice gap with the ultimate goal of improving learner achievement in science topics. The findings also support the understanding in the literature that the quality of the teachers' PCK in a specific topic is an important factor in the success of learners in the topic (Förtsch *et al*., 2016; Baumert *et al*., 2010). The insights have been provided in this study in both the planning and actual teaching contexts into the extent of describing PCK in a specific topic earlier theorized by researchers in science teaching and learning (Gess-Newsome, 2015; Abell, 2008). This study showcased appreciable benefits in both the qualitative and quantitative ways accrued to developing PSTs' specialized knowledge for teaching a core physical science topic visible in planning and actual classroom with a positive influence on learner achievement.

10.7 Implications and recommendations of the study

Although this study was conducted as a case of a group of physical science PSTs and thus, its emerging findings cannot be generalized to some other cases, the implications are discussed below with respect to the science education community and teacher preparation programmes in South African and other African countries.

(a) Implications of the study for the science education research community

- This study has added empirical evidence justifying the topic specificity of PCK and its constituent knowledge components in spite of various perspectives about what specific knowledge components constitute PCK. Thus, the notion of focusing on core topics one after the other in school science subjects using the valuable construct of TSPCK is a promising channel for understanding content-specific knowledge components needed for pedagogical transformation of content knowledge of the topic.
- This study has also provided empirical evidence establishing the cPCK-pPCK-ePCK-learner outcomes continuum link as theoretically outlined in the current Refined Consensus Model (RCM) of PCK. Such a link expanded the existing understanding

about RCM thereby validating it as a useful conceptual framework for exploring the link between teachers' TSPCK and learner outcomes within a specific topic.

- This study has provided empirical evidence supporting how higher quality of PSTs' TSPCK was strongly associated with higher learner performances. It is also worth taking note of that, Hope's learners who were in the lower Grade had higher positive shift in the conceptual performances which seemed to measure up with the positive shift experienced by Ruth's and Rose's learners and also, higher than the positive shift experienced by Mark's learners who happened to be in the higher grade, Grade 12. Through this study, empirical evidence has been provided to prove the theoretical proposition of increasing learner performances in a given science topic by enhancing the quality of teachers' PCK in the topic. Such a proposition provided the understanding about how the extent of useage of content-specific knowledge components of TSPCK in explaining a topic is positively and significantly associated with improving learner performances in the topic.

(b) Implications of the study for the science teacher education programmes in the context of South Africa and other African countries

- The findings from Chapter 5 showed that, in the presence of content knowledge, the pre-service teachers' understanding to pedagogically transform content knowledge of a given topic could be significantly improved by emphasizing interactive use of TSPCK content-specific knowledge components. The evidence of successful application of such understandings in the topic of the intervention was seen through the quality of the generated written responses demonstrated in both the completed post-TSPCK test and in the complimentary content representations. Thus, it is recommended that, the construct of TSPCK should be explicitly included in teacher education programmes particularly in the context of science education in South Africa and other developing countries where there is a high shortage of knowledgeable science teachers.
- The findings in Chapter 6 revealed the quality of enacted TSPCK in organic chemistry which was similar to the quality of planned TSPCK demonstrated by the pre-service teachers following the explicit exposure to the TSPCK construct. Thus, it is recommended that, in addressing the theory-practice dissonance in science teacher education programmes in the context of South African and other African countries,

emphasis should be on improving teachers' pedagogical transformation competence during teacher education programmes.

- The findings in Chapter 7 revealed that, the post-test learner performances improved significantly following the pre-service teachers' teaching. The performances were observed to increase in positive strength with higher categories of TSPCK episodes. Likewise, the findings in Chapter 8 showed that, the strength of positive correlation between post-test learner performances and pre-service teachers' enacted TSPCK increases with higher categories of TSPCK episodes. Therefore, it is recommended that, efforts should be made in teacher education programmes to enhance the quality of teachers' TSPCK, a promising channel for improving the quality of science classroom instructions and ultimately, learner achievement in South Africa and other African countries with records of learner poor performances in sciences.
- The findings from Chapter 9 revealed that, while the participant learners were suggesting what would make them understand the concepts better, some of them asked for more explanations with familiar examples in the cases of PSTs who had higher quantity of simple and proficient TSPCK episodes compared to sophisticated TSPCK episodes and whose eTSPCK was moderately correlated with post-test learner performances. However, the participant learners only demanded for take home exercises which they could solve on their own in the cases of the PSTs who had higher proficient and sophisticated TSPCK episodes rather than simple TSPCK episodes. This seems to imply that, the possession of different components of TSPCK is essential, it is equally important for teachers to develop the understanding of interactive use of knowledge components in planning and enacting instructions (Abell, 2008).

10.8 Critical reflections on the entire research process in this study

10.8.1 Reflection on the intervention focusing on collective TSPCK

As earlier indicated, several studies have been conducted on TSPCK with the intervention as the starting point. As a result, the intervention conducted with the participant PSTs in this study does not represent the main goal of this study but it was meant to depict a credible baseline for interpreting how TSPCK relates to learner achievement. So, there were a few interesting things

that could be pointed out about the intervention. First, the importance of maintaining the purpose of the study was realized as the intervention was being conducted through the weeks. At the beginning of each session, there was a recap of what the intervention was meant to achieve, which was to develop the understanding to pedagogically transform content knowledge of organic chemistry and how it was to be done. This helped in drawing the PSTs' attention to how the intervention differs from general pedagogical knowledge classes they had been attending. It also made it possible to connect whatever had been learnt in the previous session to the present session despite the fact that there were particular aspects of TSPCK construct focused on during each session different from other sessions. In some instances, the participant PSTs asked questions relating to previous sessions and this confirms the connection among content-specific knowledge components they were being exposed to. These observations were consistent with reports of previous researchers that it is beneficial to raise the PSTs' awareness of PCK as the knowledge they themselves are acquiring and likewise in the processes they are undergoing (Kind, 2009; Mavhunga, 2012). Second, the use of discussions was helpful as a pedagogical method of exposing the PSTs to the construct of TSPCK. This allowed for a mix of responses, questions and contributions from the participant PSTs as well as from me as the presenter of the course. From my personal perspective, I could observe in myself as well as in the PSTs, the development of conceptual understanding as discussions on pedagogical transformation of content knowledge of organic chemistry concepts unfolded during each intervention session. These instances of conceptual improvement which signaled stages of developing TSPCK and content knowledge have been provided in Chapter 4 while describing the events that took place during each intervention session. The learning environment was friendly with no sign of hostility. In the cases where there appeared to be disruption caused by two rowdy participant PSTs or laughter that underestimated another person's contributions, such were instantly and strongly discouraged. It was also helpful to the PSTs having them go into groups to complete CoRe prompts following each session, they were able to rub minds with their peers and engage in discussing content of organic chemistry further.

10.8.2 Reflections on the research methodology employed

The mixed methods research design was employed in this study, implementing its elements of qualitative and quantitative approaches in holistically investigating and understanding the

research problem. The research processes involved in this study enhanced the demonstration of two of the unique advantages of employing a mixed methods research design. The first advantage includes its enormous potential for reflecting on and understanding the complexity of a given phenomenon (Morse, 2016). The second advantage includes producing new knowledge by synthesizing findings emerging from the different research approaches involved in a mixed methods research design (Creswell & Clark, 2017). In this study, the research design has facilitated measuring, capturing and portraying the PSTs' TSPCK understood to be complex in terms of pedagogical reasoning and enactment in relation to learner achievement in the complexity of teaching and learning process. Thus, the discussions are provided below on critical reflections about aspects of this study where a mixed methods research design has been of great value.

The series of information gathered regarding efforts made during the intervention aided reflection on the multifaceted nature and complexity of influences involved in developing PSTs' PCK in a specific topic. A unique instance was the complexity of the PSTs' process of learning to reason in order to pedagogically transform their content knowledge of organic chemistry during and following the intervention. Embedded in the process were trial and error attempts by the PSTs during intervention discussions, arguing and expressing personal views during tutorials, reconstructing, implementing and reflecting on the pedagogical thoughts. These emanating processes were noticed through records of discussions held during the interventions, written explanations prior to, during and following the intervention, lesson plans developed and enactment of instructional strategies. The qualitative approaches were best suitable in capturing such pedagogical constructive processes as they manifested verbally and from written explanations provided by the PSTs. The qualitative approaches also enabled the examination of the application of PSTs' understanding of the interactive of TSPCK content-specific knowledge components acquired during the intervention in completing content representations (CoRes) on organic chemistry. Notwithstanding, the quantitative research approaches were found more enabling in gaining insights into the extent of pedagogical transformation reasoning developed by the PSTs through these processes of learning to reason and planning the topic of organic chemistry. The statistical measurement of Rasch Model Analysis brought into view the hierarchical emergence of content-specific knowledge components according to their level of difficulty following the intervention. Most significantly, the value of a mixed methods research

design employed in this study was connected to the first identified convergent point. At this point, the qualitative pattern revealing the PSTs' conceptual understandings of TSPCK components was complemented by the quantitative result revealing the extent of these understandings, individual person performances and order of item difficulty. By convergence, the patterns from both the qualitative and quantitative approaches collectively placed the quality of PSTs' planned TSPCK in the developing category which served as the credible base for interpreting the PSTs' eTSPCK and its influence on learner outcomes.

Also, for the pedagogical transformation competence demonstrated by the PSTs in the actual teaching, capturing and portraying interactions among content-specific knowledge components were best attempted through an in-depth qualitative analysis involving the identification of TSPCK episodes (Park & Chen, 2012). It was a mini-case study conducted with the subset of 4 PSTs from the cohort of 17 participant PSTs that participated in the intervention. The case study as a qualitative research strategy provided an in-depth understanding (Merriam & Tisdell, 2016) of PSTs' eTSPCK in the complexity of teaching and learning process by highlighting the PSTs' roles and learners' roles. Nonetheless, the qualitative data gathered from the PSTs' video-recorded lessons were categorized, using quantitative scores generated from the eTSPCK rubric, into different levels of TSPCK episodes visually displayed in the form of TSPCK maps. Through the use of these quantitative scores, the frequencies of emergence of TSPCK episodes from the PSTs' teaching segments were also visually represented in order to describe how the emerging categories of TSPCK episodes collectively build onto each other. Although the patterns emerging from the frequency representations could be linked to how the three categories of TSPCK episodes build onto one another using qualitative illustrations rather than rigorous statistical analysis. Thus, the visible emergence of the extent of interactive use of content-specific knowledge components signaled the quality of PSTs' eTSPCK observed in this study. At the same time, the quantitative approach through the calculation of Cohen's Kappa inter-rater enabled the peer validation of the identified TSPCK episodes emerging from the PSTs' teachings. Overall, there were welcoming classroom environments where the PSTs conducted their teachings. Nevertheless, some of the participant learners were uncomfortable regarding the video-recording of the lessons. These anxieties observed in the participant learners were immediately addressed by assuring them of the anonymity of their identities and confidentiality of information gathered from them. Most significantly, the value of a mixed methods research

design employed in this study was connected to the second identified convergent point. At this point, the qualitative pattern revealing the PSTs' understandings of interactive use of TSPCK components was complemented by the quantitative result revealing the extent of these understandings using numbers and also, establishing the credibility of such findings through the reliability calculated. By convergence, the patterns from both the qualitative and quantitative approaches collectively placed the quality of PSTs' eTSPCK principally in the proficient category.

Moreover, in determining how the PSTs' eTSPCK possibly influenced learner achievement, the quantitative research approaches were more suitable in first establishing the extent of learner performances prior to and following the PSTs' teaching. Through the statistical analysis of learners' achievement tests, the conceptual performances including the extent of significant difference was determined focusing on the learners' pre-and post-test scores. The analysis provided useful information about the learners' level of engagement on the test items prior to and following the PSTs' teachings. Building on this, the quantitative approaches further aided the examination of patterns of correlation between the PSTs' eTSPCK and learner achievement in the presence of different categories of eTSPCK episodes thereby revealing the strength and direction of correlation. However, the qualitative analysis brought to view in qualitative terms the weakness or strength of content-specific knowledge component interactions in TSPCK episodes that showed high or weak correlations to learner performances. It also enabled the examination of the quality of TSPCK episodes with respect to the quality of learners' written responses in the pre-and post-test. Most significantly, the value of a mixed methods research design employed in this study was connected to the third identified convergent point. At this point, the quantitative patterns revealed by the strength and direction of correlation were complemented by the qualitative examination revealing the weakness or strength of interactions among TSPCK components which showed high or weak correlations to learner performances. It was also revealed in the conversion of qualitative TSPCK descriptions into quantitative measures (Rasch measures) for correlation analysis. By convergence, both the qualitative and quantitative approaches collectively assisted in describing the nature of relationship between PSTs' eTSPCK and learner outcomes.

In the cases of PSTs' learning to reason and actual classroom teaching in relation to learner performances, the examples given above represent different aspects of the same sub-research question to which answers were best provided by transforming data from one strand (e.g. qualitative method) of mixed methods research design into the other strand (e.g. quantitative method). These also involved the use of data from a strand in the design in understanding different features of the phenomenon being investigated. The techniques employed right from examining the PSTs' planned TSPCK to portraying their eTSPCK and establishing its correlation to learner performances represent typical contribution to new knowledge generated from synthesizing data from the two strands of the mixed methods research design. Although the techniques seemed to be well premeditated, it was demanding to carefully check each time aspects relating to the reliability and validity of each technique as they basically differed. Consequently, ensuring proper record-keeping of artifact generated and developmental trajectory for each stage was advantageous in the course of analyzing and writing up the findings. However, it produced an enormous data collection which called for selecting thoughtfully, the pieces of evidence that would adequately provide the understanding of the issue being investigated. Terrell (2012) posits that, when a mixed methods research design is employed in an integrative way, the different strands involved are expected to be assigned equal weight and positioned towards a shared goal and thus, the strands are inevitably codependent in ensuring they retain their paradigmatic modalities. As a result, both the qualitative and quantitative research approaches had equal weight in the way they were employed in this study. Each research approach targeted a particular aspect of the same research question which the other research approach could not reflect in some instances. In some other instances, the finding emerging from analyzing using one research approach required further exploration by the other research approach in order to gain a deeper understanding. An instance was when the quantitative analysis could only explain the strength and direction of correlation between the PSTs' eTSPCK and learner performances while the qualitative analysis completed this by reveal in qualitative terms the weakness or strength of interactions among TSPCK components contributing to high or weak correlations to learner performances. These instances have been outlined in the summary section for each analysis chapter, Chapter 5-9 with evidence of integration of strands involved in mixed methods research design employed in this study. Moreover, using a case study as the research strategy in this study proved to be most suitable. Its

main benefit lies in encouraging the use of mixed methods thereby allowing for an in-depth investigation of a phenomenon even with small sample size. One shortcoming of a case study is its limitation in terms of the extent of generalization of emerging findings since it only focuses on a particular group, exclusively to others (Merriam & Tisdell, 2016). Creswell (2015) cautioned researcher to aim for and be aware of a balance between the understanding provided by in-depth exploration involved in a case and wide generalized findings which might emanate from a large research sample size. It is acknowledged in this study that, even though the entire class of PSTs was used as a research sample during the intervention, the sample size was still small and this represented one limitation of this study. Another shortcoming of a case study is the view that, it generates soft data (Mcmillan & Schumacher, 2014). The use of Rasch Model Analysis in this study was advantageous due to the fact that, its underlying assumptions were not violated by the small research sample size in the cases of the PSTs and high school learners who took part in this study. Also, the use of classical statistical analyses for small research sample sizes such as the non-parametric Wilcoxon paired signed-rank test and statistical package for the social sciences were helpful. In minimizing the effects of characteristic biases associated with methods of collecting data in a case study, the use of varied methods was employed in this study including audio recordings, collecting PSTs' written responses, video-recordings translated into transcripts which allowed for raters' scoring. These all contributed to enhancing the reliability of the data and measurements.

10.8.3 Validity and trustworthiness

In mixed methods research, data quality is generally examined by the individual standards of quality in each of quantitative strand and qualitative strand constituting the design. In this line of thought, Teddlie and Tashakkori (2009) argue that "if the data of the individual strands is valid and credible, then the mixed study will have a high overall data quality' (p. 209). As a result, ensuring different standards in the assessment of the quality of collected data through the research approaches involved a reflection of the overall quality of data and measurements in this study. At various points in the discussions above, some of the practices extensively reported in the literature to enhance data quality have been involved and provided in this study. These included the use of varied sources for data collection such as pre-and post-TSPCK tests with Content Representations, video-recording of classroom teaching with collection of lesson plans

and conducting pre-and post-lesson interviews, learner pre-and post-achievement tests with the collection of learners' views. These helped in reducing my own bias as a researcher and consequently enhanced the credibility of the research findings emanating from this study. The trustworthiness was equally ensured by involving a team of knowledgeable and experienced independent raters who helped in the analysis of completed TSPCK tests, TSPCK episodes in the video-recorded lessons, learners' pre-and post-achievement tests and identifying keywords in the learners' views.

10.9 Limitations of the study

In this study, both the qualitative and quantitative evidence were linked to the observed quality of PSTs' planned TSPCK and eTSPCK in the course of establishing the correlation between the PSTs' eTSPCK and learner outcomes in organic chemistry. While the emerging findings from this study are interesting and of great contributions to new knowledge, there are a few associated noteworthy limitations. First, it is acknowledged that, this study is a case of 17 PSTs for examining planned TSPCK prior to and following the intervention. Also, the use of a subset case of 4 PSTs for the actual classroom teaching out of the class size of N=17 was quite limiting instead of having the entire participant PSTs teach following the intervention. Due to the small sample size, the results of this study cannot be generalized to other group of PSTs. Likewise, the 4 PSTs' teaching following intervention was limited to two lessons each and only covered certain aspects in organic chemistry which made it an inadequate base on which a justification into the future with regards to teaching other science topics could be claimed. Second, due to the absence of control group for the classroom teaching or records of the PSTs' teaching prior to the intervention, it would be incautious to claim that, all which was observed with the PSTs in the actual classroom teaching was solely as a result of the TSPCK intervention. Third, the interpretations of the influence of PSTs' eTSPCK on learner achievement have been stated with caution as they depicted the examination of only 4 PSTs who taught for only 120 minutes (two lesson periods) each. Definitely, this study cannot make causal inferences with regards to how TSPCK relates to the PSTs' eTSPCK and learner achievement even for the 4 PSTs, however, the emerging findings were basically based on the empirical evidence observed in this study. As earlier indicated, the focus in this study was on evidence of PSTs' interactive use of content-specific knowledge components demonstrated planning as well as in the classroom explanations

of organic chemistry concepts. One concern with this strategy is that, while teachers' PCK and hence, TSPCK may be recognizable in how a particular topic is presented to learners in the classroom, observing classroom events cannot provide a complete portrayal of PCK due it tacit and complex nature (Alonzo *et al*., 2012; Aydin *et al*., 2014). Hence, this study does not in any way claim to have captured all aspects of the PSTs' eTSPCK. Nevertheless, all efforts were made in this study to portray the PSTs' TSPCK seen in the classroom by conducting a stimulated recall interview in addition to the video-recorded teachings and use of in-depth quantitative methods commonly used in PCK studies (Park & Chen, 2012; Mavhunga, 2019). By so doing, there was a better representation of PSTs' pedagogical transformation of content knowledge with the acknowledgement of, to what extent the teachings were learner-centered and engaging. Another concern is that while the focus was on the PSTs' identified TSPCK episodes in relation to the test items in the learners' achievement tests, it is acknowledged that the PSTs' interactions with learners at such moments could have been mediated by a myriad of factors not investigated as already acknowledged. At such instances, what might have appeared to be the absence of PSTs' demonstration of knowledge could probably depict a reasoned decision to prioritize other factors which remain invisible in the analysis done in this study (Chan & Yung, 2018). Therefore, instead of characterizing only what the participant PSTs demonstrated to know, attempts were further made in this study to investigate how the identified TSPCK episodes manifested in connection to the PSTs' interactions with learners. Moreover, bias has equally been acknowledged as a limitation arising from data collection and analysis where the process of video-recording of teachings could possibly have influenced natural behavior and setting of the both the participant PSTs and high school learners. In an attempt to mitigating the bias, the assistance of two independent raters, who are also TSPCK researchers and chemistry specialists with years of teaching experience, were solicited in scoring watching and analyzing the video-recorded lessons. Significant efforts were also made in this study to provide in-depth descriptions of the strategies followed in collecting and analyzing data. Doing this was for the purpose of interpreting thoroughly all the participants' involvements and processes involved at all stages of this study. Likewise, for a minimal influence of the observer and video-recoding of lessons on the PSTs and their learners' behavior, it always emphasized to the participants that being present in the classroom was only to understand all events during teaching and learning processes but not judge their actions.

In spite of all the above highlighted limitations, it could be reasonably argued that, the findings emerging from this study are sufficiently convincing for exploring the value of developing TSPCK in planning, actual teaching and its influence on learner achievement with sample sizes. The intervention could be argued to have offered the PSTs possible professional approach to think soundly about teaching a topic and also, enactment of instruction towards improving learners' conceptual performances. However, the different levels of difficulty experienced by the PSTs on the TSPCK components signals that the pedagogical strength of interactive use of knowledge components which could not be argued to have been perfectly mastered to the same extent by the PSTs in the topic of organic chemistry. Nevertheless, it has been empirically proven in this study that there is the possibility of fast-tracking the PSTs' development of TSPCK in the context of learning to teach as shown by previous studies (e.g. Mavhunga & Rollnick, 2013). Interestingly, this study has further established how advantageous it is to emphasize interactive use of content-specific knowledge components with the purpose of improving planned TSPCK and learner achievement in relation to eTSPCK using the construct of TSPCK. To some minimal extent, this study provided insights about the effectiveness of science pre-service teacher education programmes by focusing on TSPCK construct to positively impact educational policy on professional teacher training in university towards improving science teaching and ultimately, learner outcomes.

10.10 Future research

Firstly, it has been empirically proven in this study that, the quality of PSTs' planned TSPCK could improve as a result of explicit discussions focusing on the TSPCK content-specific components needed to pedagogical transform the content knowledge of a given topic. Secondly, this study has revealed that, the pedagogical transformation competence that the PSTs learnt in organic chemistry during the intervention was visible in their actual teaching of organic chemistry concepts. Thirdly, it has been revealed in this study that, the eTSPCK seen in the actual classroom teaching of the PSTs positively associated with learner outcomes. As earlier indicated, these findings emerged from a subset-case study of 4 PSTs. Hence, there is the need for further research to investigate how explicit discussions focusing on the pedagogical transformation of other core science topics influence the planned and enacted TSPCK of a bigger sample of PSTs in relation to learner outcomes in the topics. There is no doubt that such an

investigation on what the PSTs know across science topics, what they do in the actual classroom teaching of the topics and its impact on learner achievement may generate useful information for improving pre-service science teacher education programmes, quality of instructions and learner outcomes. Likewise, the knowledge components observed in this study to have majorly shaped the PSTs' planned TSPCK and eTSPCK in organic chemistry were learner prior knowledge, curricular saliency and representations. However, there are other knowledge components like 'what is difficult to teach or understand' and conceptual teaching strategies which hardly manifested in both the planning and actual teaching contexts. Considering the complexity of PCK in a specific topic and the place of interactions among the constituent knowledge components, understanding how all knowledge components interact to shape the PSTs' TSPCK would be a good way of providing insightful implications. Therefore, further studies should be conducted on possible ways of encouraging the interactive use of all content-specific knowledge components in the pre-service teacher education programmes.

References

Abell, S. K. (2008). Twenty Years Later : Does pedagogical content knowledge remain a useful idea ? Twenty Years Later : Does pedagogical content knowledge remain a useful idea ? *International Journal of Science Education*, *30*(10), 1405–1416.

Adadan, E., & Oner, D. (2014). Exploring the Progression in Preservice Chemistry Teachers ' Pedagogical Content Knowledge Representations : The Case of " Behavior of Gases ." *Research in Science Education*, *44*, 829–858. https://doi.org/doi.org/10.1007/s11165-014-9401-6

Ajjawi, R., & Boud, D. (2017). Researching feedback dialogue: an interactional analysis approach. *Assessment & Evaluation in Higher Education*, *42*(2), 252–265.

Akın, F. N., & Uzuntiryaki-Kondakci, E. (2018). The nature of the interplay among components of pedagogical content knowledge in reaction rate and chemical equilibrium topics of novice and experienced chemistry teachers. *Chemistry Education Research and Practice*, *19*(1), 80–105.

Aldrich, J. (2018). *Using IBM® SPSS® Statistics: An interactive hands-on approach*. Sage Publications.

Alonzo, A., Berry, A., & Nilsson, P. (2019). Unpacking the Complexity of Science Teachers' PCK in Action: Enacted and Personal PCK. In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 271–286). Springer, Singapore.

Alonzo, A., Kobarg, M., & Seidel, T. (2012). Pedagogical content knowledge as reflected in teacher–student interactions: Analysis of two video cases. *Journal of Research in Science Teaching*, *49*(10), 1211–1239.

Amelia, R., Handayanto, S., & Muhardjito, M. (2016). The Influence of V Diagram Procedural Scaffolding in Group Investigation Towards Students with High and Low Prior Knowledge. *Jurnal Pendidikan IPA Indonesia*, *5*(1), 108–115.

Anderson, T., & Bodner, G. (2008). What can we do about 'Parker'? A case study of a good student who didn't 'get'organic chemistry. *Chemistry Education Research and Practice*, *9*(2), 93–101.

Arends, R., & Castle, S. (1991). *Learning to teach (Vol. 2)*. New York: McGraw-Hill.

Ayas, A., & Demirbaş, A. (1997). Turkish Secondary Students' Conception of Introductory Chemistry Concepts. *Journal of Chemical Education*, *74*(5), 518–521.

Aydeniz, M., & Kirbulut, Z. (2014). Exploring challenges of assessing pre-service science teachers' pedagogical content knowledge (PCK). *Asia-Pacific Journal of Teacher Education*, *42*(2), 147–166.

Aydin, S., & Boz, Y. (2013). The nature of integration among PCK components : A case study of two experienced chemistry teachers. *Chemistry Education Research and Practice*, *14*(4), 615–624. https://doi.org/doi.org/10.1039/c3rp00095h

Aydin, S., Demirdogen, B., Akin, F. N., Uzuntiryaki-Kondakci, E., & Tarkin, A. (2015). The nature and development of interaction among components of pedagogical content knowledge in practicum. *Teaching and Teacher Education*, *46*, 37–50.

Aydin, S., Friedrichsen, P., Boz, Y., & Hanuscin, D. (2014). Examination of the topic-specific nature of electrochemical cells and nuclear reactions. *Chemistry Education Research and Practice*, *15*, (658–674. https://doi.org/doi.org/10.1039/C4RP00105B

Ball, D., & Forzani, F. (2009). The work of teaching and the challenge for teacher education.

Journal of Teacher Education, *60*(5), 497–511.
Barradell, S., & Kennedy-Jones, M. (2015). Threshold concepts, student learning and curriculum: making connections between theory and practice. *Innovations in Education and Teaching International*, *52*(5), 536–545.
Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., … Tsai, Y. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American Educational Research Journal*, *47*(1), 133–180.
Baxter, J., & Lederman, N. (1999). Assessment and measurement of pedagogical content knowledge. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 147–161). Springer, Dordrecht.
Bertram, A., & Loughran, J. (2012). Science teachers' views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education*, *42*(6), 1027–1047.
Blömeke, S., Olsen, R. V, & Suhl, U. (2016). Relation of Student Achievement to the Quality of Their Teachers and Instructional Quality. In *Teacher Quality, Instructional Quality and Student Outcomes* (pp. 21–50). Springer International.
Bond, T., & Fox, C. (2015). *Applying the Rasch model: Fundamental measurement in the human sciences*. Routledge.
Boone, W., Staver, J., & Yale, M. (2014). *Rasch analysis in the human sciences*. Dordrecht, the Netherlands: Springer.
Boud, D., & Molloy, E. (2013). Rethinking models of feedback for learning: the challenge of design. *Assessment & Evaluation in Higher Education*, *38*(6), 698–712.
Bradley, J., & Brand, M. (1985). Stamping out misconceptions. *Journal of Chemical Education*, *62*(4), 318.
Broadhead, P. (1996). School Improvement. What can pupils tell us? *Journal of Education for Teaching*, *22*(3), 339.
Bussey, T., Orgill, M., & Crippen, K. (2013). Variation theory: A theory of learning and a useful theoretical framework for chemical education research. *Chemistry Education Research and Practice*, *14*(1), 9–22.
Callingham, R., Carmichael, C., & Watson, J. (2016). Explaining student achievement: The influence of teachers' pedagogical content knowledge in statistics. *International Journal of Science and Mathematics Education*, *14*(7), 1339–1357.
Can, H., & Boz, Y. (2011). Evaluation of eleventh grade Turkish pupils ' comprehension of general chemistry concepts. In *Asia-Pacific Forum on Science Learning and Teaching* (Vol. 12, pp. 1–22).
Can, H., & Boz, Y. (2016). Structuring cooperative learning for motivation and conceptual change in the concepts of mixtures. *International Journal of Science and Mathematics Education*, *14*(4), 635–657.
Carlson, J., & Daehler, K. R. (2019). The refined consensus model of pedagogical content knowledge in science education. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77-92). Springer, Singapore.
Carlson, J., Gess-Newsome, J., Gardner, A., & Taylor, J. A. (2013). A Framework for Developing Pedagogical Content Knowledge: The Role of Transformative Professional Development and Educative Curriculum Materials. *ESERA Conference*.
Carlson, J., Stokes, L., Helms, J., Gess-Newsome, J., & Gardner, A. (2015). The PCK summit: A process and structure for challenging current ideas, provoking future work, and considering

new directions. In *Re-examining pedagogical content knowledge in science education* (pp. 24–37). Routledge.
Caruth, G. (2013). Demystifying Mixed Methods Research Design : A Review of the Literature. *Mevlana International Journal of Education (MIJE)*, *3*(2), 112–122.
Chan, K., & Hume, A. (2019). Towards a consensus model: Literature review of how science teachers' pedagogical content knowledge is investigated in empirical studies. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 3–76). Springer, Singapore.
Chan, K., & Yung, B. (2015). On-site pedagogical content knowledge development. *International Journal of Science Education*, *37*(8), 1246–1278.
Chan, K., & Yung, B. (2018). Developing pedagogical content knowledge for teaching a new topic: more than teaching experience and subject matter knowledge. *Research in Science Education*, *48*(2), 233–265.
Cheng, M., & Gilbert, J. (2009). Towards a better utilization of diagrams in research into the use of representative levels in chemical education. In *Multipe representations in chemical education* (pp. 55–73). Springer Netherlands.
Cohen, L., Manion, L., & Morrison, K. (2013). *Research Methods in Education*. Routledge.
Cooper, R., Loughran, J., & Berry, A. (2015). Science teachers' PCK: Understanding sophisticated practice. In *Re-examining pedagogical content knowledge in science education* (pp. 70–80). Routledge.
Creswell, J. (2012). *Education research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). USA: Pearson Education Inc.
Creswell, J. (2013). *Research design Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage.
Creswell, J. (2015). *A concise introduction to mixed methods research*. Thousand Oaks, CA: Sage.
Creswell, J., & Clark, P. (2017). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage.
Cross, D., & Lepareur, C. (2015). PCK at Stake in Teacher–Student Interaction in Relation to Students' Difficulties. In *Understanding Science Teachers' Professional Knowledge Growth* (pp. 47–61). Sense Publishers.
Daehler, K. R., Heller, J. I., & Wong, N. (2015). Supporting growth of pedagogical content knowledge in science. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 55-69). London: Routledge.
Davidowitz, B., & Potgieter, M. (2016). Use of the Rasch measurement model to explore the relationship between content knowledge and topic-specific pedagogical content knowledge for organic chemistry. *International Journal of Science Education*, *38*(9), 1483–1503.
Davidowitz, B., & Vokwana, N. (2014). Developing an instrument to assess Grade 12 teachers' TSPCK in organic chemistry. *Exploring Mathematics and Science Teachers' Knowledge: Windows into Teacher Thinking*, 178–194.
Deng, Z. (2018). Pedagogical content knowledge reconceived: Bringing curriculum thinking into the conversation on teachers' content knowledge. *Teaching and Teacher Education*, *72*, 155–164.
Denscombe, M. (2008). Communities of Practice. *Journal of Mixed Methods Research*, *2*(3), 270–283.
Depaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A

systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education*. https://doi.org/10.1016/j.tate.2013.03.001
Department of Basic Education. (2019). *National Senior Certificate 2018 Diagnostic report*. Pretoria: Government Printer.
Department of Higher Education and Training. (2015). National Qualifications Framework Act (67/2008): Revised policy on the minimum requirements for teacher education qualifications. *Government Gazette*, *596*, 1–72.
Domin, D., Al-Masum, M., & Mensah, J. (2008). Students' categorizations of organic compounds. *Chemistry Education Research and Practice*, *9*(2), 114–121.
Driscoll, D. (2011). Introduction to Primary Research : Observations, Surveys, and Interviews. In C. Lowe & P. Zemliansky (Eds.), *Writing Spaces: Readings on Writing* (p. Vol. 1).
Duit, R., Schecker, H., Höttecke, D., & Niedderer, H. (2014). Teaching physics. *Handbook of Research on Science Education*, *2*, 434–456.
Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*(6), 671–688.
Eisner, E. (2002). From episteme to phronesis to artistry in the study and improvement of teaching. *Teaching and Teacher Education*, *18*(4), 375–385.
Evens, M., Elen, J., & Depaepe, F. (2015). Developing Pedagogical Content Knowledge : Lessons Learned from Intervention Studies. *Educational Research International*, *2015*, 1–23.
Evens, M., Elen, J., Larmuseau, C., & Depaepe, F. (2018). Promoting the development of teacher professional knowledge: Integrating content and pedagogy in teacher education. *Teaching and Teacher Education*, *75*, 244–258.
Ferguson, R., & Bodner, G. (2008). Making sense of the arrow-pushing formalism among chemistry majors enrolled in organic chemistry. *Chemistry Education Research and Practice*, *9*(2), 102–113.
Fernández-Balboa, J., & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching and Teacher Education*, *11*(3), 293–306.
Förtsch, C., Werner, S., Von-Kotzebue, L., & Neuhaus, B. (2016). Effects of biology teachers' professional knowledge and cognitive activation on students' achievement. *International Journal of Science Education*, *38*(17), 2642–2666.
Frels, R., & Onwuegbuzie, A. (2013). Administering Quantitative Instruments With Qualitative Interviews : A Mixed Research Approach. *Journal of Counseling & Development*, *91*(April), 184–194. https://doi.org/doi.org/10.1002/j.1556-6676.2013.00085.x
Geddis, A. (1993). Transforming subject-matter knowledge in learning to reflect on teaching. *International Journal of Science Education*, *15*(6), 673–683.
Geddis, A. N, Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education*, *77*(6), 575–591.
Geddis, A., & Wood, E. (1997). Transformation of Subject Matter and managing dilemmas: A case study in Teacher Education. *Teaching and Teacher Education*, *13*(6), 611–626.
Geddis, Arthur N., & Wood, E. (1997). Transforming subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education*, *13*(6), 611–626. https://doi.org/10.1016/S0742-051X(97)80004-2
Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the linking from the PCK Summit. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 28–42). London: Routledge.

Gess-Newsome, J., Taylor, J. A., Carlson, J., Gardner, A. L., Wilson, C. D., & Stuhlsatz, M. A. (2019). Teacher pedagogical content knowledge, practice, and student achievement. *International Journal of Science Education*, *41*(7), 944–963.

Gholami, K., & Husu, J. (2010). How do teachers reason about their practice? Representing the epistemic nature of teachers' practical knowledge. *Teaching and Teacher Education*, *26*(8), 1520–1529.

Graulich, N. (2015). The tip of the iceberg in organic chemistry classes: how do students deal with the invisible? *Chemistry Education Research and Practice*, *16*(1), 9–21.

Greasley, P. (2007). *Quantitative data analysis using SPSS: an introduction for health & social science*. McGraw-Hill Education (UK).

Greene, C., Benjamin, L., & Goodyear, L. (2001). *The Merits of Mixing Methods in Evaluation* (Vol. 7). Thousand Oaks and New Delhi: Sage.

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

Gunckel, K. L., Covitt, B. A., & Salinas, I. (2018). Learning progressions as tools for supporting teacher content knowledge and pedagogical content knowledge about water in environmental systems. *Journal of Research in Science Teaching*, *55*(9), 1339–1362.

Gustafsson, J., & Nilsen, T. (2016). The impact of school climate and teacher quality on mathematics achievement: A difference-in-differences approach. *Teacher Quality, Instructional Quality and Student Outcomes*, *2*, 81–95.

Guzey, S., & Roehrig, G. (2009). Teaching science with technology: case studies of science teachers' development of technological pedagogical content knowledge (TPCK). *Contemporary Issues in Technology and Teacher Education*, *9*(1), 25–45.

Halim, L., Abdullah, S., & Meerah, T. (2014). Students ' Perceptions of Their Science Teachers ' Pedagogical Content Knowledge. *Journal of Science Education and Technology*, *23*(2), 227–237. https://doi.org/doi.org/10.1007/s10956-013-9484-2

Hanhimäki, E. (2011). Moral professionalism in interaction. In *Educators' relational moral voices in urban schools. Münster: Waxmann*.

Hartas, D. (2015). *Educational research and inquiry: Qualitative and quantitative approaches*. Bloomsbury Publishing.

Helmke, A. (2014). *Unterrichtsqualität und Lehrerprofessionalität [Instructional quality and teachers' professional competence]*. Seelze-Velber: Klett/Kallmeyer.

Henze, I., & Van Driel, J. (2015). Toward a more comprehensive way to capture PCK in its complexity. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 130–144). Routledge.

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

Hill, H., Ball, D., & Schilling, S. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education*, 372–400.

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of Teachers' Mathematical Knowledge for Teaching on Student Achievement. *American Educational Research Association*, *42*(2), 371–406.

Hinkle, D., Wiersma, W., & Jurs, S. (2003). *Applied statistics for the behavioral sciences*. Houghton Mifflin College Division.

Holmberg, J., Fransson, G., & Fors, U. (2018). Teachers' pedagogical reasoning and reframing of practice in digital contexts. *The International Journal of Information and Learning Technology*, *35*(2), 130–142.

Hrin, T., Milenković, D., & Segedinac, M. (2016). The effect of systemic synthesis questions [SSynQs] on students' performance and meaningful learning in secondary organic chemistry teaching. *International Journal of Science and Mathematics Education*, *14*(5), 805–824.

Hume, A., & Berry, A. (2013). Enhancing the Practicum Experience for Pre-service Chemistry Teachers Through Collaborative CoRe Design with Mentor Teachers. *Res Sci Educ*, *43*, 2107–2136. https://doi.org/doi.org/10.1007/s11165-012-9346-6

Jang, S. (2011). Assessing college students' perceptions of a case teacher's pedagogical content knowledge using a newly developed instrument. *Higher Education*, *61*(6), 663–678.

Jang, S., Guan, S., & Hsieh, H. (2009). Developing an instrument for assessing college students ' perceptions of teachers ' pedagogical content knowledge. *Procedia Social and Behavioral Sciences*, *1*(2009), 596–606. https://doi.org/doi.org/10.1016/j.sbspro.2009.01.107

Jawahar, K., & Dempster, E. (2013). A systemic functional linguistic analysis of the utterances of three South African Physical Sciences teachers. *International Journal of Science Education*, *35*(9), 1425–1453.

Johnson, L., Vare, J., & Evers, R. (2013). Let theory be your guide: Assessing the moral work of teaching. In M. Snager & R. Osguthorpe (Eds.), *The moral work of teaching and teacher education. Preparing and supporting practitioners* (pp. 92–114). New York/London: Teachers College Press.

Johnstone, A. (2006). Chemical education research in Glasgow in perspective. *Chem. Educ. Res. Pract*, *7*, 49–63.

Jonassen, D., & Grabowski, B. (1993). *Handbook of individual differences, learning, and instruction*. Hillsdale, NJ: Erlbaum.

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

Katz, M. (1996). Teaching organic chemistry via student-directed learning: A technique that promotes independence and responsibility in the student. *Journal of Chemical Education*, *73*(5), 440.

Kaya, O. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers:'Ozone layer depletion'as an example. *International Journal of Science Education*, *31*(7), 961–988.

Keller, M., Neumann, K., & Fischer, H. (2017). The impact of physics teachers' pedagogical content knowledge and motivation on students' achievement and interest. *Journal of Research in Science Teaching*, *54*(5), 586–614.

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

Kind, V., & Chan, K. (2019). Resolving the amalgam: connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education*, *41*(7), 964–978.

Kinsella, E., & Pitman, A. (2012). *Phronesis as professional knowledge: Practical wisdom in the professions*. Springer Science & Business Media.

Kirschner, S., Borowski, A., Fischer, H., Gess-Newsome, J., & Von-Aufschnaiter, C. (2016). Developing and evaluating a paper-and-pencil test to assess components of physics teachers' pedagogical content knowledge. *International Journal of Science Education*, *38*(8), 1343–1372.

Klaassen, C. A., Osguthorpe, R. D., & Sanger, M. N. (2016). Teacher Education as a Moral Endevour. In J. Loughran & M. L. Hamilton (Eds.), *International Handbook of Teacher Education* (pp. 532–557).

Krathwohl, D. (2002). A revision of Bloom's taxonomy: An overview. *Theory into Practice*, *41*(4), 212–218.

Krauss, S., Brunner, M., Kunter, M., Baumert, J., Blum, W., Neubrand, M., & Jordan, A. (2008). Pedagogical Content Knowledge and Content Knowledge of Secondary Mathematics Teachers. *Journal of Educational Psychology*, *100*(3), 716–725.

Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage Publications.

Kunter, M., Klusmann, U., Baumert, J., Richter, D., Voss, T., & Hachfeld, A. (2013). Professional competence of teachers: Effects on instructional quality and student development. *Journal of Educational Psychology*, *105*(3), 805–820.

Kuter, S., Gazi, Z., & Aksal, F. (2012). Examination of Co-construction of Knowledge in Videotaped simulated Instruction. *Educational Technology & Society*, *15*(1), 174–184.

Ladachart, L., & Ladachart, L. (2019). Thai Science Educators' Perspectives on Students' Prior Knowledge: A Documentary Research. *Science Education International*, *30*(2).

Lam, R., & Muldner, K. (2017). Manipulating cognitive engagement in preparation-to-collaborate tasks and the effects on learning. *Learning and Instruction*, *52*, 90–101.

Lancaster, J., & Bain, A. (2019). Designing University Courses to Improve Pre- Service Teachers' Pedagogical Content Knowledge of Evidence-Based Inclusive Practice. *Australian Journal of Teacher Education*, *44*(2), 51–65.

Landis, J., & Koch, G. (1977). The mesuremenent of observer agreement for categorical data. *Biometrics*, *33*, 159–174.

Lange, K., Kleickmann, T., & Moller, K. (2011). Elementary Teachers' Pedagogical Content Knowledge and Student Achievement in Science Education. In C. Bruguiere, A. Tiberghien, & P. Clement (Eds.), *Science Learning and Citizenship. Proceedings of the Ninth ESERA-Conference 2011*.

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

Lee, S., & Branch, R. M. (2018). Students' beliefs about teaching and learning and their perceptions of student-centred learning environments. *Innovations in Education and Teaching International*, *55*(5), 585–593.

Liepertz, S., & Borowski, A. (2019). Testing the Consensus Model: relationships among physics teachers' professional knowledge, interconnectedness of content structure and student achievement. *International Journal of Science Education*, *41*(7), 890–910.

Linacre, J. (2014). A user's guide to FACETS Rasch-model computer programs. *Retrieved December*, *8*, 2018.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry* (Vol. 75). Sage.

Liu, M. (2012). Discussing teaching videocases online: Perspectives of preservice and inservice EFL teachers in Taiwan. *Computers & Education*, *59*, 120–133.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and Developing Science Teachers'*

Pedagogical Content Knowledge (Vol. 12). Springer Science & Business Media.
Loughran, J., Berry, A., Mulhall, P., & Woolnough, J. (2006). *Understanding and valuing the development of pedagogical content knowledge in science teacher education*. *Towards research-based science teacher education* (Vol 10). Springer Science & Business Media.
Loughran, J., Gunstone, R., Berry, A., Milroy, P., & Mulhall, P. (2000). Science Cases in Action: Developing an Understanding of Science Teachers' Pedagogical Content Knowledge.
Loughran, J., Mulhall, P., & Berry, A. (2004). In Search of Pedagogical Content Knowledge in Science : Developing Ways of Articulating and Documenting Professional Practice. *Journal of Research in Science Teaching*, *41*(4), 370–391.
Luna, C., & Aclan, E. (2015). The Influence of Teachers' Mathematics Pedagogy Content Knowledge Training on Pupils' Mathematics Achievement. *American Journal of Educational Research*, *3*(10), 1311–1314.
Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge*. Dordrecht: Kluwer.
Mahler, D., Großschedl, J., & Harms, U. (2017). Using doubly latent multilevel analysis to elucidate relationships between science teachers' professional knowledge and students' performance. *International Journal of Science Education*, *39*(2), 213–237.
Mathewson, M., & Reid, J. (2017). (Re) turning to practice in teacher education: embodied knowledge in learning to teach. *Teachers and Teaching*, *23*(1), 42–58.
Maton, K. (2009). Cumulative and segmented learning: Exploring the Role of Curriculum Structures in Knowledge-Building. *British Journal of Sociology of Education*, *30*(1), 43.
Mavhunga, E. (2012). *Explicit inclusion of topic specific knowledge for teaching and the development of PCK in pre-service science teachers (Doctoral Thesis)*. University of the Witwatersrand.
Mavhunga, E. (2016). Transfer of the pedagogical transformation competence across chemistry topics. *Chemistry Education Research and Practice*, 1–7.
Mavhunga, E. (2018). Revealing the Structural Complexity of Component Interactions of Topic-Specific PCK when Planning to Teach. *Research in Science Education*, 1–22.
Mavhunga, E. (2019). Exposing Pathways for Developing Teacher Pedagogical Content Knowledge at the Topic Level in Science. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 129–148). Springer, Singapore.
Mavhunga, E., Ibrahim, B., Qhobela, M., & Rollnick, M. (2016). Student teachers' competence to transfer strategies for developing PCK for electric circuits to another physical sciences topic. *African Journal of Research in Mathematics, Science and Technology Education*, *20*(3), 299–313.
Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service Teachers. *African Journal of Research in Mathematics, Science and Technology Education*, *17*(1–2), 113–125.
Mavhunga, E., & Rollnick, M. (2017). Implementing PCK Topic by Topic in Methodology Courses. In *Designing and Teaching the Secondary Science Methods Course* (pp. 149–170). Brill Sense.
Mazibe, E., Coetzee, C., & Gaigher, E. (2018). A comparison between reported and enacted pedagogical content knowledge (PCK) about graphs of motion. *Research in Science Education*, 1–24.
Mcmillan, H., & Schumacher, S. (2014). *Research in Education Evidence-Based Inquiry* (7th

ed.). Edinburgh Gate Harlow: Pearson Education Limited.
Mercer, N., & Dawes, L. (2014). The study of talk between teachers and students, from the 1970s until the 2010s. *Oxford Review of Education*, *40*(4), 430–445.
Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). United States of America: Jossey-Bass.
Miheso, J. (2018). *Examining the classroom teaching of beginning physical science teachers who graduated from a topic specific pedagogical content knowledge based undergraduate programme*. (Doctoral thesis) University of the Witwatersrand, Johannesburg.
Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage.
Morrison, C., & Fitzpatrick, S. (1992). *Direct and indirect equating: A comparison of four methods using the Rasch model.Measurement and Evaluation Center*. The University of Texas at Austin. ERIC Document Reproduction Services No. ED 375152.
Morse, J. (2016). *Mixed method design: Principles and procedures*. Routledge.
Mthethwa-kunene, E., Onwu, G., & Villiers, R. (2015). Exploring Biology Teachers ' Pedagogical Content Knowledge in the Teaching of Genetics in Swaziland Science Classrooms. *International Journal of Science Education*, *37*(7), 1140–1165. https://doi.org/doi.org/10.1080/09500693.2015.1022624
Mukaka, M. (2012). A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal*, *24*(3), 69–71.
Muklis, M., Abidin, C., & Pamungkas, M. (2018). The Implementation of Cumulative Learning Theory in Calculating Triangular Prism and Tube Volumes. In *Journal of Physics: Conference Series*. IOP Publishing.
Narvaez, D., & Gleason, T. (2007). The relation of moral judgment development and educational experience to recall of moral narratives and expository texts. *The Journal of Genetic Psychology*, *168*(3), 251–276.
Neumann, K., Kind, V., & Harms, U. (2019). Probing the amalgam: the relationship between science teachers' content, pedagogical and pedagogical content knowledge. *International Journal of Science Education*, *41*(7), 847–861.
Nezvalova, D. (2011). Researching science teacher pedagogical content knowledge. *Problems of Education in the 21st Century*, *35*, 104–118.
Ngozi-Olehi, L., Duru, C., Uchegbu, R., & Amanze, K. (2018). Improving Interest and Performance in Organic Chemistry Pedagogy by Incooperating Animations. *American Journal of Educational Research*, *6*(3), 277–280.
Nicoll, G. (2001). A Report Of Undergraduates' Bonding Alternative Conceptions. *International Journal of Science Education*, *23*(7), 707–730.
Nilsson, P., & Karlsson, G. (2019). Capturing student teachers' pedagogical content knowledge (PCK) using CoRes and digital technology. *International Journal of Science Education*, *41*(4), 419–447.
Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education*, *23*(7), 699–721.
O'Cathain. (2010). Assessing the quality of mixed methods research: Toward a comprehensive framework. In *Handbook of mixed methods in social and behavioral research* (pp. 531–555).
O'Dwyer, A., & Childs, P. E. (2017). Who says organic chemistry is difficult? Exploring

perspectives and perceptions. *EURASIA J. Math. Sci. Technol. Educ*, *13*, 3599–3620.
Oh, P., & Oh, S. (2011). What teachers of science need to know about models: An overview. *International Journal of Science Education*, *33*(8), 1109–1130.
Oh, P. S., & Kim, K. S. (2013). Pedagogical Transformations of Science Content Knowledge in Korean Elementary Classrooms. *International Journal of Science Education*, *35*(9), 1590–1624. https://doi.org/doi.org/10.1080/09500693.2012.719246
Okeke, C., & Wyk, M. (2015). *Educational Research: An African Approach*.
Opie, C. (2004). Research procedures. In *Doing Educational Research* (pp. 95–129). London: Sage Publication.
Ortiz, C. B. (2019). STUDENTS' UNDERSTANDING OF PRE-ORGANIC CHEMISTRY CONCEPTS: CHEMICAL BONDING. *INTERNATIONAL JOURNAL ON LANGUAGE, RESEARCH AND EDUCATION STUDIES*, *3*(1), 33–42.
Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, 25(9), 1049-1079.
Oyoo, S. O. (2017). Learner outcomes in science in South Africa: role of the nature of learner difficulties with the language for learning and teaching science. *Research in Science Education*, *47*(4), 783–804.
Padilla, K., & Van Driel, J. (2011). The relationships between PCK components: the case of quantum chemistry professors. *Chemistry Education Research and Practice*, *12*(3), 367–378.
Pansell, A., & Bjorklund-Boistrup, L. (2018). Mathematics Teachers' Teaching Practices in Relation to Textbooks: Exploring Praxeologies. *The Mathematics Enthusiast*, *15*(3), 541–562.
Park, S., & Chen, Y. (2012). Mapping Out the Integration of the Components of Pedagogical Content Knowledge (PCK): Examples From High School Biology Classrooms. *J. Res. Sci. Teach.*, *49*(7), 922–941. https://doi.org/10.1002/tea.21022
Park, S., Chen, Y., & Jang, J. (2008). Developing measures of teachers' pedagogical content knowledge for teaching high school biology. In *International conference of the Association for Science Teacher Education*. St. Louis, MI. January.
Park, S., Jang, J., Chen, Y., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. *Research in Science Education*, *41*(2), 245–260.
Park, S., & Oliver, J. (2008). Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals. *Research in Science Education*, *38*(3), 261–284. https://doi.org/10.1007/s11165-007-9049-6
Park, S., & Suh, J. K. (2019). The PCK Map Approach to Capturing the Complexity of Enacted PCK (ePCK) and Pedagogical Reasoning in Science Teaching. In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 185–197). Springer, Singapore.
Park, S., Suh, J., & Seo, K. (2018). Development and validation of measures of secondary science teachers' PCK for teaching photosynthesis. *Research in Science Education*, *48*(3), 549–573.
Patton, M. Q. (2015). *Qualitative research and evaluation methods*. Thousand Oaks, CA: Sage.
Pea, R. D. (1987). Socializing the knowledge transfer problem. *International Journal of Education Research*, *11*, 639–663.
Penuel, W. R., Gallagher, L. P., Moorthy, S., Gallagher, L. P., & Moorthy, S. (2011). Preparing

Teachers to Design Sequences of Instruction in Earth Systems Science : A Comparison of Three Professional Development Programs. *American Educational Research Journal*, *48*(4), 996–1025. https://doi.org/doi.org/10.3102/0002831211410864

Pitjeng-Mosabala, P., & Rollnick, M. (2018). Exploring the development of novice unqualified graduate teachers' topic-specific PCK in teaching the particulate nature of matter in South Africa's classrooms. *International Journal of Science Education*, *40*(7), 742–770.

Pitjeng, P. (2014). Novice unqualified graduate science teachers' topic specific pedagogical content knowledge, content knowledge and their beliefs about teaching. In H. Venkat, M. Rollnick, M. Askew, & J. Loughran (Eds.), *Exploring Mathematics and Science Teachers' Knowledge: Windows into teacher thinking* (pp. 65–83). Oxford: Routledge.

Postman, N., & Weingartner, C. (1971). *Teaching as a subversive activity*. Harmondsworth: Penguin Books in association with Pitman Publishing.

Prain, V., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education*, *34*(17), 2751–2773. https://doi.org/doi.org/10.1080/09500693.2011.626462

Punch, K. (2009). *Introduction to research methods in education*. Sage.

Ramnarain, U., & Fortus, D. (2013). South African physical sciences teachers' perceptions of new content in a revised curriculum. *South African Journal of Education*, *33*(1).

Reddy, V., Visser, M., Winnaar, L., Arends, F., Juan, A., Prinsloo, C., & Isdale, K. (2016). TIMSS 2015: Highlights of mathematics and science achievement of grade 9 South African learners. *Retrieved from Http://Www.Hsrc.Ac.Za/En/Research-Data/Ktree-Doc/17642*.

Richardson, G., Byrne, L., & Liang, L. (2018). Making learning visible: Developing preservice teachers' pedagogical content knowledge and teaching efficacy beliefs in environmental education. *Applied Environmental Education & Communication*, *17*(1), 41–56.

Richmond, R. (2013). *Introduction to Piaget*. Routledge.

Riese, J., & Reinhold, P. (2009). Measuring physics student teachers' pedagogical Content knowledge as an indicator of their Professional action competence. In *Paper presented at the European Science Education Research Association 2009 Conference*. Istanbul, Turkey.

Rissanen, I., Kuusisto, E., Hanhimäki, E., & Tirri, K. (2018). The implications of teachers' implicit theories for moral education: A case study from Finland. *Journal of Moral Education*, *47*(1), 63–77.

Rollnick, M. (2017). Learning about semi-conductors for teaching—The role played by content knowledge in pedagogical content knowledge (PCK) development. *Research in Science Education*, *47*(4), 833–868.

Rollnick, M., & Mavhunga, E. (2014). The relationship of PCK knowledge to practice: A case study of two pre-service teachers teaching chemical equilibrium. In *Conference of the Southern African Association for Research in Mathematics, Science and Technology Education*. Port Elizabeth, South Africa.

Rollnick, M., & Mavhunga, E. (2015). The PCK summit and its effect on work in South Africa. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 135–146). London: Routlege.

Roth, K., Garnier, H., Chen, C., Lemmens, M., Schwille, K., & Wickler, N. (2011). Videobased lesson analysis: Effective science PD for teacher and student learning. *Journal of Research in Science Teaching*, *48*(2), 117–148.

Rusznyak, L. (2008). *Learning to teach: Developmental teaching patterns of student teachers*. (Doctoral thesis) University of the Witwatersrand, Johannesburg.

Sadler, P., Sonnert, G., Coyle, H., Cook-Smith, N., & Miller, J. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal*, *50*(5), 1020–1049.

Sanger, M. (2008). What we need to prepare teachers for the moral nature of their work. *Journal of Curriculum Studies*, *40*(2), 169–185. https://doi.org/doi.org/10.1080/00220270701670856

Sanger, M., Osguthorpe, R., & Fenstermacher, G. (2015). The moral work of teaching and teacher education: Preparing and supporting practitioners. Teachers College Press.

Savas, P. (2012). Use of digital video recording in the preparation stage of pre-service foreign language teachers' microteachings. *International Journal on New Trends in Education and Their Implications*, *3*(3), 107–116.

Schleicher, A. (2011). The Quality of an Education System Cannot Exceed the Quality of its Teachers. *Journal of Teacher Education*, *62*(2), 202–221.

Schneider, B. (2004). Building a Scientific Community: The Need for Replication. *Teachers College Record*, *106*(7), 1471-1483. Retrieved from http://dx.doi.org/10.1111/j.1467-9620.2004.00386.x

Schneider, R. (2015). PEDAGOGICAL CONTENT KNOWLEDGE RECONSIDERED. In *Re-examining pedagogical content knowledge in science education* (p. pp 162).

Schön, D. (1983). *Educating the reflective practitioner*. San Francisco, CA: Jossey-Bass.

Senocak, E. (2009). Development of an instrument for assessing undergraduate science students' perceptions: The problem-based learning environment inventory. *Journal of Science Education and Technology*, *18*(6), 560–569.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–22.

Shulman, L. S. (2015). PCK: Its genesis and exodus. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 13–23). Routledge.

Sirhan, G. (2007). Learning difficulties in chemistry: An overview. *Journal of Turkish Science Education*, *4*(2), 2–20.

Smith, P. S., & Banilower, E. R. (2015). Assessing PCK: A new application of the uncertainty principle. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 88–103). Oxford: Routledge.

Sockett, H. (1993). *The moral base for teacher professionalism*. Teachers College Press, 1234 Amsterdam Avenue.

Spaull, N. (2013). *South Africa's education crisis: The quality of education in South Africa 1994-2011*. Retrieved from doi.org/Report Commissioned by CDE

Star, J., & Strickland, S. (2008). Learning to observe: Using video to improve preservice mathematics teachers' ability to notice. *Journal of Mathematics Teacher Education*, *11*(2), 107–125.

Stengel, B. (2013). Teaching moral responsibility: Practical reasoning in a pedagogical "wonderland." In M. Sanger & R. Osguthorpe (Eds.), *The moral work of teaching and teacher education. Preparing and supporting practitioners* (pp. 44–59). New York/London: Teachers College Press.

Stingler, J., Gallimore, R., & Hiebert, J. (2000). Using vidoe surveys to compare classroom and teaching across cultures: Examples and lessons from the TIMSS video studies. *Educational*

Psychologist, *35*(2), 87–100.
Stürmer, K., & Seidel, T. (2017). A standardized approach for measuring teachers' professional vision: The observer research tool. In *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 359–380). Springer, Cham.
Suter, W. N. (2011). *Introduction to educational research: A critical thinking approach*. Sage.
Taagepera, M., & Noori, S. (2000). Mapping students' thinking patterns in learning organic chemistry by the use of knowledge space theory. *Journal of Chemical Education*, *77*(9), 1224.
Tan, F., Whipp, P., Gagné, M., & Van-Quaquebeke, N. (2019). Students' perception of teachers' two-way feedback interactions that impact learning. *Social Psychology of Education*, *22*(1), 169–187.
Tang, S., & Choi, P. (2005). Connecting theory and practice in mentor preparation: Mentoring for the improvement of teaching and learning. *Mentoring & Tutoring: Partnership in Learning*, *13*(3), 383–401.
Tavakol, M., & Dennick, R. (2011a). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53.
Tavakol, M., & Dennick, R. (2011b). Making sense of Cronbach ' s alpha. *International Journal of Medical Education*, *2*, 53–55. https://doi.org/doi.org/10.5116/ijme.4dfb.8dfd
Taylor, N., Fleisch, B., & Shindler, J. (2019). Education scenarios for 2019. *Key Driving Forces Scenarios*, 11-12.
Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioural sciences*. Thousand Oaks, CA: Sage.
Tepner, O., & Witner, S. (2011). *Comparison of Pre-Service and In-Service Teachers' Content Knowledge and Pedagogical Content Knowledge in Chemistry*. Paper presented at the NARST Annual International conference, Orlando, Forida, 2011, April 3-6.
Terrell, S. R. (2012). Mixed-Methods Research Methodologies. *The Qualitative Report*, *17*(1), 254–280.
Tirri, K., Toom, A., & Husu, J. (2013). The Moral Matters of Teaching: A Finnish Perspective. In From teacher thinking to teachers and teaching: The evolution of a research community (pp. 223–239). Emerald Group Publishing Limited.
Treagust, D., Nieswandt, M., & Duit, R. (2000). Sources of students difficulties in learning Chemistry. *Educación Química*, *11*(2), 228–23.
Upahi, J. E., & Ramnarain, U. (2019). Representations of chemical phenomena in secondary school chemistry textbooks. *Chemistry Education Research and Practice*, *20*(1), 146–159.
Vachliotis, T., Salta, K., Vasiliou, P., & Tzougraki, C. (2011). Exploring novel tools for assessing high school students' meaningful understanding of organic reactions. *Journal of Chemical Education*, *88*(3), 337–345.
van Driel, J. H., Berry, A., & Meirink, J. (2014). Research on Science Teacher Knowledge. In *Handbook of Research on Science Education* (pp. 848–870). New York: Taylor and Francis.
van Driel, J. H., Verloop, N., & Vos, W. De. (1998). Developing Science Teachers ' Pedagogical Content Knowledge. *Journal of Research in Science Teaching*, *35*(6), 673–695.
Veal, W. R., & Makinster, J. G. (1999). Pedagogical content knowledge taxonomies. *Electronic Journal of Science Education*, *3*, 4.
Vygotsky, L. S. (1978). Internalization of higher psychological functions. In *Mind in society:*

The development of higher psychological processes (pp. 52–57).
Webb, A. (2015). Research Interviews in the Scholarship of Teaching and Learning Transformative Dialogues. *Teaching and Learning Journal*, *8*(1), 1–8.
Whitley, E., & Ball, J. (2002). Statistics review 6: Nonparametric methods. *Critical Care*, *6*(6), 1–5.
Wilkinson, K. (2016). Guide: Assessing South Africa's schooling system. Retrieved from africacheck.org/factsheets/guide-assessing-south-africas-schooling-system
Williams, J., Eames, C., Hume, A., & Lockley, J. (2012). Promoting pedagogical content knowledge development for early career secondary teachers in science and technology using content representations. *Research in Science & Technological Education*, *30*(3), 327–343.
Wilson, S., Shulman, L., Richert, A., & Calderhead, J. (1987). *Exploring teachers' thinking*. London: Cassell, 38.
Wright, B. D. (1996). Reliability and Separation. *Rasch Measurement Transactions*, *9*, 472. Retrieved from www.rasch.org/rmt/rmt94n.htm
Yip, J., Wong, S., Yick, K., Chan, K., & Wong, K. (2019). Improving quality of teaching and learning in classes by using augmented reality video. *Computers & Education*, *128*, 88–101.
Zimmerman, G. (2015). *The design and validation of an instrument to measure the topic specific pedagogical content knowledge of physical sciences teachers in electric circuits*. University of the Witwatersrand/Unpublished Masters Research Report.
Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry (general and organic). *Journal of Research in Science Teaching*, *27*(10), 1053–1065.

Appendix I: TSPCK tool in organic chemistry

ORGANIC CHEMISTRY TSPCK TOOL

The purpose of this research is to find the difficulties that pre-service teachers experience and the strategies they use when teaching organic chemistry at schools. The assessment instrument consists of organic chemistry Topic Specific Pedagogical Content Knowledge tool

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

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

There are 5 categories of questions in this tool

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

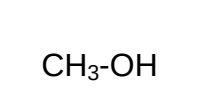
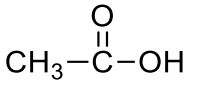
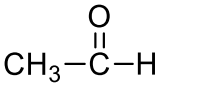
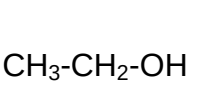
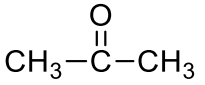
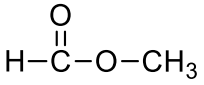
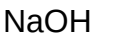
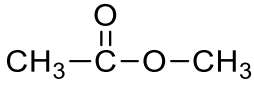
Instructions

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

Thank you for your valued input and assistance

Category A – Typical Student Responses

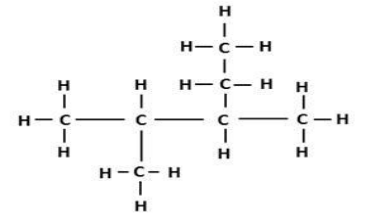
1. You hand out a worksheet to be used in a classroom activity and ask learners to select compounds that are alcohols from the table below:

1 	**2** 	**3** 	**4** 
5 	**6** 	**7** 	**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? Write your response in the space below.

2. You have asked the learners in your class to name the compound below according to the IUPAC rules. You encourage learners 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.



1 2 3 4

Both Mary and Charlie agree that this compound is 2-methyl-3-ethyl-butane. How would respond to these two learners?

Category B – Planning and Sequencing

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 **<u>three</u> 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. **Using the three selected concepts from 2 above, give the sequence you would teach them and your reasons for doing so**

Concepts	Reasons

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

5. Why is it important for students to learn about organic chemistry? Identify reasons related to:

i. Conceptual progression i.e. development of concepts
ii. Application to outside world
iii. Motivation or Interest

Category C - What makes the topic difficult to teach?

Which of the following organic chemistry concepts do you consider difficult to teach? Explain why these concepts are difficult to teach.

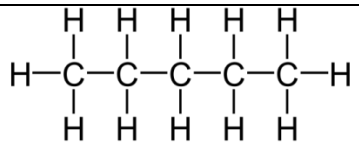
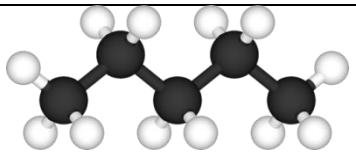
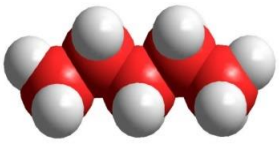
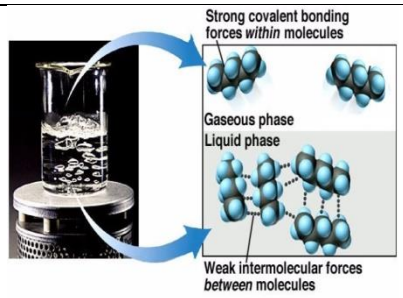
Concept	Why is it difficult to teach the concept?
Molecular formulae	
Structural formulae	
Functional groups	
IUPAC names	
Isomers	
Homologous series	
Types of organic reactions e.g. substitution, addition and elimination	
Combustion	
Esterification	

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 in 'b' 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.

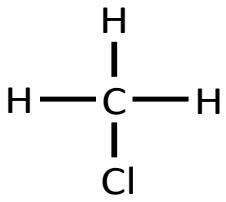
Representation	Use in teaching
1 	
2 	
3 CH_3-CH_2-CH_2-CH_2-CH_3	
4 	
5 	

Section 5 continued

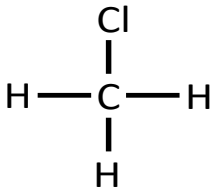
c) How would you use the representation(s) that you chose in (a) on the previous page to explain the differences in the boiling points of butane (-0.5°C) and pentane (36°C)?

Category E - Conceptual Teaching strategies

1. You draw the structure of chloromethane as shown below on the chalk board.



Teacher's Drawing

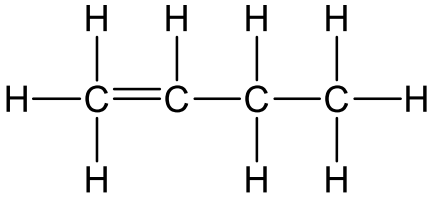


Student's Drawing

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 II: CK tool in organic chemistry

ORGANIC CHEMISTRY CK TOOL

The purpose of this research is to find the difficulties that pre-service teachers experience and the strategies they use when teaching Organic chemistry at schools. The assessment instrument consists of Organic chemistry Content Knowledge tool

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

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

Personal code:

ORGANIC CHEMISTRY BACKGROUND

1 Draw the structural formulae for each of the following compounds:

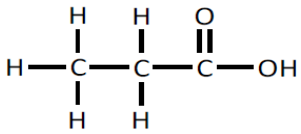
2-methylhex-3-ene	ethyl propanoate

2 Molecules with the same molecular formula can have different structures, this is known as isomerism. There are several kinds of isomerism such as structural and geometric. Answer the following questions about isomers.

a) Draw the following isomers for 2-butene.

Structural isomer of 2-butene	Geometric isomer of 2-butene

b) Structural isomers can belong to different homologous series in other words they could have different functional groups. Draw two structural isomers with different functional groups for the compound below.



Structural isomer of propanoic acid	Structural isomer of propanoic acid

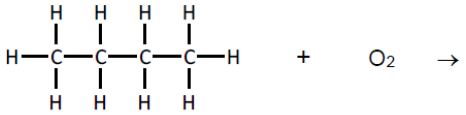
c) IUPAC name of isomer above

IUPAC name of isomer above

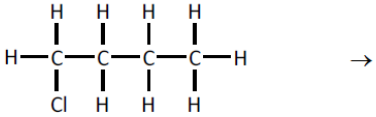
Personal code:

3 Complete each of the following chemical reactions, **balancing them where needed:**
Give the name of the organic product of each reaction.

a. **COMPLETE COMBUSTION OF BUTANE:**

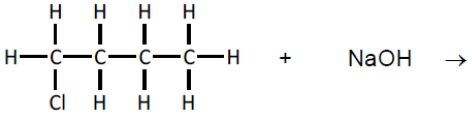


b. **ELIMINATION REACTION:**

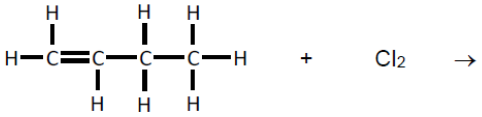


Type of elimination reaction .....

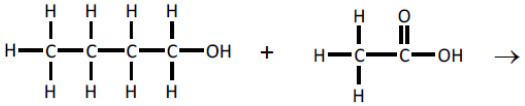
c. **SUBSTITUTION REACTION:**



d. **ADDITION REACTION**

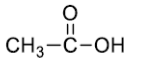
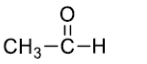
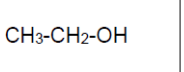
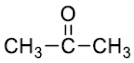
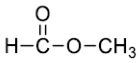
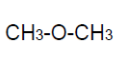
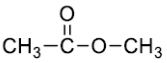


e. **ESTERIFICATION REACTION:**



Personal code:

4 The table below contains a number of organic compounds having different functional groups. Study the compounds and answer the questions that follow.

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

a)	Select which of the compounds are alcohols	
b)	Select which of the compounds are aldehydes	
c)	Select which of the compounds are ketones	
d)	Select which of the compounds are esters	
e)	Which two boxes contain the substances that are used to make the compound in box 8?	
f)	Which compound is the structural isomer of the compound in box 7?	

Personal code:

5 Study the following table and answer the questions below:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)	IUPAC name	Boiling point (°C)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

a) Why is the boiling point for hexane so much lower than that of hexan-1-ol?

b) Why is the boiling point for methanol so much lower than that of hexan-1-ol?

c) The boiling points for the carboxylic acids are not included. Do you expect their boiling points to be higher or lower than the boiling points of the alcohols with the same number of carbon atoms? **Explain** your answer.

END OF QUESTIONNAIRE

Appendix III: Content representations (CoRe)

Components of Topic Specific PCK		Big Idea 1	Big Idea 2
All these questions including formulation of Big Ideas are considered to be elements of the component of TSPCK called curricular saliency	What would you consider as Big Ideas for this topic?		
	What do you intend the learners to know about this idea?		
	Why is it important for learners to know this big idea?		
	What concepts need to be taught before teaching this big idea?		
	What else do you know about this idea (that you do not intend learners to know yet)?		
What is difficult to understand	What do you consider easy or difficult in teaching this Big Idea? Provide reasons.		
Learner Prior Knowledge	What are the typical student misconceptions in this big idea?		
	How would you go about correcting them?		
Representations	What representations would you use in your teaching strategies, and why?		
Conceptual teaching strategies	What conceptual teaching strategies would you sue in teaching this big idea?		

Appendix IV: TSPCK lesson plan template

LESSON PLAN

(Topic Specific PCK Lesson Plan)

Subject	
Grade	
Topic covered	
Specific Concept	
Allocated time	

CATEGORY A: ASPECTS RELATED TO CURRICULUR SALIENCY

1. Purpose: (What do you intend learners to know in this lesson? You can list this a set of specific outcomes)
2. List the most immediate concepts needed prior to teaching the concepts you intend to teach. Indicate how these genuinely affect your lesson.
3. Summarize your understanding of the most important *content knowledge* of this lesson.

CATEGORY B: ABOUT LEARNER PRIOR KNOWLEDGE

4. List common misconceptions and errors by learners specific to the concepts intended for this lesson.

CATEGORY D: SUMMARY OF THE TEACHING STRATEGY

5. Strategies that would be employed in teaching the concept.

CATEGORY E: SUMMARY OF THE SEQUENCE OF THE LESSON.

6. Explaining how the lesson will unfold.

CATEGORY G: SUPPORTING RESOURCES

7. Resources to be used during the lesson

CATEGORY H: CONCLUSION

8. Closure
9. Lesson reflection

Appendix V: A pre-lesson interview protocol guide

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 VI: A post-lesson interview protocol guide

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 VII: Achievement test on functional groups and IUPAC nomenclature (with marking memo)

LEARNER ACHIEVEMENT TEST
IUPAC nomenclature and functional groups of organic compounds

Instructions:

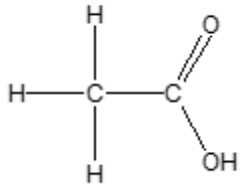
This achievement test is for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning in the topic of organic chemistry.

Write your name here:

WORKSHEET

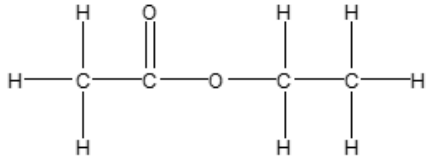
1. Identify the functional groups on the following organic molecules.

a.



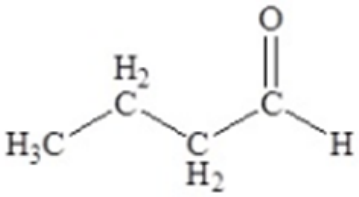
_____

b.



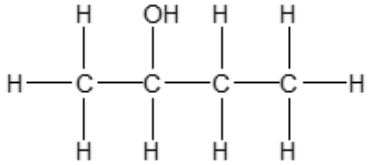
_____

c.



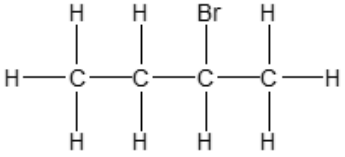
_____

d.



_____

e.



_____

2. Draw simple organic molecules that contain the following functional groups.

   a. Cycloalkane

   ---

   b. Ketone

   ---

   c. Ether

   ---

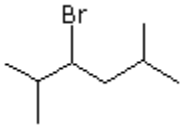
   d. Thiol

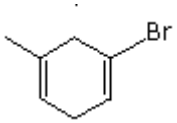
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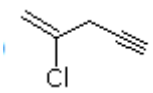
   e. Aldehyde

   ---

3. Name the following compounds according to the IUPAC system:

(i) 

(ii) 

(iii) 

---

4. Write the structural formula for the following organic compounds

(i) Dichloromethane

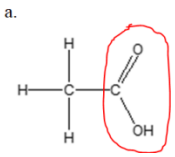
(ii) butane-1,4-diamine

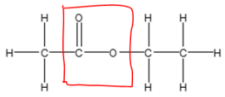
(iii) diethyl ether

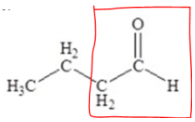
(iv) 1-butene

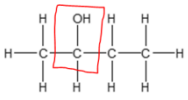
……

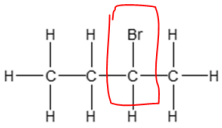
Marking memorandum

1a  Carboxylic acid functional group (1mark)

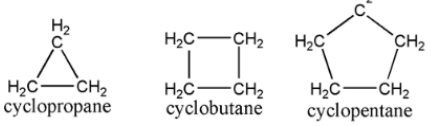
1b  Ester functional group (1mark)

1c  Aldehyde functional group (1mark)

1d  Alcohol functional group (1mark)

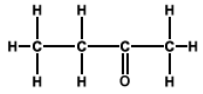
1e  Haloalkane functional group (1mark)

2a A molecule of cylcoalkane for 1 mark e.g.



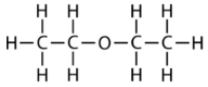
(1 mark)

2b A molecule of ketone for 1 mark e.g.

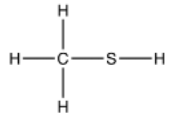


(1mark)

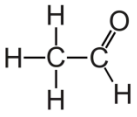
2c A molecule of ether for 1 mark e.g.


(1mark)

2d A molecules of thiol for 1 mark e.g.


(1mark)

2e A molecule of aldehyde for 1 mark e.g.

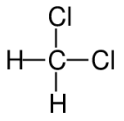

(1mark)

3a 2,5 dimethyl 3-bromohexane (1mark)

3b 1-bromo 3-methylbenzene (1mark)

3c 2-chlorobut-1-ene-3yne (1mark)

4a CH_2Cl_2


(1mark)

4b $C_4H_{12}N_2$ (1mark)

4c $(C_2H_5)_2O$ (1mark)

4d C_4H_8 (1mark)

A sample of learners' written pre-and post-test written work



LEARNER ACHIEVEMENT TEST
IUPAC nomenclature and functional groups of organic compounds

Instructions:

This achievement test is for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning in the topic of organic chemistry.

6/17

Write your name here:

Mokde Koretso

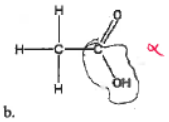
Code
R002

pre

WORKSHEET

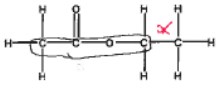
1. Identify the functional groups on the following organic molecules.

a.



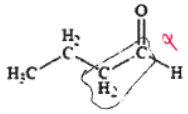
C–OH alcohol ✗ 0

b.



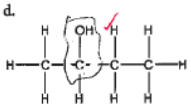
–C–O–C ✗ 0

c.



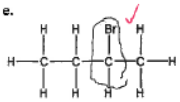
carbon single chain ✗ 0

d.



alcohol ✓ (1)

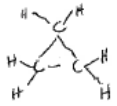
e.



bromobutane ✓ (1)

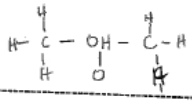
2. Draw simple organic molecules that contain the following functional groups.

a. Cycloalkane



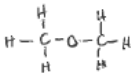
✓ (1)

b. Ketone



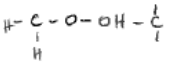
✗ 0

c. Ether



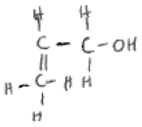
✓ (1)

d. Thiol



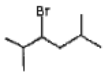
✗ 0

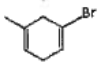
e. Aldehyde



✗ 0

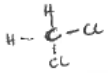
3. Name the following compounds according to the IUPAC system:

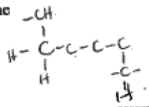
(i)  bromopentane ✗ 0

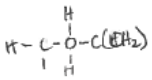
(ii)  benzene ✗ 0

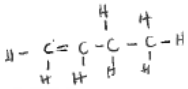
(iii)  Dichloromethane ✗ 0

4. Write the structural formula for the following organic compounds

(i) Dichloromethane  ✓ (1)

(ii) butane-1,4-diamine  ✗ 0

(iii) diethyl ether  ✗ 0

(iv) 1-butene  ✓ (1)

LEARNER ACHIEVEMENT TEST
IUPAC nomenclature and functional groups of organic compounds

Instructions:

This achievement test is for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning in the topic of organic chemistry.

Write your name here:

motale koketso

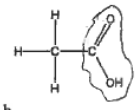
14/17

Code Rud2 post

WORKSHEET

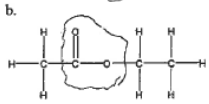
1. Identify the functional groups on the following organic molecules.

a.



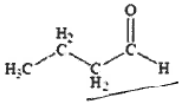
carboxylic functional group ✓ (1)

b.



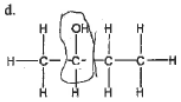
ester functional group ✓ (1)

c.



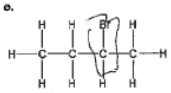
aldehyde function group ✓ (1)

d.



Butanol, hydroxyl functional group ✓ (1)

e.



haloalkane function group ✓ (1)

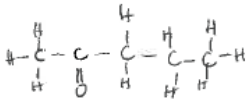
2. Draw simple organic molecules that contain the following functional groups.

a. Cycloalkane



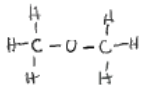
✓ (1)

b. Ketone



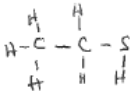
✓ (1)

c. Ether



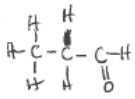
✓ (1)

d. Thiol



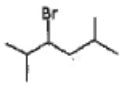
✓ (1)

e. Aldehyde

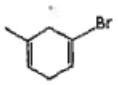


✓ (1)

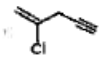
3. Name the following compounds according to the IUPAC system:

(i) 

2,5 dimethyl-3 bromohexane ✓ (1)

(ii) 

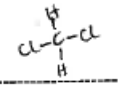
methylbromobenzene ✗ (0)

(iii) 

1, 2, dichloroalkenealkyne ✗ (0)

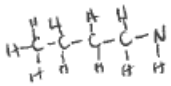
4. Write the structural formula for the following organic compounds

(i) Dichloromethane



CH_2Cl_2 ✓ (1)

(ii) butane-1,4-diamine



✗ (0)

(iii) diethyl ether

$(C_2H_5)_2O$ ✓ (1)

(iv) 1-butene

C_4H_8 ✓ (1)

Appendix VIII: Achievement test on physical properties and structures of organic compounds (with marking memo)

ACHIEVEMENT TEST

Physical properties and structures of organic compounds

Instructions:

This achievement test is for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning in the topic of organic chemistry.

Write your name here:

WORKSHEET

A. Study the following table and answer the question 1- 10 below:

No. of carbons	Alkanes		Alcohols		Carboxylic acids	
	IUPAC name	Boiling point (^oC)	IUPAC name	Boiling point (^oC)	IUPAC name	Boiling point (^oC)
1	Methane	-164	Methanol	65	Methanoic acid	
2	Ethane	-89	Ethanol	78	Ethanoic acid	
3	Propane	-42	Propan-1-ol	97	Propanoic acid	
4	Butane	-0.5	Butan-1-ol	118	Butanoic acid	
5	Pentane	36	Pentan-1-ol	138	Pentanoic acid	
6	Hexane	69	Hexan-1-ol	152	Hexanoic acid	

1. Describe the pattern across the alkanes……

2. Explaining the reason for your answer in question 1 above……

3. Describe the pattern across the alcohols……..

4. Explain the reason for your answer in question 3 above……..

5. Describe the pattern between the alkanes and alcohols……..

6. Explain the reason for your answer in question 5 above……..

7. Why is the boiling point for hexane so much lower than that of hexan-1-ol? ……..

8. Why is the boiling point for methanol so much lower than that of hexan-1-ol? ……

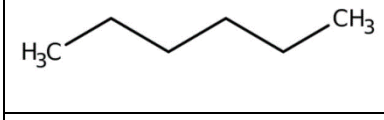
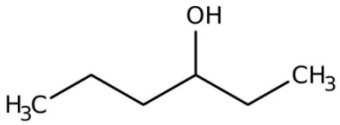
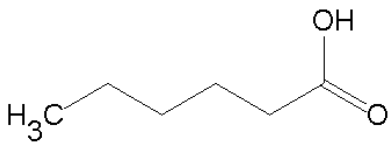
9. The boiling points for the carboxylic acids are not included in the Table above. Do you expect their boiling points to be higher or lower than the boiling points of the alcohols with the same number of carbon atoms?

……

10. Explain the reason for your answer in question 9 above.

……

11. Arrange the three compounds below according to their solubility in water, put the most soluble compound first, followed by the next and then the least soluble.

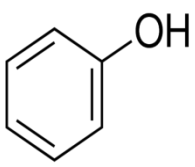
		
Compound 1	Compound II	Compound III

……

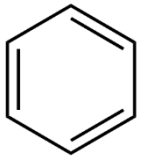
12. Explain the reason for the order you have chosen in question 11 above.

……

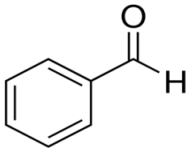
13. Arrange the four compounds below according to their expected boiling points. Put the compound with the highest boiling point first, followed by the next and then the compound with the least boiling point as the last. Give reasons for the order you have given. Write your answers in the spaces provided below.



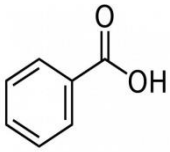
(i) phenol



(ii) benzene



(iii) benzaldehyde



(iv) benzoic acid

……

14. Explain the reason for the order you have chosen in question 13 above.

……

Appendix IX: Questions for collecting Learners' views

LEARNERS' VIEWS ABOUT STUDENT-TEACHERS' TOPIC SPECIFIC PCK

Write your Name in this space

Information:

The questions below are for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning in the topic of organic chemistry.

1. What did the student-teacher do, that helped you to understand the concepts? Give an example……

2. What was done in the class by the student-teacher that you liked most ……

3. What was done in the class by the student-teacher that you did not like? ……

4. What do you think would help you to understand better? ……

Appendix IX: Questions for collecting Learners' views

LEARNERS' VIEWS ABOUT STUDENT-TEACHERS' TOPIC SPECIFIC PCK

Write your Name in this space

Information:

The questions below are for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning in the topic of organic chemistry.

1. What did the student-teacher do, that helped you to understand the concepts? Give an example ……

2. What was done in the class by the student-teacher that you liked most?

……

3. What was done in the class by the student-teacher that you did not like?

……

4. What do you think would help you to understand better?

……

Appendix X: planned TSPCK rubric

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
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 more than one TSPCK component.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two other component of TSPCK interactively.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on three or more other components 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 exclude conceptual considerations and show no evidence of drawing on more than one TSPCK component.	• 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 two 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 include conceptual scaffolding with reference to other TSPCK components
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.
Representat-ions	• 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

Appendix XI: Enacted TSPCK rubric

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 • 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 submicroscopic 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

Appendix XII: Ethics approval



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

03 March 2017

Student Number: 882611

Protocol Number: 2017ECE006D

Dear Olutosin Solomon Akinyemi

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:

Exploring the development of preservice teachers' Topic Specific PCK and its influence on learners' outcomes

The committee recently met and I am pleased to inform you that **clearance was granted**. However, there were a few small issues which the committee would appreciate you attending to before embarking on your research.

Appendix XIII: GDE Approval

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

8/4/4/1/2

GDE RESEARCH APPROVAL LETTER

Date:	07 March 2017
Validity of Research Approval:	06 February 2017 – 29 September 2017 2017/24
Name of Researcher:	Akinyemi, O. S
Address of Researcher:	19, 1st Avenue
	Westdene
	Johannesburg, 2092
Telephone Number:	061 152 7011
Email address:	tosaakin1@hotmail.co.uk
Research Topic:	Exploring preservice teachers' development of Topic Specific Pedagogical Content Knowledge and its influence on learners' conceptual understanding and achievement.
Number and type of schools:	Six Secondary Schools
District/s/HO	Johannesburg Central 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 to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

08/03/2017

1

Making education a societal priority

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

APPENDIX XIV: Consent form for Pre-service teachers

LETTER TO THE PRE-SERVICE TEACHERS – PHYSICAL SCIENCE IV

DATE:

Dear Pre-service teacher,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' outcomes.

I am inviting you as a pre-service teacher to participate in my research study. The study aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge. The study is located in your methodology course for physical science. I have chosen your course because it has a unique aim of developing your professional knowledge called Topic Specific Pedagogical Content Knowledge (TSPCK) in chemistry topics, particularly organic chemistry. I will be participating in some sessions of your course as an observer and in some as your tutor. I will be collecting your views about teaching a chemistry topic like organic chemistry through the specially designed Topic-Specific PCK tool in organic chemistry and your content knowledge in organic chemistry before and on completion of your methodology course. I also request permission to make a copy of our submitted coursework such as assignments for analysis once it has been marked, and a marked copy will be returned to you for feedback by your course lecturer as usual. Later towards TE, I will ask for few (6) volunteers who would like to teach the topic of organic chemistry in selected schools during TE and allowing me to follow to observe their classroom teaching. The volunteers will have three of their lessons video recorded and their learners opened to evaluation of the impact of teaching. The volunteers will also be interviewed after their lessons.

I therefore need your permission for the above laid activities. You are allowed to refuse permission. There will be no penalty in any form to you for refusing to participate in this research study. Although the study involves an intervention as part of your coursework, participation in this study is voluntary. Should you wish not to consent, all that it means is that I will not make a copy of your submitted work and will not include you in the selection of classroom teaching. Should half the class not consent, it means that I will not participate in your class at all. Should you express discomfort with being video recorded or allowing her/his work to be used in the process, all efforts will be done to remove your work or video recordings. There will be no prejudice or advantage in terms of your marks by participating or non-participating, as I will only have access to your submitted work after marking has been done. The value of the responses gathered and recordings is to improve the way Universities prepare and train future science teachers. Also, if you decide halfway through that you prefer to stop, this is completely your choice and will not affect you negatively in any way.

In my analysis I will not be using your own name but I will make one up so no one can identify you. All information about you will be kept confidential in all my writing about the study. If a need arises for me to quote a statement from the recordings a pseudo (not a real name) name will be used. Also, all recordings and collected information will be stored safely in a lockable place and destroyed between 3-5 years after I have completed my project.

If you wish for further information regarding your rights, as a research participant, you may contact:

Human Research Ethics Committee (HREC) at 0117173055 or Ms. Matsie Mabeta via email at

Matsie.Mabeta@wits.ac.za.

I look forward to working with you!

Please feel free to contact me if you have any questions.

Thank you



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

PRE-SERVICE 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 Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

Circle one

Permission to participate

I agree to participate in this research study YES/NO

I know that my responses to the tools and submitted work will be used for this study YES/NO

Permission to be followed in classroom teaching

I agree to be followed in teaching the topic of organic chemistry	YES/NO
I know that all information gathered will be used for this research study only	YES/NO

Permission to videotape my classroom teaching

I agree that my lessons should be video recorded	YES/NO
I know that all the recordings will be used for this research study only	YES/NO

Permission to interview

I agree to be interviewed	YES/NO
I know that all information gathered will be used for this research study 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 videotaped.
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

APPENDIX XV: Consent form for Course co-ordinator

LETTER TO THE COURSE CO-ORDINATOR

DATE:

Dear Course Co-ordinator,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' outcomes.

I am inviting your methodology class to participate in this research study. I have chosen your course because it has a unique aim of developing pre-service teachers' professional knowledge called Topic Specific Pedagogical Content Knowledge (TSPCK) in chemistry, particularly organic chemistry. The focus of this study is to ensure that pre-service teachers can transform their understanding of concepts to versions that are accessible to learners. I would request to participate in some sessions of your course as an observer and in some as a tutor, supporting the course lecturer. I would like to gather evidence of the pre-service teachers' development of pedagogical transformation competence as they are being exposed to the construct of TSPCK in the methodology sessions. This entails collecting the pre-service teachers' views about teaching a chemistry topic like organic chemistry through the specially designed Topic-Specific PCK tool and content achievement tool in electricity before and on completion of the methodology course. I also request permission to make a copy of the pre-service teachers' submitted coursework such as assignments for analysis once it has been marked. Later towards TE, I will ask for few (6) volunteers who would like to teach the topic of organic chemistry in selected schools during TE and allowing me to follow to observe their classroom teaching. The volunteers will have three of their lessons video recorded and their learners opened to evaluation of the impact of teaching. The volunteers will also be interviewed after their lessons.

I therefore need your permission for all these activities. I am aware that consent is also needed from the participant pre-service teachers. Such consent forms have been prepared; I attached samples to this letter. Also attached is the approval letter from the Human Research Ethics Committee (HREC), Wits University. All participations will remain voluntary. Should a pre-service teacher wish not to consent, all that it means is that I will not make a copy of his/her submitted work and will not include him/her in the selection of classroom teaching. Should half of the class not consent, it means that I will not participate in your methodology course at all. Should a student express discomfort with being video recorded or allowing her/his work to be used in the process, all efforts will be done to remove his/her work or video recordings.

In line with ethical considerations, all information collected will stay in a lockable place up to five years, and then destroyed. If a need arises for me to quote a statement from the written responses and recordings, a pseudo name will be used. There are no foreseeable risks in participating in this study. The participants will not be paid for this study. The names of the research participants and identities will be kept confidential at all times and in all academic writing about the study. Their individual privacy will be maintained in all published and written data resulting from the study. The research participants will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this project without any penalty. 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 it is convenient.

Yours sincerely,



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

Course Co-ordinator's Consent Form

Please fill in and return the reply slip below indicating your willingness to allow the participation of your methodology class in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

Circle one

Permission to use physical science methodology course

I agree that physical science methodology class should be used for this research study YES/NO

I agree that the researcher should act a tutor supporting the lecturer YES/NO

Permission to use students' responses to the research tools and submitted work

I agree that student responses and submitted should be used for this research only YES/NO

I know that all responses will be used for this project study only YES/NO

Permission to follow students in classroom teaching

I agree that students should be followed in teaching organic chemistry YES/NO

I know that all information gathered will be used for this research study only YES/NO

Permission to videotape students' classroom teaching

I agree that students' lessons should be video recorded YES/NO

I know that all the recordings will be used for this research study only YES/NO

Permission to interview students

I agree that students should be interviewed YES/NO

I know that all information gathered will be used for this research study only YES/NO

Informed Consent

I understand that:

- the name and information of pre-service teachers in my class will be kept confidential and safe and that all identities involved will not be revealed.
- Participant pre-service teachers do not have to answer every question and can withdraw from the study at any time.
- Participant pre-service teachers can ask not to release their submitted work for this study
- Participant pre-service teachers can ask not to be videotaped
- All the data collected during this study will be destroyed within 3-5 years after completion of my research study.

Sign_____ Date_____

APPENDIX XVI: Consent form for Course lecturer

LETTER TO THE COURSE LECTURER

DATE:

Dear Course Lecturer,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' outcomes.

I am inviting your methodology class to participate in this research study. I have chosen your course because it has a unique aim of developing pre-service teachers' professional knowledge called Topic Specific Pedagogical Content Knowledge (TSPCK) in chemistry topic, particularly organic chemistry. The focus of this study is to ensure that pre-service teachers can transform their understanding of concepts to versions that are accessible to learners. I would request to participate in some sessions of your course as an observer and in some as a tutor. I would like to gather evidence of the pre-service teachers' development of pedagogical transformation competence as they are being exposed to the construct of TSPCK in the methodology sessions. This entails collecting the pre-service teachers' views about teaching a chemistry topic like organic chemistry through the specially designed Topic-Specific PCK tool and content achievement tool in organic chemistry before and on completion of the methodology course. I also request permission to make a copy of the pre-service teachers' submitted coursework such as assignments for analysis once it has been marked. Later towards TE, I will ask for few (6) volunteers who would like to teach the topic of organic chemistry in selected schools during TE and allowing me to follow to observe their classroom teaching. The volunteers will have three of their lessons video recorded and their learners opened to evaluation of the impact of teaching. The volunteers will also be interviewed after their lessons.

I therefore need your permission for all these activities. I am aware that consent is also needed from the participant pre-service teachers. Such consent forms have been prepared; I attached samples to this letter. Also attached is the approval letter from the Human Research Ethics Committee (HREC), Wits University. All participations will remain voluntary. Should a student wish not to consent, all that it means is that I will not make a copy of his/her submitted work and will not include him/her in the selection of classroom teaching. Should half of the class not consent, it means that I will not participate in your methodology course at all. Should a student express discomfort with being video recorded or allowing her/his work to be used in the process, all efforts will be done to remove his/her work or video recordings.

In line with ethical considerations, all information collected will stay in a lockable place up to five years, and then destroyed. If a need arises for me to quote a statement from the written responses and recordings, a pseudo name will be used. There are no foreseeable risks in participating in this study. The participants will not be paid for this study. The names of the research participants and identities will be kept confidential at all times and in all academic writing about the study. Their individual privacy will be maintained in all published and written data resulting from the study. The research participants will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this project without any penalty. 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,



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

Course Lecturer's Consent Form

Please fill in and return the reply slip below indicating your willingness to allow the participation of your methodology class in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

Circle one

Permission to use my methodology course

I agree that my methodology class should be used for this research study YES/NO

I agree that the researcher should act a tutor supported by me YES/NO

Permission to use students' responses to the research tools and submitted work

I agree that student responses and submitted should be used for this research only YES/NO

I know that all responses will be used for this project study only YES/NO

Permission to follow students in classroom teaching

I agree that students should be followed in teaching organic chemistry YES/NO

I know that all information gathered will be used for this research study only YES/NO

Permission to videotape students' classroom teaching

I agree that students' lessons should be video recorded YES/NO

I know that all the recordings will be used for this research study only YES/NO

Permission to interview students

I agree that students should be interviewed YES/NO

I know that all information gathered will be used for this research study only YES/NO

Informed Consent

I understand that:

- the name and information of pre-service teachers in my class will be kept confidential and safe and that my name and that of my school will not be revealed.
- Participant pre-service teachers do not have to answer every question and can withdraw from the study at any time.
- Participant pre-service teachers can ask not to release their submitted work for this study
- Participant pre-service teachers can ask not to be videotaped
- All the data collected during this study will be destroyed within 3-5 years after completion of my research study.

Sign_____ Date_____

APPENDIX XVII: Consent form for School Principals

LETTER TO THE SCHOOL PRINCIPAL

DATE:

Dear Principal,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' conceptual understanding and achievement. The research aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge (TSPCK). The approach of TSPCK is considered valuable by the science education community, nationally and internationally.

The research is at a stage where I need to evaluate the effectiveness of teaching by our student teachers posted to your school for a teaching experience this academic session. I would like to use this opportunity to evaluate the quality of their teaching and its influence on the Grade 11 learners' conceptual understanding and achievement as they teach their lessons. In order to do this, the learners will be given a content achievement test and a questionnaire (to capture their views about the student teacher's enacted TSPCK) as a set of pre and post-tests before and immediately after the lessons. The lessons will also be video recorded. I will stand behind the learners in the class to video record the moves and actions of the student teacher and the learners during the lesson.

I therefore need your permission for above laid activities. I am aware that consent is also needed from the supervising teacher, participant learners' parents and participant learners. Such consent forms have been prepared; I attached samples to this letter. Also attached is the approval letter from the Human Research Ethics Committee (HREC), Wits University and Gauteng Department of Education (GDE). All participations will remain voluntary. All recordings and responses from the learners, in alignment to humanities ethics, will not be made public. They will be used by me, my research supervisor and the student teacher as we draw academic lessons from the recordings and responses. Effort will be made to avoid capturing of learners who have not consented and if captured unavoidably, their faces will be screen blocked. The recordings and responses will be kept confidential and saved in a lockable manner (e.g. password protected e-files). Your learners' names, school's name and identities will be kept confidential at all times and in all academic writing about this study. The privacy of the learners will be maintained in all published and written data resulting from this study. If a need arises that we need to quote from the recordings and responses, a pseudo name will be assigned to the person quoted.

Your learners will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this research without any penalty. There are no foreseeable risks in participating and your learners will not be paid for participating in this study.

All research data will be destroyed between 3-5 years after completing of the research. Please let me know if you require any further information.

Thank you for your help.

Yours sincerely,



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

SCHOOL PRINCIPAL'S CONSENT FORM

Please fill in and return the reply slip below indicating your willingness to allow your school and learners to participate in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

	Circle one
Permission to participate	
I agree that my school should participate in the research study	YES/NO
I know all responses and recordings will be used for this research only	YES/NO

Permission to use learners' written responses

I agree that my learners written responses to the research tools should be used in this study YES/NO

I know that all responses will be used for this research study YES/NO

Permission to videotape

I agree that student teachers' lessons and participant learners should be videotaped YES/NO

I know that the videotapes will be used for this research study only YES/NO

Informed Consent

I understand that:

- my school's and learners' names and information will be kept confidential and safe and that the names and identities will not be revealed.
- my learners do not have to answer every question and can withdraw from the study at any time.
- my learners can ask not to be audiotaped, videotaped and participate in responding to the questionnaires.
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_____ Date_____

APPENDIX XVIII: Consent form for Physical sciences teachers

LETTER TO THE SUPERVISING TEACHER

DATE:

Dear Supervising Teacher,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' conceptual understanding and achievement. The research aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge (TSPCK). The approach of TSPCK is considered valuable by the science education community, nationally and internationally.

The research is at a stage where I need to evaluate the effectiveness of teaching by our student teachers posted to your school for a teaching experience this academic session. I would like to use this opportunity to evaluate the quality of their teaching and its influence on the Grade 11 learners' conceptual understanding and achievement as they teach their lessons. In order to do this, the learners will be given a content achievement test and a questionnaire (to capture their views about the student teacher's enacted TSPCK) as a set of pre and post-tests before and immediately after the lessons. The lessons will also be video recorded. I will stand behind the learners in the class to video record the moves and actions of the student teacher and the learners during the lesson.

I therefore need your permission for above laid activities. I am aware that consent is also needed from the supervising teacher, participant learners' parents and participant learners. Such consent forms have been prepared; I attached samples to this letter. Also attached is the approval letter from the Human Research Ethics Committee (HREC), Wits University and Gauteng Department of Education (GDE). All participations will remain voluntary. All recordings and responses from the learners, in alignment to humanities ethics, will not be made public. They will be used by me, my research supervisor and the student teacher as we draw academic lessons from the recordings and responses. Effort will be made to avoid capturing of learners who have not consented and if captured unavoidably, their faces will be screen blocked. The recordings and responses will be kept confidential and saved in a lockable manner (e.g. password protected e-files). Your learners' names, school's name and identities will be kept confidential at all times and in all academic writing about this study. The privacy of the learners will be maintained in all published and written data resulting from this study. If a need arises that we need to quote from the recordings and responses, a pseudo name will be assigned to the person quoted.

Your learners will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this research without any penalty. There are no foreseeable risks in participating and your learners will not be paid for participating in this study.

All research data will be destroyed between 3-5 years after completing of the research. Please let me know if you require any further information.

Thank you for your help.

Yours sincerely,



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

SUPERVISING TEACHER'S CONSENT FORM

Please fill in and return the reply slip below indicating your willingness to allow the participation of your learners in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

	Circle one
Permission to participate	
I agree that my learners should participate in the research study	YES/NO
I know all responses and recordings will be used for this research only	YES/NO

Permission to use learners' written responses

I agree that my learners written responses to the research tools should be used in this study YES/NO

I know that all responses will be used for this research study YES/NO

Permission to videotape

I agree that student teachers' lessons and participant learners should be videotaped YES/NO

I know that the videotapes will be used for this research study only YES/NO

Informed Consent

I understand that:

- my learners' names and information will be kept confidential and safe and that the names and identities will not be revealed.
- my learners do not have to answer every question and can withdraw from the study at any time.
- my learners can ask not to be videotaped and participate in responding to the questionnaires.
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_____ Date_____

APPENDIX XIX: Consent form for Learners

LETTER TO THE LEARNERS

DATE:

Dear Learner,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' conceptual understanding and achievement.

The student teacher taking your class for physical science lessons has been exposed to a new approach of preparing and teaching science topics. This approach is called Topic Specific Pedagogical Content Knowledge TSPCK. The focus is to ensure that concepts are explained in a manner that you as a learner can understand. During the teaching practice, the student teacher's lessons will be video recorded. The recordings are to focus on the actions and moves of the student teacher as well as your contributions as a learner during the lessons. I will stand at the back of the class to video record all that happens during the lessons. Likewise, to be able to measure any shift in your conceptual understanding and achievement, a set of questionnaires will be administered to you as a set of pre and post tests before and after the lessons.

I therefore need your permission for the above mentioned activities. All the recordings and responses from the you, in alignment to humanities ethics, will not be made public. They will be used by me, my research supervisor and the student teacher as we draw academic lessons from the recordings and responses. The recordings and responses will be kept confidential and saved in a lockable manner (e.g. password protected e-files). Your name and identity will be kept confidential at all times and in all academic writing about this study. If a need arises that we need to quote from the recordings and responses, a pseudo name will be assigned to the person quoted. You will not be advantaged or disadvantaged in any way. You can choose to withdraw your permission at any time during this research without any penalty. There are no foreseeable risks in participating and you will not be paid for participating in this study. However, you are allowed to refuse permission. In such a case, all efforts will be done to remove your written responses and electronically block your voice and physical recording. There will be no penalty in any form to you for refusing to be audio recorded, video recorded and participate in responding to the questionnaires. The value of the recordings and responses to the questionnaires is to improve the way Universities prepare and train future science teachers.

All research data will be destroyed between 3-5 years after completing of the research. Please let me know if you require any further information.

I look forward to hear from you and wish you an enjoyable experience with our student teacher.

Thank you for your help.



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

LEARNER'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 Topic Specific Pedagogical Content Knowledge

I, _____ give my consent for the following:

Circle one

Permission to participate

I agree to participate in the research study YES/NO

I know my responses will be used for this research only YES/NO

Permission to use written responses

I agree that my written responses to the research tools should be used in this study YES/NO

I know that all responses will be used for this research study YES/NO

Permission to be videotaped

I agree to be videotaped during the classroom teaching YES/NO

I know that the videotapes will be used for this research 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 audiotaped and videotaped.
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_____ Date_____

APPENDIX XX: Consent form for Parents

LETTER TO THE PARENTS

DATE:

Dear Parent,

My name is Akinyemi Olutosin Solomon. I am a Ph.D. student in the School of Education at the University of the Witwatersrand. I am doing research on the development of (senior phase/FET) Pre-service teachers' Topic Specific Pedagogical Content Knowledge and its influence on learners' conceptual understanding and achievement. The research aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge (TSPCK). The approach of TSPCK is considered valuable by the science education community, nationally and internationally.

The research is at a stage where I need to evaluate the effectiveness of teaching by our student teachers posted to your child's school for a teaching experience this academic session. During this time, student teachers, under the guidance of a practicing teacher, are assigned to teach various classes in the Senior/FET phase. I would like to use this opportunity to evaluate the quality of their teaching and its influence on the Grade 11 learners' conceptual understanding and achievement as they teach their lessons. In order to do this, the learners will be given a content achievement test and a questionnaire (to capture their views about the student teacher's enacted TSPCK) as a set of pre and post-tests before and immediately after the lessons. The lessons will also be video recorded. I will stand behind the learners in the class to video record the moves and actions of the student teacher and the learners during the lesson.

I therefore need your permission for the above laid activities. All the recordings and responses from your child, in alignment to humanities ethics, will not be made public. They will be used by me, my research supervisor and the student teacher as we draw academic lessons from the recordings and responses. The recordings and responses will be kept confidential and saved in a lockable manner (e.g. password protected e-files). Your child's name and identity will be kept confidential at all times and in all academic writing about this study. The privacy of your child will be maintained in all published and written data resulting from this study. If a need arises that we need to quote from the recordings and responses, a pseudo name will be assigned to the person quoted.

Your child will not be advantaged or disadvantaged in any way. He/she will be reassured that they can withdraw their permission at any time during this research without any penalty. There are no foreseeable risks in participating and your learners will not be paid for participating in this study.

All research data will be destroyed between 3-5 years after completing of the research. Please let me know if you require any further information.

Thank you for your help.

Yours sincerely,



Name: Akinyemi Olutosin Solomon

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 882611@students.wits.ac.za

Phone Number: 0611527011

PARENT'S CONSENT FORM

Please fill in and return the reply slip below indicating your willingness to allow the participation of your child in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

Circle one

Permission to participate

I agree that my child should participate in the research study YES/NO

I know all responses and recordings will be used for this research only YES/NO

Permission to use learners' written responses

I agree that my child's written responses to the research tools should be used in this study YES/NO

I know that all responses will be used for this research study YES/NO

Permission to be videotape

I agree that my child should be videotaped YES/NO

I know that the videotapes will be used for this research only YES/NO

Informed Consent

I understand that:

- my child's name and information will be kept confidential and safe
- my child does not have to answer every question and can withdraw from the study at any time.
- my child can ask not to be audiotaped, videotaped and participate in responding to the questionnaires.
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_____ Date_____

Appendix XXI: Planned TSPCK inter-rater reliability

Observer A	Rater_1
Observer B	Rater_2

	Observer A		
Observer B	2	1	
1	1	2	3 (60.0%)
2	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 0.86

Observer A	Rater_1
Observer B	Rater_3

	Observer A		
Observer B	3	1	
1	2	0	2 (50.0%)
3	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_2
Observer B	Rater_3

	Observer A		
Observer B	3	2	
2	1	2	3 (60.0%)
3	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 0.86

[a] Quadratic weights

Appendix XXII: Rasch Person Measures (Pre/Post planned TSPCK)

TABLE 17.1 Pre-TSPCK test ZOU132WS.TXT Apr 2 2018 11:35
INPUT: 17 Person 5 Item REPORTED: 17 Person 5 Item 4 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.47 REL.: .68 ... Item: REAL SEP.: 1.58 REL.: .75

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
8	11	5	-.55	.81	.61	-.5	.61	-.5	.11	.41	80.0	61.1	Madi
13	11	5	-.55	.75	1.80	1.2	1.65	1.1	.02	.41	40.0	61.1	Tuli
6	11	5	-.55	.81	.52	-.7	.51	-.7	.23	.41	80.0	61.1	Hope
14	10	5	-1.15	.85	1.65	1.0	1.58	.9	-.12	.42	60.0	65.5	Peta
2	10	5	-1.15	.81	.21	-1.4	.22	-1.4	.00	.42	100.0	65.5	Jean
15	10	5	-1.15	.85	.21	-1.4	.22	-1.4	.00	.42	100.0	65.5	Rose
3	10	5	-1.15	.87	.72	-.2	.73	-.2	.76	.42	60.0	65.5	Tato
12	10	5	-1.15	.81	1.60	.9	1.62	1.0	-.08	.42	60.0	65.5	Yola
16	9	5	-1.84	1.88	2.44	1.7	2.42	1.7	-.16	.42	20.0	70.4	Tabo
17	9	5	-1.84	.75	.95	.2	.99	.2	-.23	.42	60.0	70.4	Ruth
7	9	5	-1.84	.85	.95	.2	.99	.2	-.23	.42	60.0	70.4	Mark
10	8	5	-2.58	.75	1.51	1.0	1.78	1.3	-.53	.38	40.0	65.9	Atoe
11	8	5	-2.58	1.13	.60	-.6	.56	-.7	.61	.38	80.0	65.9	Debi
4	8	5	-2.58	.87	.50	-.8	.47	-.9	.71	.38	80.0	65.9	Bapa
1	6	5	-4.37	.81	1.07	.3	1.00	.4	.11	.22	80.0	80.1	Semo
5	5	5	-5.76	1.88	1.90	.4	1.98	.4	.00	.00	100.0	100.0	Tefo
9	5	5	-5.76	.87	1.90	.4	1.98	.4	.00	.00	100.0	100.0	Zasi
MEAN	8.8	5.0	-2.15	.96	.11	.0	.11	.0			70.6	60.0	

TABLE 17.1 Post-TSPCK test ZOU149WS.TXT Apr 2 2018 10:54
INPUT: 17 Person 5 Item REPORTED: 17 Person 5 Item 4 CATS MINISTEP 3.90.2

Person: REAL SEP.: 2.45 REL.: .88 ... Item: REAL SEP.: 2.13 REL.: .91

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
5	19	5	5.42	1.90	.19	-.9	.18	-.8	.99	.40	100.0	85.3	Madi
2	18	5	4.01	1.13	.27	-.8	.17	-.7	.98	.44	100.0	80.7	Ruth
16	18	5	4.01	1.13	.27	-.8	.17	-.7	.98	.44	100.0	80.7	Atoe
11	17	5	3.05	.87	.57	-.5	.70	-.2	.61	.52	80.0	72.0	Tuli
13	17	5	3.05	.87	.91	.1	.63	-.3	.98	.52	80.0	72.0	Jean
15	17	5	3.05	.87	.50	-.6	.56	-.4	.71	.52	80.0	72.0	Hope
17	17	5	3.05	.87	.50	-.6	.56	-.4	.71	.52	80.0	72.0	Yola
1	16	5	2.39	.76	1.82	1.3	1.93	1.4	.26	.53	80.0	59.0	Semo
7	16	5	2.39	.76	.58	-.6	.59	-.6	.53	.53	60.0	59.0	Peta
10	16	5	2.39	.76	.58	-.6	.59	-.6	.53	.53	60.0	59.0	Mark
12	16	5	2.39	.76	.76	-.2	.73	-.3	.87	.53	60.0	59.0	Rose
14	16	5	2.39	.76	.58	-.6	.59	-.6	.53	.53	60.0	59.0	Tato
9	14	5	1.37	.68	1.11	.4	1.06	.3	.68	.50	40.0	53.8	Bapa
6	13	5	.92	.67	.92	.1	1.15	.4	.97	.47	60.0	56.4	Zasi
4	12	5	.46	.68	1.50	1.0	1.63	1.1	.77	.44	40.0	54.1	Debi
3	11	5	-.02	.71	1.59	1.0	1.60	1.0	.80	.42	40.0	50.9	Tabo
8	10	5	-.55	.75	.88	.1	.92	.1	.80	.41	40.0	61.1	Tefo
MEAN	15.5	5.0	2.34	.88	.79	.0	.81	.0			68.2	65.2	

Appendix XXIII: Rasch Item measures (Pre/Post planned TSPCK)

Pre-TSPCK item measure planned

```
TABLE 13.1 Pre-TSPCK test                          ZOU149WS.TXT  Apr  2 2018 10:54
INPUT: 17 Person  5 Item  REPORTED: 17 Person  5 Item  4 CATS    MINISTEP 3.90.2
-------------------------------------------------------------------------------
Person: REAL SEP.: 1.47  REL.: .68 ... Item: REAL SEP.: 1.58  REL.: .75

         Item STATISTICS:  MEASURE ORDER

-----------------------------------------------------------------------------------------------------------------
|ENTRY   TOTAL  TOTAL           MODEL|   INFIT  |  OUTFIT  |PTMEASUR-AL|EXACT MATCH|                            |
|NUMBER  SCORE  COUNT  MEASURE  S.E. |MNSQ  ZSTD|MNSQ  ZSTD|CORR.  EXP.| OBS%  EXP%| Item                       |
|------------------------------------+----------+----------+-----------+-----------+----------------------------|
|     5     23     34    3.71     .32| .92   -.3|1.05    .3|  .77   .80| 64.5  59.3| Conceptual Teaching Strategies|
|     3     21     34    2.81     .32| .86   -.5| .89   -.3|  .86   .85| 61.3  65.6| What is difficult to teach |
|     1     18     34    1.85     .33| .80   -.7| .76   -.8|  .88   .85| 64.5  66.6| Learner Prior Knowledge    |
|     4     15     34    1.29     .33|1.14    .6|1.08    .4|  .85   .85| 67.7  66.6| Curricular saliency        |
|     2     10     34    0.55     .33|1.09    .4| .90   -.2|  .88   .86| 74.2  67.8| Representations            |
|------------------------------------+----------+----------+-----------+-----------+----------------------------|
```

Post-TSPCK planed

```
TABLE 13.1 Post-TSPCK test                         ZOU149WS.TXT  Apr  2 2018 10:54
INPUT: 17 Person  5 Item  REPORTED: 17 Person  5 Item  4 CATS    MINISTEP 3.90.2
-------------------------------------------------------------------------------
Person: REAL SEP.: 2.45  REL.: .88 ... Item: REAL SEP.: 2.13  REL.: .91

         Item STATISTICS:  MEASURE ORDER

-----------------------------------------------------------------------------------------------------------------
|ENTRY   TOTAL  TOTAL           MODEL|   INFIT  |  OUTFIT  |PTMEASUR-AL|EXACT MATCH|                            |
|NUMBER  SCORE  COUNT  MEASURE  S.E. |MNSQ  ZSTD|MNSQ  ZSTD|CORR.  EXP.| OBS%  EXP%| Item                       |
|------------------------------------+----------+----------+-----------+-----------+----------------------------|
|     5     23     34   -3.63     .32| .92   -.3|1.05    .3|  .77   .80| 64.5  59.3| Representations            |
|     3     21     34   -2.35     .32| .86   -.5| .89   -.3|  .86   .85| 61.3  65.6| Curricular saliency        |
|     1     18     34   -1.08     .33| .80   -.7| .76   -.8|  .88   .85| 64.5  66.6| Learner Prior Knowledge    |
|     4     15     34    0.42     .33|1.14    .6|1.08    .4|  .85   .85| 67.7  66.6| What is difficult to teach |
|     2     10     34    2.65     .33|1.09    .4| .90   -.2|  .88   .86| 74.2  67.8| Conceptual teaching strategies|
|------------------------------------+----------+----------+-----------+-----------+----------------------------|
```

Appendix XXIV: Stacked data Rasch Person measure (Post planned TSPCK)

TABLE 17.1 Post-test Anchored ZOU025WS.TXT Aug 29 2018 21:21
INPUT: 17 Person 5 Item REPORTED: 17 Person 5 Item 4 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.12 REL.: .80 ... Item: REAL SEP.: 1.79 REL.: .94

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
5	20	5	4.85	1.90	.35	-.9	.24	-.8	.99	.58	100.0	80.0	Madi
2	19	5	3.42	1.14	.28	-.7	.18	-.7	.98	.44	100.0	80.8	Ruth
16	19	5	3.42	1.14	.28	-.7	.18	-.7	.98	.44	100.0	80.8	Atoe
11	18	5	2.45	.86	.56	-.4	.71	-.2	.61	.51	80.0	72.0	Tuli
13	18	5	2.45	.86	.91	.1	.62	-.3	.98	.51	80.0	72.0	Jean
15	18	5	2.45	.86	.49	-.6	.58	-.4	.71	.51	80.0	72.0	Hope
17	18	5	2.45	.86	.49	-.6	.58	-.4	.71	.51	80.0	72.0	Yola
1	17	5	1.81	.75	1.76	1.2	2.02	1.5	.26	.54	80.0	59.4	Semo
7	17	5	1.81	.75	.57	-.6	.62	-.5	.53	.54	60.0	59.4	Peta
10	17	5	1.81	.75	.57	-.6	.62	-.5	.53	.54	60.0	59.4	Mark
12	17	5	1.81	.75	.70	-.3	.69	-.3	.87	.54	60.0	59.4	Rose
14	17	5	1.81	.75	.57	-.6	.62	-.5	.53	.54	60.0	59.4	Tato
9	15	5	.86	.65	.99	.2	1.04	.3	.68	.57	40.0	50.8	Bapa
6	14	5	.46	.63	.52	-.8	.53	-.7	.97	.58	60.0	53.0	Zasi
4	13	5	.07	.62	.95	.1	.94	.1	.77	.57	40.0	51.2	Debi
3	12	5	-.30	.61	.88	.0	.88	.0	.80	.55	60.0	50.2	Tabo
8	11	5	-.66	.60	.41	-1.1	.40	-1.1	.80	.52	80.0	48.0	Tefo

Appendix XXV: Pre-and Post CK performance

Summary of PSTs' CK performances			
Prreservice	**Pre-test % score**	**Post-test % Score**	**%Gain**
Semo	52	76	24
Rose	45	88	43
Hope	40	90	50
Jean	60	86	26
Peta	60	81	21
Ruth	58	83	25
Atoe	42	70	28
Mark	47	85	38
Tato	35	84	49
Tefo	40	72	32
Bapa	51	80	29
Debi	54	70	16
Madi	61	70	9
Zasi	57	89	32
Tuli	43	91	48
Tabo	42	92	50
Yola	40	85	45
Average	48.65	81.88	33.24

Appendix XXVI: Enacted TSPCK inter-rater

Observer A	Rater_1
Observer B	Rater_2

	Observer A		
Observer B	1	2	
2	1	2	3 (55.0%)
1	0	2	2 (45.0%)
	1 (45.0%)	4 (55.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.92

Observer A	Rater_2
Observer B	Rater_3

	Observer A		
Observer B	3	2	
3	2	0	2 (50.0%)
2	1	1	2 (50.0%)
	3 (50.0%)	1 (50.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.235 to 1.000

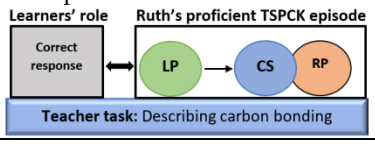
Observer A	Rater_1
Observer B	Rater_3

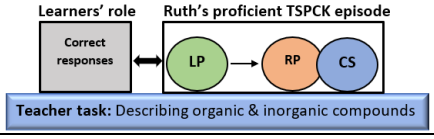
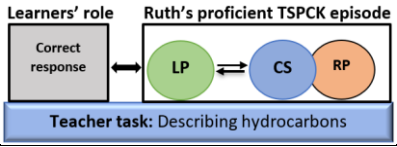
	Observer A		
Observer B	3	1	
1	1	2	3 (60.0%)
3	0	2	2 (40.0%)
	1 (40.0%)	4 (60.0%)	5

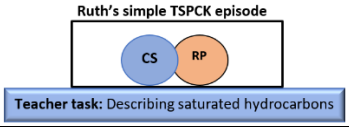
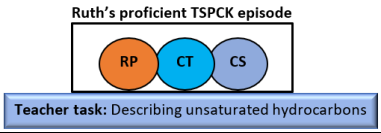
Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.92

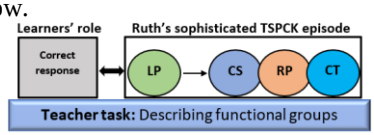
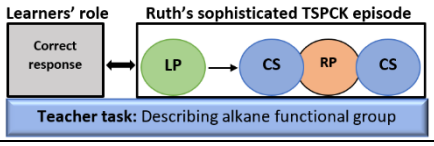
Quadratic weights

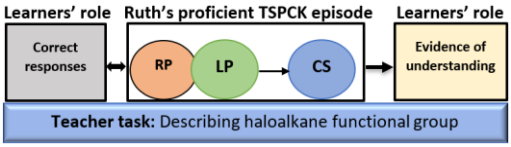
Appendix XXVII: Detailed analysis of Ruth's lesson

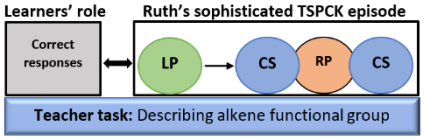
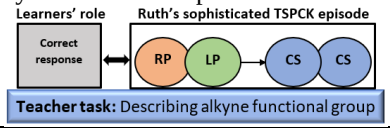
Lesson 1	
Extracts of Ruth's teaching in sequence	Comments/Qualitative in-depth analysis
0-2min: Describing carbon's ability to form bonds **Ruth**: Great! Now, from what you have learnt in organic chemistry, what is it or what is that special character or a property that carbon has that makes us to be able to study carbon compounds? *There was no response from learners* **Ruth**: Ok, they say that carbon has the ability to catenate, what does that mean? SF2: it's the ability of carbon form bonds. **Ruth**: You got it! So, carbon forms bonds just like other elements to attain stability right **(LP)** however, carbon is special in that it forms covalent bonds among its own atoms, atoms of other elements much more than any elements such that we have small and very large organic molecules **(CS)** let's see an example (*she put the chemical formula and structure of chloropropane on the board*), here we can see one carbon bonded to another carbon and to another carbon,**(RP)** at the same time, carbon is bonded to these hydrogen atoms and chlorine atom so as carbon can form small molecules like this, you can all see this right?	**Comment**: The extract here was part of the Ruth's lesson introduction focusing on carbon bonding. **In-depth Qualitative Analysis**: **Ruth's role:** In an attempt to understand learners' existing knowledge, Ruth asked learners about the carbon's unique property. **Learners' role:** Learner SF2 correctly referred to carbon catenation as its ability to form bonds which Ruth then knew it was knowledge that learners have in place (LP). **Ruth's role:** Expatiating on SF2's response, Ruth emphasized carbon forming covalent bonds its own atoms and atoms of other elements to form small and large organic molecules, an aspect important for learners to understand (CS). She also used the structure of chloropropane as well as the chemical formula to make learners understand carbon's bonding to its own atoms and atoms of other elements. This is a use of representation at a symbolic level to promote learner understanding (RP). Ruth's interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 
2-4min: Describing organic and inorganic compounds **Ruth**: So, now we have organic chemistry, one important branch of chemistry where we talk about organic compounds, now refresh your mind Grade 12, what can you say about organic compounds? **SM2**: compounds of carbon **Ruth**: Compounds of carbon, any other opinion? **SM3**: Organic compounds are made up of carbon and hydrogen **Ruth**: Aright, he said organic compounds are compounds of carbon, there's something you must know here, it's not all compounds of carbon that are organic compounds, **(LP)** take for instance CO_2, it's a compound of carbon (*Ruth drew the structure of carbon dioxide as shown below*) **(RP)** here, carbon is covalently bonded to oxygen, electrons are shared among them note that, but since carbon is not covalently bonded to hydrogen, it is not an organic compound, **(CS)** meanwhile the other guy said organic compounds consist of carbon and hydrogen right, very well here is an example (*Ruth drew the structure of methane on the board*) carbon covalently bonded to four hydrogens, so this compound is organic, we can as well	**Comment**: The extract here was the continuation of the lesson introduction, focusing on establishing learners' existing knowledge about what organic and inorganic compounds are. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners what they could say about organic compounds by recalling what they previously learnt. **Learners' role:** Through their responses, learner SM2 and SM3 revealed general correct understanding of organic compounds which they are bringing into the discussion (LP). **Ruth's role:** Expatiating on SM2's response, Ruth in her statement cautioned learners about assuming that all compounds of carbon are organic compounds. This is an understanding of a possible misconception (LP). Showing her understanding of the use of a symbolic representation, she supported her explanation using carbon dioxide and its structure as an example (RP). She also expatiated on learner SM3's response by using methane and its

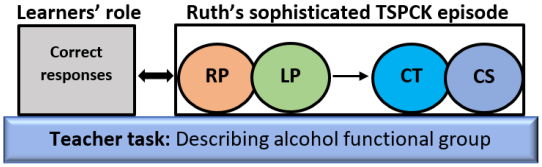
have other compounds which are organic but they consist of other elements in addition to carbon and hydrogen, an example is here (*Ruth referred to the structure of chloropropane already drawn on the board*), so, in organic compounds carbon is covalently bonded to hydrogen, very compulsory, is that ok?	structure as an example of carbon covalently bonded to hydrogen. Ruth's interactive use of TSPCK components (LP-RP/CS) at a proficient level of TSPCK episode in connection to a learners' correct responses is given by the TSPCK map below. 
4-6min: Describing Hydrocarbons **Ruth**: So let's discuss saturated and unsaturated hydrocarbon as a class of organic compound. What do you think we mean by hydrocarbons? SM3: compounds of carbon and hydrogen **Ruth**: Who has got something to add? There was no response from the learners **Ruth**: Indeed, in hydrocarbons we've got carbon and hydrogen atoms even in all organic compounds **(LP)** but one thing about hydrocarbons is that they consist of only carbon and hydrogen atoms covalent bonded, please take note of that guys, other organic compounds may contain carbon, hydrogen and other elements except hydrocarbons **(CS)** the simplest hydrocarbon is methane, our CH_4 shown here (she pointed at the structure of methane on the board) **(RP)** . Then, we all know fuels right, natural gases and even gasoline, those are common examples of mixtures in our environment containing hydrocarbons we will look at them later, are you following? Ss: yes	**Comment**: The discussion here focused on describing hydrocarbons serving as a foundation for later discussions on the functional group for alkanes, alkenes and alkynes. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe hydrocarbons before providing her own explanation. **Learners' role:** Through his response, learner SM3 showed a good understanding to an extent by describing hydrocarbons described as the compounds of carbon and hydrogen (LP). **Ruth's role:** Commenting on SM2's response, Ruth considered important for learners to know, the inclusion of the word 'only' to SM2's description of hydrocarbons, thereby adding value by locating where emphasis is to be placed in the established learner prior knowledge about carbon and hydrogen and also linked that to classifying hydrocarbons as the simplest of all organic compounds thereby demonstrating an understanding of curricular saliency (CS). She supported her explanation with giving methane as an example explained using its structure thereby demonstrating her understanding of the use of a symbolic representation (RP). She also gave familiar examples of hydrocarbons in order to situate her explanation in the learners' context which further talks to the Ruth's understanding of learner prior knowledge (LP). Ruth's interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 
6-7min: Describing saturated hydrocarbons **Ruth**: So, when we talk about saturated hydrocarbons we're referring to the hydrocarbons which have got only single covalent bonds between carbon atoms and hydrogen atoms **(CS)**, let's take for instance propane here (*she pointed at the structure of propane on the bond*), here is carbon bonded to	**Comment**: The discussion here focused on describing what saturated hydrocarbons are in relation to the previous discussion on hydrocarbons. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth described saturated hydrocarbons as consisting of only single covalent bonds between

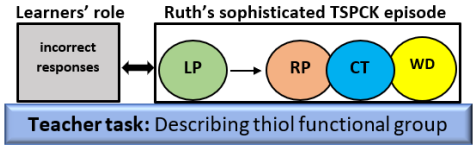
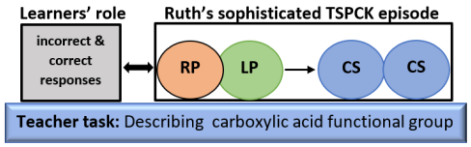
another carbon, **(RP)** and then these carbons are bonded to hydrogen atoms right, so to these carbon atoms (*she pointed at the last carbon to the right hand side and the first to the left hand side*), we have maximum of three hydrogen atoms completely bonded to each end-carbon, you see but to this middle carbon atom, we have two hydrogen atoms bonded to it, so the carbon forming 4 bonds is catered for right? **Ss**:…..(yes)……	atoms of carbon emphasised as the important aspect for learners to know at this point (**CS**). She supported her explanation with reference made to the structure of propane drawn on the board in explaining this (**RP**). **Learners' role**: None Ruth's interactive use of TSPCK components (CS/RP) at a simple level of TSPCK episode is given by the TSPCK map below. 
7-8min: Describing unsaturated hydrocarbons **Ruth**: And then, in unsaturated hydrocarbons, that is where we have either a double or triple bond between carbon atoms just like in here (she drew the structure of ethene on the board), here we've got two carbon atoms bonded to four hydrogen atoms, and you see a double covalent bond between carbon atoms? **(RP)** and another type of unsaturated neh that's similar to this one (*she pointed to the structure of ethene on the chalk board*) is having at least one triple covalent bonds between carbon atoms **(CT)** like (*she drew the structure of ethyne on the board*), now there is something about this, this tells us that, in a single bond, there are two pairs of electrons which are shared and in a double bond, there are four pair of electrons which are shared, and then a triple bond, there are six pair of electrons which are shared, so you've got to understand what those bonds actual mean, (**CS**) are we together? **Ss**:…..(yes)…….	**Comment**: The discussion here focused on describing unsaturated hydrocarbons in relation to the previous discussions on hydrocarbons. **In-depth Qualitative Analysis**: **Ruth's role:** Using the structures of ethene and ethyne, Ruth described unsaturated hydrocarbons with at least a double covalent bond or triple covalent bond between atoms of carbon. She most importantly explained a single covalent bond representing two pairs of electrons. She demonstrated the understanding of conceptual teaching strategies (CT) interactively used with representations (RP) as she explained the similarity and difference between ethene and ethyne with emphasis on the type of carbon-carbon covalent bond (CS). **Learners' role**: None The Ruth's interactive use of TSPCK components (RP/CT/CS) at a proficient level of episode is given by the TSPCK map below. 
8-10min: Describing functional groups **Ruth**: Now, we come to talk about functional groups yeah, what is a functional group? SF3: A group of atoms in organic chemistry Ruth: Any other opinion? (***There was no response***) **Ruth**: Right, chemists commonly use the term functional groups with organic compounds, (**LP**) they are referred to as the central atoms in a molecule, but they most importantly give organic molecules their reaction characteristics, here we've got the homologous series, **(CS)** with a particular functional group which is common to all the members, so functional group is what makes an organic compound which belongs to a given homologous series different from another organic compound that belongs to a different homologous series let's say this (*she drew the structure of ethane*) **(RP)**, it's ethane and then (*she drew the structure of ethene on the board*), ethene right and	**Comment**: The discussion here focused on describing what functional groups represent in the study of organic compounds. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe functional groups as a starting point preceding her explanations. **Learners' role:** Learner SF3 correctly referred to functional group as a group of atoms in organic chemistry but without stating their uniqueness (LP). **Ruth's role:** Ruth expatiated on SF3's response by linking the organic reactions undergo by homologous to their functional groups thereby demonstrating the most important element of what learners should know, an aspect of curricular saliency (CS). She used structural representations of ethane and ethene (RP) to further explain how

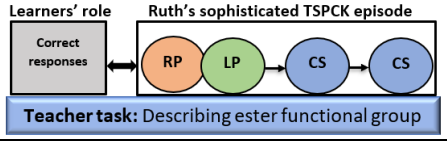
then **(CT)** (*she drew the structure of ethyne on the board*), they both have carbon and hydrogen atoms but different functional groups, am I right? Ss: yes	functional groups differentiate one homologous series from the other, an element of conceptual teaching strategies (CT). Ruth's interactive use of TSPCK components (LP-CS/RP/CT) a level of episode in connection to a learner's correct response is given by the TSPCK map below. 
10-11min: Describing Alkane functional group **Ruth**: Now, from our discussions, how would you describe alkanes and their functional group, that's two in one, yes? **SF2**: Alkanes are saturated hydrocarbons and they've got single covalent bonds between carbon atoms **Ruth**: That's brilliant! We have explained saturated hydrocarbons as having single covalent bonds between carbon atoms and carbon atoms are covalently bonded to hydrogen atoms (**LP**) as well so now each time we come across alkane homologous series neh, all the members are identified by single covalent bonds between carbon atoms in their molecules, please always remember that, (**CS**) so we represent the alkane functional group as (*she put wrote C-C on the chalk board*), **(RP)** with this functional group, if one member undergoes let's say substitution reaction, all other members too will undergo the same organic reaction **(CS)**, yeah that's for alkanes, any question before we move on? *There was no response from learners.*	**Comment**: The discussion here focused on describing the alkane functional group. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to first describe alkanes and their functional groups as a starting point preceding her explanations. **Learners' role:** Learner SF2's response showed a good understanding of alkanes as saturated hydrocarbons with single covalent bonds between carbon atoms (LP). **Ruth's role:** Ruth expatiated on SF2' response by indicating the alkane functional group characterized by a single carbon-carbon bond, is used for identifying organic compounds in the alkane homologous series thereby demonstrating the understanding of what learners should know, an aspect of curricular saliency (CS). She supported her explanation with the structure of alkane functional group drawn on the board thereby describing her knowledge of the use of a symbolic representation (RP). She further referred to the common organic reactions like substitution reaction that all members of alkanes undergo due to their common functional group. This describes Ruth's understanding of additional aspect of what learners needed to know about alkane functional group ahead of a specific discussion on organic compounds reactions, an aspect which will serve as a prior knowledge to the discussion on organic reactions, this is also a demonstration of an element of curricular saliency (CS) of a different kind that brings additional depth, other than emphasis of most important aspects, lit is about laying a group with prior concepts for a near future discussion. Ruth's interactive use of TSPCK components (LP-CS/RP/CS) at a sophisticated level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 

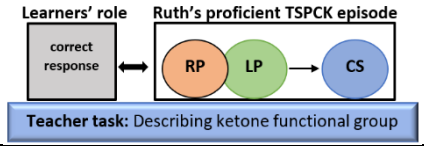
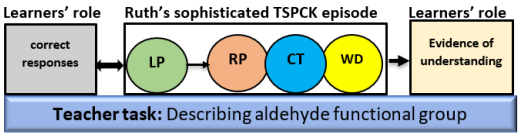
11-13min: Describing Haloalkane functional group **Ruth**: Let's see a similar group here (*She drew the structure of bromobutane*), **(RP)** who can tell us what this Br represent? **SM10**: Bromine **Ruth**: It's bromine, an element from which group? **SM10**: 7 **Ruth**: And what do you call those elements? Yes? **SF7**: They are halogens **Ruth**: So, Other examples include? **Ss**: Chlorine, Fluorine, Iodine, Bromine **Ruth**: Brilliant, so whenever we talk about halogenated compounds, those are compounds that contain the atoms of those elements you just mentioned **(LP)**. Now, so here (*she pointed at the structure of bromobutane*) is similar group to alkanes, we refer to them as haloalkanes, just like saying halogenalkanes, but it's correct to say haloalkanes, they are special homologous series of saturated hydrocarbons, which has got single carbon to carbon covalent bonds and then one more halogens, **(CS)** note here they are saturated class of hydrocarbons, we represent the functional group as (*she wrote R-X on the board*), here, our alkyl R is bonded to halogen X. Any question? **SF8**: Ma'am can one haloalkane have two halogens like Flourine and Chlorine in one molecule? **Ruth**: Here is a question for you guys, who is gonna help? SM2: yes, as long as they are halogens **Ruth**: Exactly, when we see it like that, it is still gonna be a haloalkane, it doesn't change the homologous series. Any other question? **Ss**….(No response from learners)	**Comment**: The discussion here focused on describing the haloalkane functional group. **In-depth Qualitative Analysis**: **Ruth's role:** Using the structure of bromobutane drawn on the board (**RP**), Ruth asked learners to know if they could recognize bromine in the structure. **Learners' role:** The Learners' responses showed understanding of Bromine, their group in the periodic table, their common name and other elements in the group (**LP**). **Ruth's role:** As an important aspect for learners to know, Ruth expatiated on the learners' correct responses to describe haloalkanes and their functional group with R-X as a symbolic representation. **Learners' role**: Learner SM2 responded in agreement to SF8's question asking if a haloalkane could have two halogens in the same organic molecule. This suggests SM2's understanding of Ruth's explanations. Ruth's interactive use of TSPCK components (RP/LP-CS) at a proficient level of TSPCK episode in connection to the learners' correct responses and reflecting learners' understanding of the explanations provided by Ruth is given by the TSPCK map below. 
13-15min: Describing Alkene functional group **Ruth**: Now, how about alkenes and their functional group guys? Who's gonna tell us something? **SM11**: They are unsaturated hydrocarbons **Ruth**: Yes, how can we recognize them? **SM8**: They have got double bond **Ruth**: Yeah, alkenes are unsaturated hydrocarbons as we earlier discussed, **(LP)** that's right. We've got to have at least a double covalent bond between carbon atoms in alkenes, so we use it to represent the functional group for all the members in the alkenes homologous series **(CS)** we represent functional group for alkenes by simply writing (*she put C=C on the chalk board*) on the board, so we find that, in all organic compounds that belong to the alkene homologous series neh **(RP)**. Something interesting to know about alkenes is that, if they react with hydrogen gas (*she put the equation of ethene and hydrogen gas on the board*), the hydrogen gas are added across the double bond and then, it becomes an ethane, we call that reaction halogenation of alkenes, all members of alkenes undergo it (**CS**) because they've got the same functional group, any question? *There was no response from learners.*	**Comment**: The discussion here focused on describing the alkene functional group where Ruth engaged learners in questioning before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe alkenes and their functional groups in order to first establish their existing understanding. **Learners' role:** Learner SM11 and SM8's responses showed good understanding of alkenes as unsaturated hydrocarbons with a double covalent bond between carbon atoms (**LP**). **Ruth's role:** Ruth expatiated on the learners' correct responses by re-emphasizing a double covalent bond between carbon atoms, an important aspect (**CS**) and using a symbolic representation of its functional group (**RP**). Another important aspect pointed out in her explanation was the halogenation reaction of alkenes to become alkanes (**CS**). Ruth's interactive use of TSPCK components (LP-CS/RP/CS) at a sophisticated level of TSPCK episode in connection to learners' correct responses

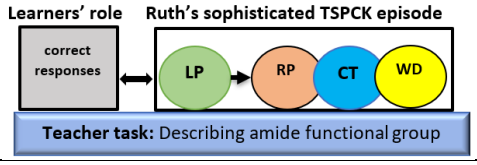
	is given by the TSPCK map below. 
15-16min: Describing Alkyne functional group **Ruth**: So, how about alkynes guys? SM5: They are also unsaturated hydrocarbons because they have got a triple bond between carbon atoms. **Ruth**: Yes, in the case of alkynes, a triple covalent bond is present between the two carbons **(LP)** as we can see here (*she referred to the structure of ethyne on the board*), we have the number of hydrogens reduced to two because of the triple bond neh. **(RP).** Now, when it comes to the functional group, all organic compounds in the alkyne homologous series have got their own functional group which we can find in molecules which makes them to be different from other organic compounds **(CS)** (*she put the structure of the functional group on the board*) of alkynes is given as this and this means that, there are six bonding electrons between these two carbons so, we identify all members of alkynes with this triple bond between two carbon atoms, so now, because alkynes have their the same functional group in their molecule, they undergo similar organic reaction like addition reaction, they first form alkenes and then further reaction leads to the formation of alkane, (**CS**) you see, so functional groups make you think different when you come across organic compounds right? Ss: yes	**Comment**: The discussion here focused on describing the alkyne functional group where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to describe alkynes in order to first establish their existing understanding thereby. **Learners' role:** Learner SM5 showed a good understanding by describing alkynes as unsaturated hydrocarbons with at least a triple covalent bond between carbon atoms (**LP**). **Ruth's role:** In her explanation, Ruth re-emphasized the triple covalent bond between carbon atoms as the first important aspect for learners to note thereby describing her knowledge of an aspect of curricular saliency (**CS**). She simultaneously used the structure of ethyne drawn on the board to identify the alkyne functional group a symbolic representation of the functional group (**RP**). She further related the functional group to similarity in the organic reactions that all members of alkyne homologous series undergo thereby showing another important aspect for learners to understand about the alkyne functional group (CS). Ruth's interactive use of TSPCK components (RP/LP-CS/CS) at a sophisticated level of TSPCK episode in connection to a learner's correct response is given by the TSPCK map below. 
16-18min: Describing Alcohol functional group **Ruth**: We've come to the next functional group (*she faced the chalk board and wrote R-OH*), **(RP)** so now which functional group are we talking about here guys looking at this? What class of organic compounds does this represent? **SM1**: hydroxyl group **Ruth**: Is it? **Ss**…(Learners echoed yes)…. **Ruth:** So what class of organic compounds does it represent? **SF2**: Alcohols **Ruth**: Very good, you said this OH here? **SF2**: Hydroxyl group **Ruth**: Hydroxyl group, that's good, so here we're talking about the hydroxyl group OH, our oxygen is covalently bonded to hydrogen, so you don't think it's the same as the hydroxide group **(LP)** which we normally represent as OH^- for	**Comment**: The discussion here focused on describing the alcohol functional group where Ruth asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Using the structure of alcohol functional group drawn on the board (RP), Ruth asked learners to mention the functional group indicated and class of organic compounds represented in order to first establish learner prior knowledge. **Learners' role:** Learner SM1 and SF2 showed a good understanding as they correctly identified OH as the hydroxyl group and alcohol functional group as represented (LP). **Ruth's role:** Ruth confirmed the learners' existing

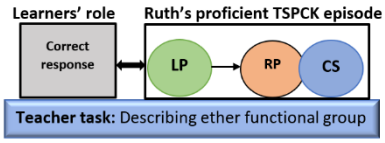
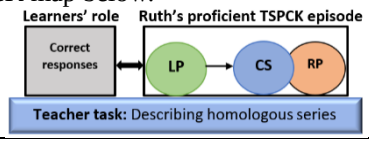
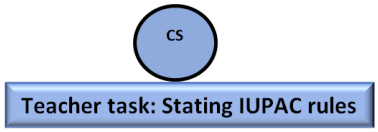
instance in NaOH, it's an hydroxide ion in inorganic compounds but in organic compounds, it's an hydroxyl group so you don't confuse the two, OH here it's the functional group of all alcohols, it's for members in the alcohol homologous series (**CT**) here is ethanol (***she drew the structure***), as you can see, it consists of five carbons single covalent bonds bonded to hydrogens to represent our alkyl R, now our R is bonded to OH group so we do represent all alcohols by R-OH to show the functional group and because all members in the alcohol homologous series have got same OH, they all undergo reactions like oxidation, esterification and so on, one important thing for you note, **(CS)** you see when alcohols are oxidized, they produce other organic compounds like ketones, carboxylic acids, that's not the focus for today, just take note of that.	knowledge of hydroxyl group for alcohols. She further cautioned learners not to confuse the hydroxyl OH in alcohols with the hydroxide ion (OH^-) in inorganic compounds because of their similarity in representations. This logic of describing the difference and similarity of hydroxide group and hydroxide ion seemed to describe Ruth's knowledge of a conceptual teaching strategy (CT) used in science teaching. In addition to emphasizing the hydroxyl functional group for alcohols, she further referred to the types of organic reactions (e.g. oxidation, esterification) that all members of alcohols undergo because they all contained the hydroxyl functional group. This appeared to describe her knowledge of a Big Idea in organic chemistry, an element of curricular saliency (CS). Ruth's interactive use of TSPCK components RP/LP-CT/CS at a sophisticated level of TSPCK episode in connection to the learners' correct responses is given by the TSPCK map below. 
18-20min: Describing Thiols functional group **Ruth**: So, now there's a group of organic compounds which are very similar to alcohols when you look at their name, who can tell us? SM12: Aldehyde **Ruth**: How? SM13: Alkanols Ss: (Laugh!!!) **Ruth**: Eish guys, aldehyde are organic compounds with a specific functional group but they aren't in any way thiols and alkanols are also known as alcohols, **(LP)** ok. Another similar group of organic compounds is called Thiols (*she wrote the name on the board*), we can see that the name is similar to alcohols right? Ss: yes **Ruth**: Yeah, Thiols have got their functional group here is it (*she wrote R-SH on the chalk board*), here is our SH, **(RP)** sulfhydryl group, bonded to an alkyl group, R just like we've got CH_3SH, its name is methanethiol we can also see that, the functional group for our alcohol here (*she pointed at the R-OH on the chalk board*) is somehow similar to this thiol right? Ss: yes **Ruth**: So now you've got to understand that in alcohol, we have got our hydroxyl group OH bonded to a carbon atom but in thiol functional group, we can see that oxygen atom in OH has been replaced by Sulphur S **(CT)** so because of how similar thiols are to alcohols, it may be difficult to remember it's hydryl in Thiols but in alcohols, it's hydroxyl, so you've got to be careful to avoid mistakes, you see the difference?	**Comment**: The discussion here focused on explaining the Thiols functional group where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners to mention any similar organic compounds to alcohols already discussed with them in an attempt to investigate their prior knowledge of Thiols. **Learners' role:** In their responses to Ruth's question, Learner SM12 and SM13 wrongly referred to aldehyde and alkanols respectively as the similar organic compounds to alcohols they could think of (LP). **Ruth's role:** Ruth commented on the learners' responses by indicating alcohols are the same as alkanols and writing Thiols on the board to see how 'ol' is present in both Thiols and Alcohols as their similarity. She referred to the sulfhydryl group with its symbolic representation as the unique Thiols functional group thereby demonstrating her knowledge of what learners should know (curricular saliency, CS) and use of representation (RP). Also, she showed how similar and different the hydryl group is to the hydroxyl group thereby showing the understanding of what could be difficult for learners (WD). Making learners to understanding the difference and similarity between alcohols and thiols

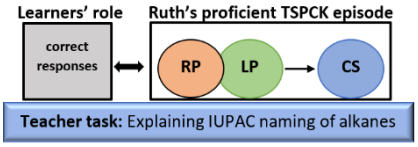
(**WD**) Ss: yes **Ruth**: So we can say that sulfur S has taken the place of oxygen in OH, that's the logic, so instead of having hydroxyl, we now have sulfhydryl SH, that's the functional group for Thiols, once we see it in an organic compound, we know such a compound belongs to Thiol homologous series and one special thing about Thiols is that, they've a strong odour like that of rotten eggs, that kind of bad odour we all know right? Ss: yes	also signals Ruth's understanding of conceptual teaching strategies (CT). She further talked about Thiols identified with a strong odour like that of rotten eggs, thereby describing Thiols physical property, another important aspect for learners to know. Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to the learners' incorrect responses is given by the TSPCK map below. 
20-23min: Describing Carboxylic functional group **Ruth**: Now, let's see the next one (*she put the structure of carboxylic acid functional group on the chalk board*) **(RP)**, we can simple write it as RCOOH), yeah so which organic compound does this functional group represent? Ss: ….(No response from learners)…. **Ruth**: What does this R represent guys? SM10: Alkyl group **Ruth**: That's like CH3 right? SM10: yes **Ruth**: (She pointed at the C=O portion), what's this? SF8: it's like carbon monoxide Ss: …..(Learners laugh)…… **Ruth**: Carbon monoxide is a gas remember, it's an inorganic compound, **(LP)** please not that here *(she pointed at the structure on the chalk board*) it's our C=O is a carbonyl group, we've got carbon double bonded to oxygen, it's a functional group in organic chemistry, **(CS)** so now how about this (*she pointed at the OH portion*)? SF9: hydroxyl functional group Ruth: Functional group for SF9: Alcohols **Ruth**: So, we're saying here is our hydroxyl group OH, the functional group of alcohols homologous as we discussed before, so here our OH and C=O form the carboxylic functional group, we can write it as (she wrote COOH on the board) or (she wrote C(=O)OH on the board), we've got a carbon double bonded to an oxygen, it's also bonded to one hydroxyl group and on the other side, to an alkyl group, yeah, with this functional group we can identify and name all the compounds in the carboxylic acid homologous series like using oic for methanoic acid, ethanoic acid, propanoic acid and so, you can see the trend right, so because they've got the same functional group, they undergo same organic reactions, **(CS)** is that understood now? Ss: yes	**Comment**: The discussion here focused on describing the carboxylic acid functional group where Ruth asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of carboxylic acid functional group drawn on the board (RP), Ruth asked learners the organic compound represented by the structure **Learners' role**: Learners provided no answer in response to what organic compounds are represented by the functional group. However, SM10 and SM9 correctly identified R as the Alkyl and OH as the hydroxyl group for alcohols respectively. SF8 wrongly referred to C=O as carbon monoxide (LP). **Ruth's role:** Taking all learners' responses into consideration, Ruth first indicated the hydroxyl and carbonyl group as the constituents of carboxylic functional group used for identifying and naming all carboxylic acids. This suggests the an aspect important for learners to know thereby describing Ruth's knowledge of curricular saliency (**CS**). Another important aspect describing Ruth's knowledge of curricular saliency was the effect of all members having the same functional group as seen through similar organic reactions they undergo (**CS**). Ruth's interactive use of TSPCK components (RP/LP-CS/CS) at a sophisticated level of TSPCK episode in connection to the learners' incorrect and correct responses is given by the TSPCK map below. 
23-27min: Describing Esters functional group **Ruth**: And then we have the functional group for esters here	**Comment**: The discussion here focused on describing the ester functional group where Ruth

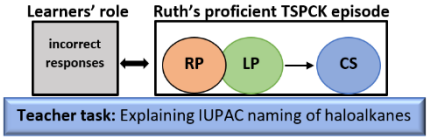
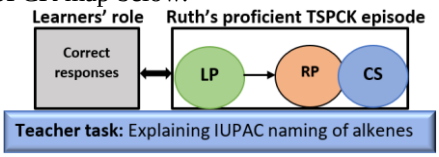
(*she drew the structure on the chalk board*) **(RP)** looking at this can anyone tell us from which compounds we could say an ester has possibly formed? **SM7**: carboxylic acid **Ruth**: Why? **SM7**: there's a carbonyl group **Ruth**: Carbonyl group and then? **SF8**: hydroxyl group **Ruth**: Yeah, he's right by saying carboxylic acid because here is the carbonyl group, you must always remember that carboxylic acid functional group does not consist of carbonyl group only right, it's also got an hydroxyl group as well **(LP)**, so here it is (*she pointed at the functional group of carboxylic acid*). So now we can say that the functional group for esters is derived from a carboxylic acid and from an alcohol, that's the point **(CS)** as we can see here (*she referred to the structure of ester functional group*), here is our carbonyl group C=O, and here is OH **(RP)** but now H has been replaced by alkyl, such instead of OH, we've got O-alkyl, so all compounds in the ester homologous series commonly have general molecular formula RCOOR', they all end with 'oate', you've come across that? **SF10**: Like propanoate **Ruth**: Exactly, here is an example (*she put the symbolic structure of ethyl propanoate on the board*), it's ethyl propanoate yeah, it tells us that the IUPAC name for members in the ester homologous series ends with 'oate' **(CS)** and you can see they've got hydrogen bonds right, so they are polar, they are soluble in water to an extent, chemists normally use those esters that have got low molecular weight to make fragrances which some of us use, yeah. Any question on that? **Ss**: (No response)	asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of ester functional group drawn on the board (RP), Ruth asked learners possible compounds from which esters could have formed. **Learners' role**: Learner SM7 suggested carboxylic acid as the compound that could have produced ester. Also, learner SF8 also identified hydroxyl group in the structure of carboxylic acid. These correct learners' responses showed their good prior knowledge (LP) and understanding of the previous discussion on carboxylic functional group **Ruth's role:** Ruth expatiated on the learners' correct responses to emphasis key aspects she wanted learners to know. These included: esters as derived from carboxylic acids and alcohols with 'oate' as the suffix in naming esters; esters as polar substances making them soluble in water and their application in making fragrances. These two points were considered different but related aspects of esters that learners needed to know thereby demonstrating Ruth's knowledge of curricular saliency (CS). Ruth's interactive use of TSPCK components (to RP/LP-CS-CS at a sophisticated level of TSPCK episode in connection to the learners' correct responses is given by the TSPCK map below. 
27-29min: Ketone functional group **Ruth**: We have a ketone, its functional group can be *represented as, here it is (she drew and referred to the structure drawn on the board*), **(RP)** you can see that neh. What did we call this portion containing a double bond between carbon and oxygen the other time? **SM5**: carbonyl group **Ruth**: ok thanks; remember we said in carbonyl group, carbon is double bonded to oxygen, that's our C=O **(LP)** so, a ketone functional group consists of a carbonyl group **(CS)** as we can see in this structure (*she referred to the structure drawn on the board*) and the remaining two bonds of this carbon may consist of alkyl group R that is CH3 as shown here, ethyl group like (*she put CH_2CH_3 as representing R in the structure*), so here we've got our butanone. Ss: yes	**Comment:** The discussion here focused on describing the ketone functional group where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** With reference made to the structure of ketone functional group drawn on the board (RP), Ruth asked learners to indicate what C=O represent in order to establish their understanding of previous discussions on identifying carbonyl group. **Learners' role**: Learner SM5 correctly referred to the portion as the carbonyl group showing the learner's understanding of the previous discussions (LP). **Ruth's role:** In her explanation Ruth further reminded learners of what carbonyl group is and she pointed out what constitutes the ketone functional group as an important aspect she wanted learners to understand (CS). Ruth's interactive use of TSPCK components (RP/LP-CS) at a proficient level of TSPCK episode

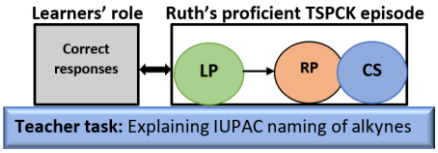
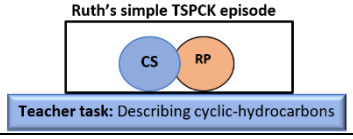
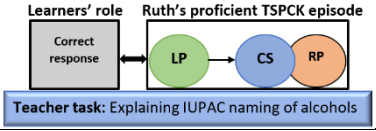
	in connection to a learner's correct response is given by the TSPCK map below. 
29-33min: Describing Aldehyde functional group **Ruth**: Now, what do you know about aldehydes and their functional group? Yes SM12: They look like ketone in a way **Ruth**: (Smile), in which way? Learner SM12 was silent. SM13: They have got a carbonyl group **Ruth**: Yes, Aldehydes are similar organic compounds to ketones but we must be careful, we mustn't think they are the same, they are different, **(LP)** let's see the functional group (*she drew the structure of aldehyde functional group on the board*), we can see here **(RP)** aldehydes have got carbonyl group with the carbon here bonded to hydrogen on one side, same carbon is bonded to an alkyl group, R on other side this bonding arrangement very important, so unlike here in our ketone functional group (*she pointed at the structure of ketone functional group*) where carbonyl group is bonded to one alkyl group on one side and another alkyl group on the other side, **(CT)** it becomes difficult to distinguish between the two functional groups once we forget what is bonded to the central carbon atom on these two sides. **(WD)** SF2: How does that affect their names? **Ruth**: Good question, remember I said for naming ketones, you replace ane in alkanes by one just like butane to butanone but for aldehydes, their IUPAC name ends with 'al' just line replacing ane with anal (she faced the board and put the structure of ethanal on the board), so what are u gonna call this? SF3: ethanal **Ruth**: And this (she put the structure of ethenone on the board)? SF4: ethanone **Ruth**: That shows we can differentiate ketones from aldehydes Ss:….(Learners echoed 'yes') Ruth: So, let's say we've got [she put CH3C(CH3)OHCH3 on the board), and then, here is another [she put CH3CH2CH2COOH on the board], and then [she put CH3CH2COOCH2CH3 on the board], now who is gonna help us name the functional group in [she pointed at she put CH3C(CH3)OHCH3]? SM10: hydroxyl group SM11: alcohol functional group Ruth: It's an alcohol because of this OH and this one [she pointed at CH3CH2CH2COOH]? SF8: it's a carboxylic acid Ruth: because of COOH, good and this one [she pointed at she put CH3CH2COOCH2CH3]? SM2: ester functional group Ruth: yeah, RCOOR right?	**Comment:** The discussion here focused on describing the aldehyde functional group where Ruth asked learners questions before providing explanations. **In-depth qualitative analysis:** **Ruth's role:** Ruth asked learners what they knew about aldehydes and their functional group. **Learners' role:** Learners' responses revealed an understanding that, aldehydes are similar to ketone as they both has carbonyl group as part of their functional groups (LP). **Ruth's role:** Taking learners' correct responses into consideration, Ruth cautioned learners about thinking ketones are the same as aldehydes because of their similar functional group thereby showing awareness of a possible misconception, an aspect of learner prior knowledge (LP). As an important aspect for learner to know, she used the drew the structure of aldehyde functional group and explained it is made up of. Likewise, she referred to the structure ketone in order to make the learners understand how carbonyl group is bonded. This suggests Ruth's knowledge of the use of symbolic representations (RP) in explaining the similarity and difference between aldehydes and ketones (CT). Demonstrating her knowledge of what is difficult (WD), she indicated inability to remember how carbonyl group is bonded in each case of ketone and aldehyde as what could make them difficult to differentiate. **Learners' role:** The Learner SF3 and SF4's ability to mention ethanal and ethenone as examples of aldehyde and ketone respectively suggests evidence of their understanding of the explanations Ruth provided. Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to learners' correct responses and also accompanied by evidence suggesting learners' understanding of the explanations provided by Ruth is given by the TSPCK map below. 

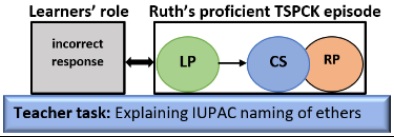
Ss: yes	
33-36 min: Describing Amide functional group **Ruth**: And then, we have amide. Does anyone have an idea of how the functional group looks like? Ss: (no response) **Ruth**: OK, from all we have discussed so far, can someone describe the functional group for carboxylic acid? Please, think guys I need someone to help. **SM1**: It has got a carbonyl group and hydroxyl group **Ruth**: That's a good point, ok guys, one thing about functional groups is that they are similar somehow, **(LP)** so you must identify the differences and similarities between them, is that ok? Ss: yes **Ruth**: Ok guys, remember we talked about the carboxylic acid functional group right here (*She pointed at the structure*) so if here we replace the OH by **(RP)** NH_2 then we have an amide functional group, in other words, the key here is that our amide functional group is made up of a carbonyl group which is bonded to NH_2 as we can see here (*She drew and referred to the structure*). You can see the difference between carboxylic acid functional group and amide functional group right **(CT)** as we have here, while in carboxylic acid functional group we have OH as you can see here, in amide we have NH_2, so if you forget that to carbon in the carbonyl group, we have got NH_2 attached it would be hard for you to describe amide, you might find it difficult to distinguish it from carboxylic acid and others with similar structure, so please don't confuse them, **(WD)** Is that understood? Ss: yes	**Comment:** The discussion here focused on describing the amide functional group where Ruth asked learners questions before providing explanations. **In-depth qualitative analysis:** **Ruth's role:** Ruth asked learners about how amide functional group looks. When there was no response from learners, she asked them to describe the carboxylic acid functional group which she had earlier explained to them like. **Learners' role:** Learner SM1 correctly mentioned carboxylic acid functional group as consisting of carbonyl and hydroxyl group (LP). **Ruth's role:** Using the structure drawn on the board (RP), Ruth explained the constituent of carboxylic acid functional group as an important aspect she wanted learners to understand. She did this by differentiating amide functional group from carboxylic acid functional (CT) and cautioned learners of any learning difficulty that could emanate from the similarity of the two functional groups (WD). Ruth's interactive use of TSPCK components (LP-RP/CT/WD) at a sophisticated level of TSPCK episode in connection to a learners' correct responses is given by the TSPCK map below. 
36-40 min: Describing Ether functional group **Ruth**: And then we have ether. Does anyone know how the functional group look like? SM4: It contains oxygen **Ruth**: Yes, but remember oxygen alone can't form the functional group. Who has got something to say? (No response from learners) **Ruth**: As he rightly said, oxygen is part of it but oxygen alone does make the functional group for ether, **(LP)** now the functional group (*she drew the structure of ether functional group*), so here is Ether functional group, **(RP)** what has it got? In the functional group, we have got an atom of oxygen which is bonded to the alkyl R on this side and another alkyl R on the other side, you must not forget, **(CS)** our O is bonded to one alkyl group and another alkyl group, can you all see that? Ss: yes	**Comment:** The discussion here focused on describing the ether functional group where Ruth asked learners questions before providing explanations. **In-depth qualitative analysis:** **Ruth's role:** Ruth asked learners about how ether functional group looks. **Learners' role:** Learner SM4 could correctly identify the presence of oxygen atom in the ether functional group (LP). **Ruth's role:** Ruth expatiated on the learner's correct response using the structure drawn on the board to explain what ether functional group comprises of as an important aspect she wanted learners to understand. This suggests her understanding of the use of a symbolic representation (RP) and curricular saliency (CS). Ruth's interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode in connection to a learners' correct responses is given by the TSPCK map below.

	
Lesson 2	
<u>0-4min: Homologous series</u> **Ruth**: Now we gonna be discussing the IUPAC naming of organic compounds. We've all along been talking about homologous series right, so now I would like someone to tell us something generally about homologous series, yes? SM5: Like an alkane consists of members and they are similar **Ruth**: Similar in what sense? SM5: They have similar names **Ruth**: Any other opinion? (There was no response) **Ruth**: As he rightly said, homologous series consists of members and all the members have something in common, that is the functional group, even though members in a homologous series have got same functional group, their carbon chain length differs depending on the number of carbon atoms, for example, an alkane is one homologous series, an alkene is another homologous series. As we can see here, we have methane with one carbon and four hydrogens, our CH_4 on the other hand, this structure of ethane shows two carbon atoms with six hydrogens. The similarity between these compounds is the single bond between carbon atoms and their names end with 'ane' neh, that is for all members of alkanes	**<u>Comment</u>:** The discussion here focused on describing homologous series as a starting point for discussions on IUPAC nomenclature of compounds. **<u>In-depth qualitative analysis:</u>** **Ruth's role:** Ruth reminded learners of the homologous series which she has been mentioning in her previous discussions and then asked them to describe it. **Learners' role:** Learner SM5's response showed an understanding of homologous series as having members with similar names (LP). **Ruth's role:** Ruth expatiated on the learner SM5's response by pointing out the functional group as the major similar feature for describing homologous series, an important aspect she wanted learners to understand. She also used the structure of methane and ethane to support her explanation. This suggests her understanding of the use of a symbolic representation (RP) and curricular saliency (CS). The Ruth's proficient TSPCK episode (LP-CS/RP) mediated by a learner's correct response is given by the TSPCK map below. 
<u>4-9min: IUPAC naming rules stated</u> **Ruth**: As indicated in the paper I gave you, in naming organic compounds generally we have prefixes, 'meth' is for one carbon atom, 'eth' is for two carbon atoms, 'pro' is for three carbon atoms and others as stated there. In naming the alkanes, alkenes and alkynes, there are a few things you need to note. The IUPAC name for an alkane always ends with 'ane', for alkenes, it ends with 'ene' and for alkynes, it ends with 'yne' and a prefix is attached to this ending to indicate the number of Carbon atoms present in the molecule. These prefixes apply to all hydrocarbons and they call be given only for straight-chain compounds. For branched-chain compounds, different names have evidently to be given to the different isomers and IUPAC has recommended certain procedures. T: You need to identify the longest continuous chain also called the parent chain of carbon atoms in the molecule and name it.	**<u>Comment</u>:** The discussion here focused on describing the IUPAC rules for naming organic compounds. **<u>In-depth qualitative analysis:</u>** **Ruth's role:** Ruth talked through the rules for naming hydrocarbons as stated in the sheets of paper she distributed to the learners. The explanations suggest her understanding of an aspect important that learners needed to know. **Learners' role**: None The Ruth's use of use of knowledge of curricular saliency in describing IUPAC rules. 
<u>9-18min: Naming alkanes</u> **Ruth**: Let's have this compound for instance (She drew the structure of 2-methyl, 5-ethyl heptane), how many carbon atoms do we have? SF1: Ten	**<u>Comment</u>:** The discussion here focused on applying the earlier stated IUPAC rules in naming an isomer of octane. **<u>In-depth qualitative analysis:</u>** **Ruth's role:** Ruth drew the structure of 2-methyl, 5-

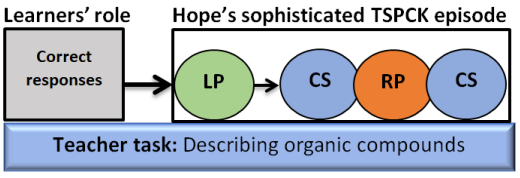
Ruth: Ten, how many carbon atoms do you think make up the longest continuous chain? SF2: seven **Ruth**: Please, come show us how you counted and got seven *(SF2 went out and counted from the longest continuous chain from the left such that the compound would have been name 3-ethyl, 6-methyl heptane).* **Ruth**: That's correct we have seven carbon atoms that form the longest continuous chain. Now, the next step is to identify the substituent group attached to the parent chain. As we can see here (She points to the structure on the board), there are two substituent groups, this one (she points to the methyl) and this one (she points to the ethyl). We can this one the methyl group because it contains one carbon and three hydrogens and we call this one ethyl because it consists of two carbons and five hydrogen atoms. Is that clear now? Ss: yes **Ruth**: Now, we need to name the compound by numbering the carbon atoms in the parent chain from the left to the right the reason being that we name from the carbon to which the smallest substituent group is attached. In this case, we have two substituent groups, the methyl group and the ethyl group such that we have methyl on carbon number 2 and ethyl on carbon number 5. Since the parent name is heptane because we have seven carbon atoms, then we can name it as 2-methyl, 5-ethyl heptane. If we number from the right to the left as she earlier said, what would the name be? Yes? SM1: 3-ethyl, 6-methyl heptane **Ruth**: 3-ethyl, 6-methyl heptane, this is not correct because the numbers associated with the naming 3 and 6 are larger than those in the IUPAC name 2 and 5. Is that clear now? Ss: yes **Ruth**: If two or more substituent groups are identical, use the prefix di- for two, tri-for three and so on for example if we change ethyl here to methyl, then we have methyl on carbon number 2 and carbon number 5. In this case, we gonna name the compound as 2, 5 di-methyl heptane, it cannot be 2-methyl, 5-methyl heptane is that understood? Ss:….(Learners echoed yes)…..	ethyl heptane and asked learners how many carbon atoms were there in the molecule and the number of carbon atoms that make up the longest chain. **Learners' role:** The learner SF1 and SF2's responses showed understanding of what it means to have a longest continuous carbon as Ruth previously discussed with them (LP). **Ruth's role:** Taking learners' responses into consideration, Ruth named the molecule with learners as an important aspect she wanted them to understand by the structure of the molecule drawn on the board. using symbolic structural representations. Ruth also provided explanations that distinguished a correct name from wrong name of the molecule. This suggests her understanding of the use of a symbolic representation (RP) and curricular saliency (CS). The Ruth's proficient TSPCK episode (RP/LP-CS) mediated by a learner's correct response is given by the TSPCK map below. 
<u>18-23min: Naming haloalkanes (</u>2-bromo, 3-chlorobutane) **Ruth**: Now, let's all look at the structure here (She drew and referred to the structure of 2-chloro, 3-bromobutane on the board), what is the IUPAC name? Yes, anyone? We need to know the name of this molecule, yes. SM1: 2-chlorobutane **Ruth**: Is that? SF2: Haibo, bromobutane is also there. **Ruth**: And so, what should the name be? SF2: I think it should be 2-chloro, 3-bromobutane **Ruth**: Really? SF2: yes **Ruth**: We cannot name this compound 2-chloro, 3-bromobutane that is not right now if you looking at this very carefully, we must first understand that according to the IUPAC rules, we've got to first find the longest carbon chain, that's very important (She counted the number of carbon	**<u>Comment</u>:** The discussion here focused on applying the earlier stated IUPAC rules in naming haloalkanes using 2-bromo, 3-chlorobutane as an example. **<u>In-depth qualitative analysis:</u>** **Ruth's role:** Ruth drew the structure of 2-bromo, 3-chlorobutane and asked learners what the IUPAC name of the molecule should be. **Learners' role:** Learner SM1 and SF2 gave incorrect responses to revealing their level of misunderstanding (LP). **Ruth's role:** In correctly naming the molecule, Ruth provided explanations that emphasized the IUPAC rules as an aspect learners needed to take note of and understand with reference made to the structure of the molecule drawn on the board. This suggests her understanding of the use of a symbolic representation (RP) and curricular saliency (CS).

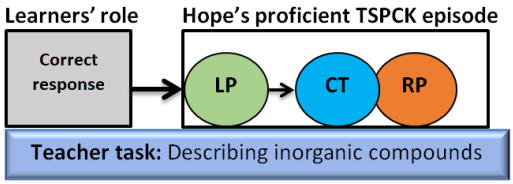
atoms), so we have four carbon atoms, since we've got single covalent bonds between them, then it's butane, that's sorted and then, now someone can number this side (she numbered and counted from the left-hand side) and say I have got I have got 2-bromo, 3-chlorobutane right, let's keep that, another person could number from this side (She numbered from the right-hand side) and then we have 2-chloro, 3-bromobutane, now which one is correct, which one is wrong because we've got only single covalent bonds between all the carbons and now, we are getting two names if you number from the left hand side, bromo is on the second carbon whereas from the right, it's on the third carbon, so we go for the lowest, then the name becomes 2-bromo, 3-chlorobutane, letter b comes before letter c in English, any question? Any contrary opinion? Ss: No	The Ruth's proficient TSPCK episode (RP/LP-CS) mediated by learners' incorrect responses is given by the TSPCK map below. 
23-25min: Naming alkenes **Ruth**: Now let's talk about alkenes. The IUPAC rules for naming alkenes are similar to those for alkanes neh, but there are two differences. One, you need to know that in alkenes, the parent chain must be selected so that it includes all the double bonds; it may therefore not be the longest in the molecule. Another thing is that, the parent chain must be numbered from the end that gives the lower number for allocation of the double bond. So, when we have one double bonds, what do we call it? SM2: its ene Other learners laughed **Ruth**: Is that funny? And those with two double bonds? SM3: diene **Ruth**: Good, we call the alkenes that have double bonds 'dienes', is that clear now. Let's look at this for example. (*She drew the structure of 2-methyl-1-pentene on the board. In naming the compound, she counted from the right to the left such that the double bond is on the first carbon atom, ethyl group on the same second atom and there are five carbons on the straight chain that makes up the parent chain. She named that with the learners as 2-methyl-1-pentene*) **Ruth**: Likewise, we can have name this compound (She drew the structure of 1,3-butadiene on the board and name it with the learners).	**Comment:** The discussion here focused on applying the earlier stated IUPAC rules in naming alkenes taking 2-methyl-1-pentene as an example. **In-depth qualitative analysis:** **Ruth's role:** Before naming the molecule, Ruth asked learners what a double covalent bond and two double covalent bonds between two carbon in an organic molecule represented. **Learners' role:** Learner SM2 and SM3 responded correctly by referring to them as 'ene' and 'diene' respectively (LP). **Ruth's role:** Then, using the symbolic structure drawn on the board (RP), Ruth named the molecule with learners (CS). The Ruth's proficient TSPCK episode (LP-RP/CS) mediated by learners' correct responses is given by the TSPCK map below. 
25-28min: Naming alkynes **Ruth**: For naming alkynes, what do we first look for? SM8: a triple bond **Ruth**: yes, that's very important, a triple covalent bond between two carbon atoms is the functional group, ok so now for naming of alkynes, we also number all the carbon atoms in the longest chain starting from the end which is closest to the triple bond in the compound. Let's look at this compound for instance (She drew the structure of but-1-yne on the board). I would like you to know this compound in two different ways. If we number from the left to the right, on which carbon is the triple bond? SM2: it's on carbon one **Ruth**: carbon number one, then, how would you name it? SF3: but-1-yne **Ruth**: what if you number the carbons from right to left, on	**Comment**: The discussion here focused on the IUPAC naming of alkynes where Ruth asked learners questions before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners what should first be looked for in naming alkynes thereby probing learner prior knowledge about alkyne functional group. **Learners' role**: Learner SM8 indicated the triple carbon-carbon covalent which represented the alkyne functional group (LP). **Ruth's role**: By engaging learners in the process of questioning and dialoguing, Ruth explained the IUPAC naming of alkynes using but-1-yne and its structure as an example. Considering Ruth's effort to investigate learner prior

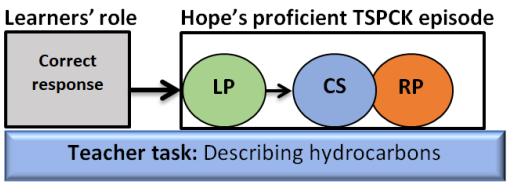
which carbon atom is the triple bond? SF4: carbon three **Ruth**: Good, how would you name it now? SF5: but-3-yne **Ruth**: Depending how we number, which of 'but-3-yne' and 'but-1-yne' is the correct name and you have to tell me the reason? SM2: but-1-yne because 1 is less than 3 **Ruth**: In the case of but-1-yne, the carbons are numbered such that the carbon on which we have the triple bond is the simplest. Is that clear now? Ss: yes	knowledge of the alkyne functional group, using the symbolic representation of but-1-yne in explaining its IUPAC naming, she could be observed to have displayed proficient TSPCK episode as shown in the TSPCK map below. **LP-RP/CS** 
28-30min: Describing cyclic-hydrocarbons **Ruth**: We also have cycloalkanes which are hydrocarbons that exist as cyclic or ring compounds in which the ring has three to many carbon atoms. Cyclic compounds of alkanes are called cycloalkanes while those of alkenes are called cycloalkenes (***she drew the structural representations of cyclopropane, cyclobutane, cyclobutene and cyclohexyne***), as you can see here (she pointed at the structures), the number of hydrogen atoms has reduced compared to the unbranched chain alkane, so the cycloalkanes have got the general formula C_nH_{2n}, hope you understand that, any question? **Ss**: …(There was no response from learners)…..	**Comment**: The discussion here focused on describing cyclic-hydrocarbons without any efforts made to investigate learner prior knowledge. **In-depth qualitative analysis:** **Ruth's role**: Through a direct talk, Ruth explained cyclo-alkanes as what learners should know about (CS) with their structural and molecular formula (RP). **Learners' role**: None The Ruth's simple TSPCK episode (CS/RP) is given by the TSPCK map below. 
30-32min: Naming alcohols **Ruth**: And then, we come to name alcohols, what do you know about naming alcohols? **SM5**: Their names end with 'ol' in such a way that, we replace 'ane' in alkanes to 'ol' to give us alcohols. **Ruth**: You guys are so brilliant. So, we first locate the longest carbon chain and then, we find the position of the hydroxyl group, where does it belong? To which carbon is it attached, you know that's the functional group. And then, we gonna number the carbon atoms in the longest chain from the end that is near the hydroxyl group. And you must understand that if in a molecule of alcohol, we've got two hydroxyl group, we call it 'diol', if we have got three hydroxyl groups, we call it 'triol', let's say we have this (she drew the structure of 2-methyl, 2-butanol on the board), since OH is on the second carbon and likewise CH3, we name it 2-methyl, 2-butanol. Any question on that? **Ss**:….(Learners echoed 'No')……	**Comment**: The discussion here focused on IUPAC naming of alcohols where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**: **Ruth's role:** Ruth asked learners what they knew about naming of alcohols in order investigate their prior knowledge. **Learners' role:** In her response to Ruth's question, learner SM5's response showed a good understanding of suffix 'ane' in alkanes becoming 'ol' in alcohols (LP) **Ruth's role:** Expatiating on SM5's response, Ruth explained how to name alcohols as an important aspect she wanted learners to understand using the structure of 2-methyl, 2 butanol. She also pointed out referring to two and three hydroxyl groups in a molecule of alcohols as diol and triol respectively. The Ruth's proficient TSPCK episode (LP-CS/RP) mediated by the a learner's correct response is given by the TSPCK map below 
32-36min: Naming ethers **Ruth**: Now, let's see if we can just look at the IUPAC naming of ethers quickly. Does anyone have an idea of a member of ether? Any name related?	**Comment**: The discussion here focused on IUPAC naming of ethers where Ruth asked learners a question before providing explanations. **In-depth Qualitative Analysis**:

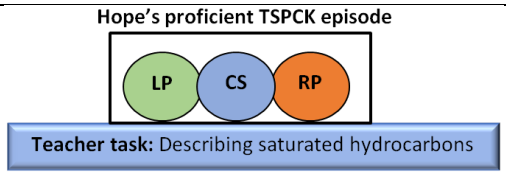
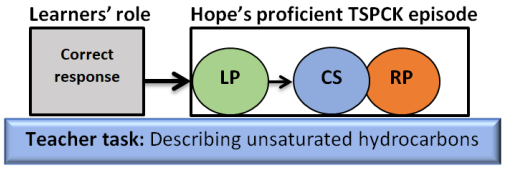
SF4: Vinegar **Ss**:….(Learners laughed)…… **Ruth**: Guys, he said vinegar. Is vinegar an ether? **Ss**: ..no…yes….no…yes…. **Ruth**: For those saying no, give us an example then Ss: … (No response) **Ruth**: Thanks, but vinegar is not an ether ok, **(LP)** vinegar is an acetic acid, also known as ethanoic, it's a carboxylic acid because it has got COOH as its functional group, please take note of that guys. (**CS**) Now, Let's see an example of ether here (She put the structure of ethyl methyl ethyl on the board), yeah here is our ether, you can see that O is bonded to our CH3CH2 here and here it's attached to a methyl, CH3, this one (She pointed at CH3CH2) is our ethyl, so we name it ethyl methyl ether, (**RP**) e comes before m, very important. Is that clear? Ss: yes	**Ruth's role:** Ruth asked learners about common compounds of ethers to order investigate their prior knowledge. **Learners' role:** In her response to Ruth's question, SF4 mentioned vinegar which was supposed to be an example of carboxylic acids. Some learners agreed SF4's response while some of them disagreed (LP). **Ruth's role:** In her response, Ruth first indicated to the learners that vinegar is an acetic acid with the reason that, vinegar has COOH has its functional group. This suggests Ruth's understanding of what should be emphasized to learner, an aspect of curricular saliency (CS) in addressing a learners' misunderstanding, an aspect of learner prior knowledge (LP). Using the structure of ethyl methyl ether drawn on the board, she explained how to name ethers thereby demonstrating the knowledge of the use of a symbolic representation (RP). The Ruth's proficient TSPCK episode (LP-CS/RP) mediated by the a learner's incorrect response is given by the TSPCK map below. 
36-40min: Ruth asked learners questions on all the concepts covered in order to evaluate their understanding.	

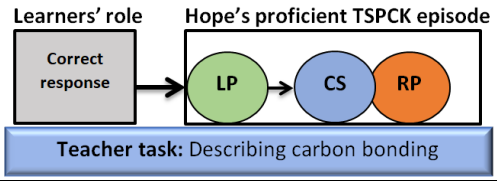
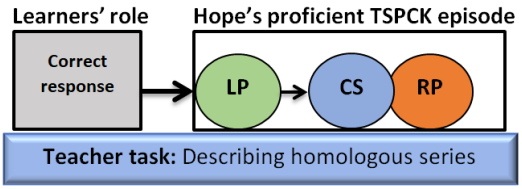
Appendix XXVIII: Detailed analysis of Hope's lesson

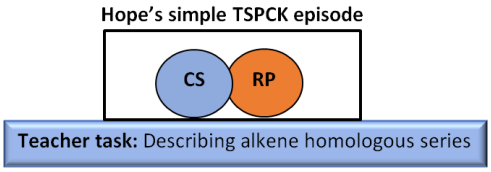
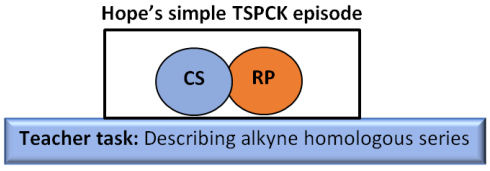
Teaching events in sequence	Comments/Qualitative in-depth analysis
0-4 Organic compounds (Intro) T: Good morning class. Ss: Morning ma'am. T: Today, we will be looking at an aspect of chemistry called the organic chemistry; we all know that carbon is one of the elements like Hydrogen, Oxygen that you have come across in your previous grades. We consider carbon and its bonding property very important in organic chemistry because that is the key, it helps us understand organic compounds. Hope: …I am aware that at the beginning of the term you have learnt about the different types of chemical bonding, right? Ss: yes Hope: Can someone tell us? SM1: ionic bonding Hope: yes, which other one? SM2: covalent bonding Hope: So now what is ionic bonding? Refresh your mind Grade 11. What is ionic bonding? Yes SM1: the transfer of electron Hope: yes, in ionic bonding we have the transfer of electrons so if I'm carbon and you are oxygen, you will take the electrons from me, does it make sense? Ss: yes Hope: How about covalent bonding? You mentioned it right? SM2: yes SF1: electron sharing. Hope: It involves sharing of electrons, that's just to remind you, we need those good ideas here, (LP) ok let's talk about compounds generally, compounds can generally be classified into inorganic and organic compounds and when we talk about organic compounds, organic compounds normally comprise of carbon covalently bonded to hydrogen and they may have any other non-metals, so most importantly we talk about covalently bond between at least a carbon atom and a hydrogen atom, (CS) let's see methane here as an example (*she drew the structure*), it has got the molecular formula of CH_4, (RP) this means hydrogen forms one covalent bond with this carbon atom, but in the case of carbon, as you can see here, it forms four covalent bonds with hydrogen atoms, remember from your previous lessons on periodic table, hydrogen needs one electron to complete its shell so it's in group 1 and so it forms one bond, but carbon is in group four, it needs four more electrons, so it forms four bonds yeah, other examples of organic compounds, you all know our household vinegar right, we call it acetic acid, it's an organic compound, so the chemistry of organic compounds has got so many applications and we can't count its benefits in our homes and society. (CS) Can you hear me those of you at the back?	Comment: This section introduced the lesson by first establishing learners' prior knowledge before providing explanations. Hope's role: As the introductory part of the lesson, identified carbon and its bonding property as important in learning about organic chemistry. He then engaged learners in questioning and dialoguing to investigate their prior knowledge about types of chemical bonding. Learners' role: Learners correctly mentioned and defined ionic bonding and covalent bonding. This shows the correct learner prior knowledge which Hope expected all learners to bring into the discussion (LP). Hope's role: Hope acknowledged learners' correct prior knowledge of what ionic and covalent bonding represent. In her explanation, he referred to the covalent bonding of carbon atoms and with atoms of hydrogen as most important. This is an element of curricular saliency (CS), the knowledge of what is important for learners to know. She also made reference to the structure of methane drawn on the board in order to support her explanation. This shows her knowledge of the use of a symbolic representation (RP). She called the learners' attention to the industry application of organic chemistry in producing organic compounds like vinegar which learners could easily relate with in homes. This is another element of curricular saliency, the applications of organic chemistry, an important aspect in chemistry (CS). Hope's use of TSPCK components (LP-CS/RP/CS) at sophisticated level in connection to learners' correct responses is given by the TSPCK map below. 

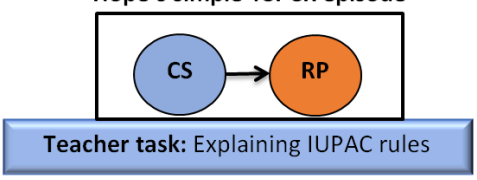
4-6 minutes Inorganic compounds T: OK, inorganic compounds, we have carbon dioxide, the gas we breath in neh, also carbon monoxide, we use water every day, and it's abundantly available we all know that right, it's another example of an inorganic compounds, also we add table salt to our food right in our homes right, it's another example of inorganic compounds and we've got lots of them you can see that as we have carbon in inorganic compounds, we also have it in organic compounds? Ss: yes T: Can someone tell me why carbon dioxide is not an organic compound? Yes, anybody? SF3: it does not contain hydrogen Hope: Yes, as we can see, carbon is not covalently bonded to hydrogen that's the idea, we don't just say the compound does not contain hydrogen. (LP) Like let's look at (*she put $NaHCO_3$ on the board*), that's sodium hydrogen carbonate, (RP) even though it contains hydrogen and carbon, we see that there is sodium ion (she put Na^+ on the board), we've also got here (*she put HCO_3^- on the board*), so it's an ionic compound, we can't say carbon is covalently bonded to hydrogen here is that understood? This is unlike our organic compounds (CT) like this one (*she referred to the formula for methane on the chalkboard*) where we can see hydrogen bonded to carbon, it's an example of organic compounds right? Ss: yes	Comment: This section focused on distinguishing inorganic compounds from organic compounds already described by first establishing learners' prior knowledge before providing explanations. Hope's role: She described inorganic compounds using carbon dioxide as an example. Then, she probed learners' prior knowledge asking why carbon dioxide is not considered an organic compound. Learners' role: Learners correctly referred to carbon dioxide not containing hydrogen. Why this learners' response was correct (LP), it was insufficient in that, only the presence of hydrogen atom in a carbon containing compound does not make the compound an organic compound. Hope's role: Hope acknowledged learners' correct prior knowledge about why carbondioxide is not an organic compound despite the fact that, it is a carbon containing compound. In an effort to deepen the learners' understanding, she placed methane side by side with sodium hydrogen carbonate in order to make learners understand that, all not carbon containing compound which also contain hydrogen atom are organic compound. She showed how organic compounds and inorganic compounds are similar and different. This is an element of a conceptual teaching strategy (CT). Her use of chemical formulae in explaining these concepts also signals her knowledge of symbolic representations (RP). Hope's use of TSPCK components (LP-CT/RP) at proficient level in connection to a learner's correct response is given by the TSPCK map below. 
6-9 minutes Hydrocarbons T: Now, let's focus on organic compounds. Has anyone heard of hydrocarbons before? SF8: Yes T: Who else? Ss: …No response… T: Tell us what you know about them SF8: They are chemical compounds.	Correct Comment: This section focused on describing hydrocarbons by first establishing learners' prior knowledge before providing explanations. Hope's role: She probed learners' prior knowledge asking what they knew about hydrocarbons

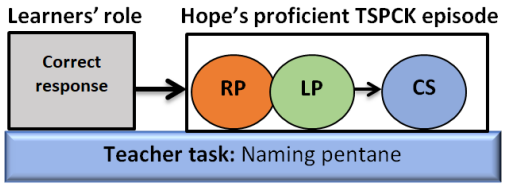
T: (laugh!), indeed thank you, they are chemical compounds, you've learnt about compounds in chemistry right, so these ones are a class of compounds (LP). Ok, we have hydrocarbons, they are the simplest class of organic compounds, they have got in them, only carbon and hydrogen, that's important, we've got only carbon atoms bonded to hydrogen atoms in hydrocarbons for instance our methane here (*she pointed at the structure of methane*), (RP) we have only carbon here neh covalently bonded to hydrogen, you got that? Ss: yes T: Now, in hydrocarbons, we can have single covalent bonds between carbons or double covalent bonds or triple covalent bonds depending on the type of homologous series, each speaks to a particular homologous series, alkane or alkenes or alkynes neh, what I'm saying is that hydrocarbons have got three different families, the alkane family, the alkene family, the alkyne family. Each family has got children, we call them members neh, and then we call each family a homologous series. So, what is common to all family of alkanes is, we have only got carbon and hydrogen as the elements in their compounds, any question on that? Ss: (No response)	Learners' role: The only learner who responded referred to the hydrocarbons as chemical compounds. This suggests some level of awareness that learners could regard hydrocarbons as part of the compounds in chemistry, the understanding Hope was expecting them to have in place (LP). Hope's role: Hope acknowledged learners' correct prior knowledge which regarded hydrocarbons as compounds in chemistry. She used the chemical structure of methane to explain hydrocarbons as the simplest class of organic compounds which only contain carbon and hydrogen atom, emphasized as what was important for learners to know. Her explanations demonstrated the knowledge of curricular saliency, what was important to emphasize (CS) and use of symbolic representation (RP). Hope's use of TSPCK components (LP-CS/RP) at proficient level in connection to a learner's correct response is given by the TSPCK map below. 
9-10 Saturated hydrocarbons LP/CS/RP T: Now we have got saturated hydrocarbons as the first type of hydrocarbons. You must always remember what we just said about hydrocarbons right; they've got only carbon atoms and hydrogen atoms in their molecules (LP). Now, In saturated hydrocarbons, we find that we have single carbon to carbon bond, in their compounds, only single carbon to carbon covalent bond exists between all carbon atoms, that's their characteristic feature that you must watch out for (CS) such as the ethane shown here (*She referred to the structure of ethane drawn*), so here (RP) carbon is covalently bonded to another carbon, and each carbon atom is completely bonded to three hydrogen atoms. Any question? *There was no response from learners*	Direct Knowledge Comment: In connection to hydrocarbons, this section focused on saturated hydrocarbons. Hope's role: She reminded learners what they just learnt about hydrocarbons consisting of only atoms of carbon and hydrogen covalently bonded. This shows her understanding what learners' prior knowledge should be in place before telling them about saturated hydrocarbons and this reflects her learner prior knowledge (LP). Using the chemical structure of ethane drawn on the board (RP), she called learners' attention to single covalent bonds between atoms of carbon and hydrogen as the key characteristic feature of saturated hydrocarbons. Such an emphasis is an element of curricular saliency (CS). Learners' role: None Hope's use of TSPCK components (LP/CS/RP) at proficient level is given by the TSPCK map below.

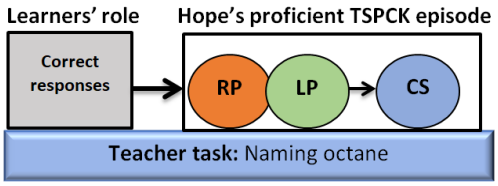
	
10-11 Unsaturated hydrocarbons T: So, now we can move to the second type of hydrocarbons but before that, can someone just remind us how we described hydrocarbons, chemical compounds right (she smiled)? Ss: Laugh SF1: they are organic compounds T: What's special about them? SF2: they've got only carbon and hydrogen atoms T: Yeah, they've got only atoms of carbon and hydrogen covalently bonded together, that was what we said (LP). Yeah, talking about unsaturated hydrocarbons, there must be at least one double covalent bonds between carbon atoms, let's see here (*she drew the structure of ethene on the board*), (RP) we call this an alkene, so those such hydrocarbons are unsaturated, likewise if we've got at least one triple covalent bond between carbon atoms, (CS) then we call such hydrocarbons alkynes like (she drew the structure of ethyne on the chalk board). Any question? Ss: (No response) T: Am I too fast? Ss: No	Comment: In connection to hydrocarbons, this section focused on unsaturated hydrocarbons where she first established learners' understanding about hydrocarbons before providing explanations. Hope's role: She asked learners to describe hydrocarbons as they have previously learnt. Learners' role: One learner correctly described hydrocarbons as consisting of carbon and hydrogen atom, part of the understanding Hope wanted them to have in place before telling them about unsaturated hydrocarbons (LP) Hope's role: She first acknowledged learners' understanding of what hydrocarbons are, adding 'covalently bonded' to the description provided by the learner (LP). She further explained how focus is on at least a double covalent bond between carbon atoms in alkene and at least a triple covalent bond between carbon atoms in alkyne. Such a emphasis seems to describe Hope's knowledge of curricular saliency, pointing out what was important for learners (CS). She also used symbolic representations (RP) in the process of explaining the concepts. Hope's use of TSPCK components (LP-CS/RP) at proficient level in connection to the learners' correct response is given by the TSPCK map below. 
Teaching events in sequence	Comments/Qualitative in-depth analysis
11-12 Carbon bonding LP-CS/RP T: Now, we already understood that carbon forms how many bonds? Yes, you? SM3: 4 T: Why? SM3: it required four electrons to complete its shell. Hope: Great! From our knowledge of elements in the periodic table, we know that carbon forms four bonds (LP). So now, we say carbon is different in reality from other elements, it can form millions of millions of compounds by just bonding covalently to its own atoms, and to atoms of hydrogen, and that	Correct response Comment: This section focused on carbon bonding where she first established learners' prior knowledge before providing explanations. Hope's role: She asked learners about the number of electrons that carbon forms as the knowledge required of them to have in place. Learners' role: One learner indicated carbon forms four bonds and with the understanding that that,

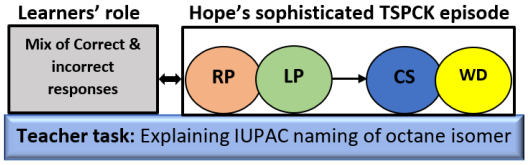
makes it unique compared to other elements with similar characteristic, so we can see carbon forming bonds with carbon to another carbon to another carbon and so on, for instance, let's see this long carbon chain (*she drew the structure of decane with ten carbon atoms*), so this ability of carbon to bond to its own atoms in order to form small and large organic molecules is called catenation, that's its unique nature which gives birth to the study of organic chemistry, any question on that? Ss: No response	those four electrons are required for it to complete its shell, the knowledge Hope was expecting them to have in place as a result of their prior knowledge of periodic table (LP) Hope's role: She first acknowledged correct learners' prior knowledge of the number of bonds that carbon forms. Then, she linked that prior knowledge to why carbon is different from other elements due to its ability to forms millions of bonds, representing the important aspect she wanted learners to understand (CS). She also used the symbolic representation of decane to support her explanation (RP). Hope's use of TSPCK components (LP-CS/RP) at proficient level in connection to the learners' correct response is given by the TSPCK map below. 
12-16 Homologous series (Alkanes) LP-CS/RP T: Now, let's look at each homologous series in hydrocarbons, we start with alkanes. What did I first call them anybody? SF2: A family which has got children SM2: father and mother Ss: Laugh!! T: Where is the family and mother in this, you guys are funny. Ss: Laugh!! T: In deed, each homologous series is like one family because all the members they've got something common to them, we refer to such family of organic compounds as homologous series right? (LP) Ss: yeah T: So, all alkanes, they have the general formula (she wrote CnH2n+2 on the chalkboard), that's one unique thing about that (CS) , it's CnH2n+2 (RP) here n is the number of carbon atoms present in the molecule using this (*referring to the formula*) we can get the molecular formula for the compound. For example, this methane (*she referred to its structure on the board*) has n equals 1 neh so the molecular formula is C1 and H 4 right. You can see that this carbon has used its bodies for electrons this tells us that, in alkanes we must have hydrogen atoms attached to the carbons completely. T: So, examples of these are methane, ethane, hexane, decane etc. They have the siffix 'a'. So, they take the suffix from the name. You see this one, this part (pointing at the figure below) the 'a', it shows that, that molecule or compound that you are dealing with, it is an alkane, ok, can you see that? Ss: yes T: Any question? *There was no response from learners.*	Correct Comment: This section focused on homologous series with emphasis on alkanes. Hope's role: She asked learners how homologous series was earlier described. Learners' role: Drawing on what they had earlier learned, two learners jokingly referred to homologous series as a family. This seems to reveal that, learners had a likely resemblance of what homologous series, the understanding Hope expected them to have in place (LP). Hope's role: In connection to the learners' correct prior knowledge in place, Hope pointed out the general formula of alkanes as what all members in the series have in common, an important idea she wanted learners to understand (CS) explained with the use of a symbolic representation (RP). Hope's use of TSPCK components (LP-CS/RP) at proficient level in connection to the learners' correct response is given by the TSPCK map below. 

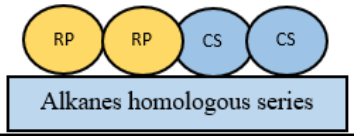
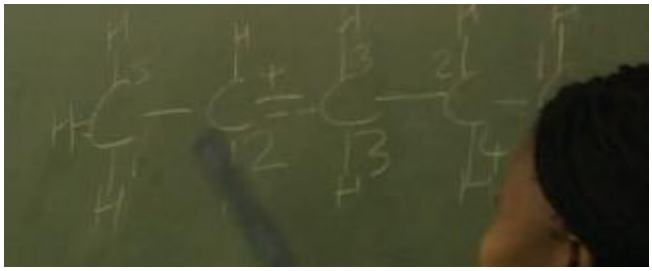
16-18 Alkenes homologous series CS/RP T: Let's move to the next homologous series. We have alkenes, these ones have got at least a double covalent bond between carbon atoms, most importantly all the members in the alkenes homologous series have the general formula CnH2n (CS) and they take the siffix from –ene, we have an example ethene with molecular formula of C2H4, propene is another member of alkene with molecular formula of C3H6, (RP) isopropene u know, every one of them has the -ene at the end of their compound name. Do you get that? Ss: yes T: Any question? There was no response from learners	Direct Knowledge Comment: This section focused on alkenes homologous series. Hope's role: She explained all members in the alkenes homologous series having a general molecular formula common to them as an important point for learners to know (CS) using the molecular formula of ethene as a symbolic representation (RP). Learners' role: None Hope's use of TSPCK components (CS/RP) at simple level is given by the TSPCK map below. 
18-20 Alkyne homologous series CS/RP Hope: Now, we can talk about another group of homologous neh, we've alkynes homologous series, all the members are known to have the general formula (She faced the chalkboard and wrote CnH2n-2), that's our CnH2n-2 which is common to all alkynes in their homologous series, please take note of that, for example in our ethyne we have got n=2, so that formula is gonna be C2H2 right. Can those of you at the back see what I wrote on the board please?	Comment: This section focused on alkyne homologous series. Hope's role: She explained all members in the alkyne homologous series having a general molecular formula common to them as an important point for learners to know (CS) using the molecular formula of ethyne as a symbolic representation (RP). Learners' role: None Hope's use of TSPCK components (CS/RP) at simple level is given by the TSPCK map below. 
20-24 IUPAC rules T: In naming an organic compound, you first find the longest chain or main chain with a substituent. Then, you number the main chain. T: You then identify the suffix root and prefixes and their position numbers in the chain, these aspects of IUPAC rules are very important here to avoid confusions (CS). Write the full name, prefixes parent suffix. For prefix, identify a branch or group attached to the main chain. For suffix, identify the type of organic compound. For the root, identify the number of carbon atoms. T: The root is the number of carbon in the longest and the suffix	Direct Knowledge Comment: This section focused on explaining IUPAC rules for naming organic compounds. Hope's role: She sequentially explained IUPAC rules for naming organic compounds emphasising the identification of prefix, suffix and root as important aspects that learners must take note of (CS). She also used the symbolic representation of five carbon atoms with single covalent bonds in-between them to support her explanations (RP).

is the one from the alkanes, alkenes or alkynes. And then, you identify a group or branch attached to the main chain, sometimes you find that you have a chain of carbons and then you have another carbon branching off that chain and then you have a halogen or anything which is embedded on the chain. And then, like I said the prefix identifies a branch or group attached on the chain so if you have another carbon branching off from another carbon and then you have numbered your chain, from that numbers, you will indicate where that other carbon is branching off from by indicating that number when you name. And then, you have the suffix which is the type of organic compound which is the number of carbon atoms. T: And these are the roots for naming organic compounds. If you have one carbon which is bonded to others, to hydrogen, you have the root name 'meth', I will keep on coming back to that. And then, if you have two carbons in a chain, you have the root name 'eth'; if you have three, it's 'pro'; four is 'but'; five is 'pent'; six is 'hex'; seven is 'hept'; eight is 'oct', nine is 'non' and ten is 'dec', it doesn't mean that it ends there, it is just that most teachers prefer you to know all that. So, now we goona do examples for naming alkanes and I'm gonna start with unbranched one. So, these are just rules or steps to follow when you name alkanes, ok? Ss: yes T: So, the first one for the unbranched is that you indicate the number of carbon atoms in a chain with a prefix followed by ending 'ane' so, for example, if we have five carbon chain like (she faced the chalkboard and wrote symbolically C-C-C-C-C), that's five carbon atoms with single bonds right (RP) and you see carbon align like this, the first thing that you start to do is that, you look to see if carbons are branched or what. In this case, they are straight and so, what you do (*she put hydrogen atoms to each carbon atom in the straight chain*) (RP) is that, you number the longest chain, ok. . In this case, we have four carbons then we call that 'but', you can see single bonds between the carbons right, so that's an alkane, and so, we have 'butane' as the name for this compound. Is that clear now? Ss: yes T: So, in terms of alkanes, it doesn't matter where you start numbering the carbon atoms since single bonds are present between carbon atoms. We normally start from left to right, ok.	Learners' role: None Hope's use of TSPCK components (CS-RP) at simple level is given by the TSPCK map below. **Hope's simple TSPCK episode** 
24-27 Naming pentane T: Let's say for example, we have got five carbon atoms as given here (*she referred to the structure of five carbon atoms on the chalkboard*) (RP) and how many hydrogen atoms should have around these carbon atoms? SM8: 12 T: 12, why? SM8: there is a single bond between the carbon atoms T: So what does that mean? SF5: it is saturated T: Thank you, I'm happy you could remember what we earlier discussed that's the reason for asking those questions it's a saturated hydrocarbons (LP) since it consists of carbons bonded to hydrogen atoms and between the carbons here (*she pointed to*	Correct Comment: This section focused on naming of alkanes taking pentane as an example. Hope's role: With reference to the symbolic notation of five carbon atoms containing single covalent bonds drawn on the chalkboard (RP), she asked learners about the number of hydrogen atoms that should be bonded to the carbon atoms in order to first establish their understanding. Learners' role: One learner responded by indicating that twelve hydrogen atoms would be needed to bond with the provided carbon atoms and also the

the structure on the board and added hydrogen atoms), we've got only covalent bonds neh, remember that we earlier said carbon forms four bonds right, so we can see here, on the last two carbons atoms, to the left and to the right, we have three hydrogen atoms and another carbon bonded to this to make four and each carbon in-between is bonded to two hydrogen and to two carbon atoms, each carbon has got four bonds and in all we have 12 hydrogen atoms, can you see that? Ss: yes T: So, what is the root name for these five carbon atoms SM9: pentane T: it's pent and then you say ok this chain means that I'm gonna have my root as 'pent'. Remember, that you must have the 'pre', the 'root', and the 'suffix' and so now, your 'root' now is what? SF6: pent T: pent and then if you look, you don't have any branch or any suffix on this chain ok. So, what do you do? You exclude 'prefix' because you don't have another compound which is bonded here or another carbon carried on of another carbon, ok. And then, what do you do? you go and look for the suffix, what type of a molecule is this, what type of a hydrocarbon. Is this single bonded? What did we say a single bonded carbon to carbon atom molecule is? SM6: it's an alkane T: it's an alkane. What type of a suffix does it take? SM7: ane T: So at the end of (referring to 'pent') next to the end of 't', you do what? You write 'ane' (then, she wrote 'pentane') and this molecule is called Ss: pentane T: Pentane, good. Any question? There was no response from learners	fact that, the molecule represents a saturated hydrocarbon. While this signals learners' good understanding of the previous discussions, it also served as good prior knowledge which Hope expected them to have in place for the discussion in this section (LP). Hope's role: Using the structure of the pentane molecule drawn on the chalkboard, Hope identified with learners, the prefix, suffix and root, the three aspects considered important in the IUPAC rules for naming. This is an element of curricular saliency (CS). Hope's use of TSPCK components (RP/LP-CS) at a proficient level in connection to a learner's correct response is given by the TSPCK map below. 
27-29 Naming octane RP/LP-CS T: Now, let's look at another one (*She drew eight carbon atoms on the board with hydrogen atoms*) (RP) ok, and then we have another hydrocarbon and then, you start counting again. We have eight carbon bonded and then, you say, what kind of a root do I have? Ss: oct T: you say oct and then you look for any prefix, is there any branch? Ss: there is no branch. T: there is no branch and then what is the suffix? SM6: ane T: Why? SM6: because it is single bonded T: You got it, that's good, so here (*she pointed to the structure on the board*) we have eight carbons and we call that 'oct' you can all remember (LP) right? Ss: yes T: Good, so now these single covalent bonds between carbons show we have alkanes right and so we have the suffix 'ane, according to our IUPAC rule, don't forget, very important (CS) and then we call this compound 'octane. Is that clear now? Ss: yes	Correct Comment: This section focused on naming of octane as an example of alkane. Hope's role: With the structure of eight carbon atoms containing single covalent bonds drawn on the board (RP), she asked learners about the root name for the molecule in an attempt to first establish their prior knowledge. Learners' role: Learners correctly referred to the structure of eight carbon to carbon single covalent bonds on the chalkboard as representing octane. While this signalled learners' good understanding of the previous discussions, it also served as good prior knowledge which Hope expected them to have in place for the discussion in this section (LP). Hope's role: She emphasized the use of IUPAC rule in naming the structure of octane on the board. Calling learners' attention to IUPAC rules is an element of curricular saliency (CS), an important aspect for learners to take note of. Her use of the

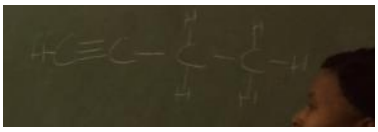
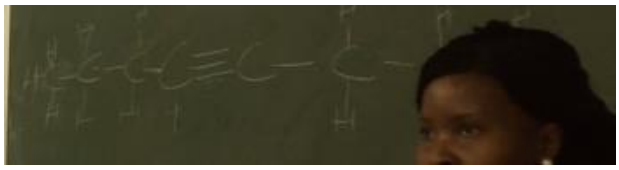
T: And then, there is something that I forgot to tell you, let me just tell you. You see this type of representation, these type of molecules, as I have drawn them, they are the structural formula of these compounds and then, we normally use skeletal for this where we don't normally show the hydrogens, ok. So, when you draw that structure formula, you can see that the chain then straight but in a skeletal formula, it shows you how the carbon atoms are in the molecule, so normally find that they are not straight as in this, they are curved as this and you find that, here is a carbon, and here is another carbon and here is another carbon (pointing to the dots), it's single bonded and so, it's a propane, one two three carbon and single bonded is? Ss: ane T: and so, it's propane. And then, if it is show octane in a skeletal formula, what you gonna do is that, you start with carbon number one, two, three, four, five, six, seven, eight. So, this arrangement shows carbons are in a molecule, they are not always straight, they are curved ok. and these lines, they show you that, it is single bonded, so, Ok.	structure of pentane also referred to the knowledge of symbolic representation. Hope's use of TSPCK components (RP/LP-CS) at a proficient level in connection to learners' correct responses is given by the TSPCK map below. 
29-31 Naming octane isomer (2-methylheptane) Hope: Now let's see (*she drew the molecular structure of 2-methylheptane*), (RP) if we focus on the longest continuous chain (*she covered up the methyl group CH_3 with her palm*) so what is the prefix? SM2: It's gonna be hept Hope: Why? SM2: it's got 7 carbons Hope: Exactly, the prefix is gonna be hept according to our IUPAC nomenclature rule because we just look at the longest continuous chain and we have got seven carbon atoms bonded together with hydrogen atoms. (LP) Now, what do we call this type of molecule? SM3: organic compound Hope: What class? SM3: saturated hydrocarbons Hope: It's saturated hydrocarbon because? SF7: It's got single bond between all the carbons.	Comment: This teaching segment focused on naming an isomer of octane (2-methylheptane). In-depth qualitative analysis *Hope's role*: Using the molecular structure of 2-methylheptane drawn on the chalk (RP), Hope asked about the prefix for the molecule, the understanding she expected them to have acquired from her previous discussions with them. *Learners' role*: Learner SM2 showed a good existing knowledge of prefix hept for 7 carbon atoms in the longest continuous chain. Learner SM3 further showed the understanding that the molecule is a saturated hydrocarbon because of the single covalent bonds (LP). *Hope's role*: Hope further asked learners about the position of the methyl group. *Learners' role*: Learners gave a mixed of correct and incorrect responses regarding numbering the

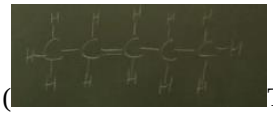
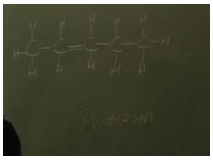
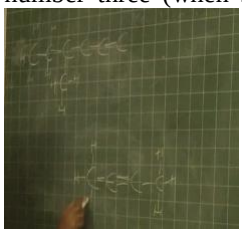
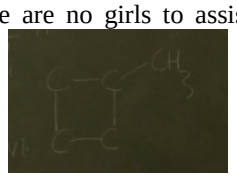
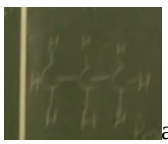
Hope: Good, it's a saturated hydrocarbon because it has got only carbon to carbon covalent bonds so now here (*she pointed at the methyl group CH_3*) is our methyl group, it's a substituent. So now, at what carbon number is our methyl group? Yes? SM8: carbon 6 Hope: Carbon 6? SM9: carbon 2 Hope: Which one are we gonna take between carbon 2 and carbon 6? (*Learners' chorus answers….carbon 2….carbon 6…)* Hope: We need to remember our IUPAC rule. Now, if we count our longest carbon chain from right, we gonna have methyl group on carbon 6 right? Ss: yes Hope: That's gonna be 6-methyl what? SF2: heptane Hope: 6-methylheptane. And then, if we number our longest chain from the left here then, our methyl gonna be on carbon 2 and we gonna name it 2-methylheptane right? Ss: yes Hope: So, now since 2 is less than 6 and we have an alkane, then the correct name is 2-methylheptane, that's the correct name. So, now since we have got 8 carbon atoms in the whole molecule, then we call 2-methylheptane an isomer of octane. Both octane and 2-methylheptane are saturated hydrocarbons because of this single carbon to carbon covalent bonds (she pointed at the structure on the board), they both belong to the alkane homologous series remember that neh (CS) but what might be challenging is let's say one of this (she changed C-C to C=C on the board), that's a double bond and then, we have a substituent like that, then we must first consider the position of this double bond, don't confuse naming single covalent carbon-carbon with double covalent carbon to carbon, (WD) ok we gonna discuss that later. Any question on naming alkanes? *There was no response from learners*.	longest carbon chain (LP). *Hope's role*: As a strategy for naming the molecule, Hope involved the learners in first numbering from the right and then from the left in order to show the learners both the correct (2-methylheptane) and wrong (6-methylheptane) name. She also referred to the molecule as an isomer of octane previously discussed with emphasis on their C-C bond. This describes Hope's understanding of symbolic representation (RP) in teaching what is important for learner to know, an element of curricular saliency (CS). She referred to a challenging aspect, naming differently when there is a double carbon to carbon covalent bond where the position of the double bond must first be considered in naming. This suggests Hope's understanding of what might be difficult for learners (WD). The Hope's understanding of the interactive use of TSPCK components (RP/LP-CS/WD) at a sophisticated level of TSPCK episode linked to learners' mix of correct and incorrect responses is provided in the TSPCK map below. 
31-32 Alkanes members displayed RP/RP/CS/CS Hope: So, we've got here (*Hope displayed the first ten members of alkanes with their names, chemical formula, structural formula, sub-microscopic representations and physical states*) (RP), these are examples of alkanes, we have got, methane which is the first member, it's got CH_4, that's its molecular formula, as you can see (she pointed at the structure), here is its structure showing us C is bonded to carbon, the letters are there, and then this (she pointed at the sub-microscopic representation) I decided to put to show you how atoms of carbon are bonded to atoms of hydrogens, that's the level we can't see, it's the microscopic picture of this (she referred to the symbolic representation), (RP) and then here is the line (she referred to the symbolic representation) which is our single covalent bond between carbon atoms (she pointed at other members), it's telling us about the functional group, that've all got it and it differentiates alkane homologous series (CS) from other organic compounds, and then this column (she pointed at the physical properties) tells us some are gases because of their very low boiling points, some are liquids with a little higher boiling points, and we can have solids the number of carbons increases,	Comment: This section focused on summarising key aspects alkanes. Hope's role: Hope displayed the chemical formulae and structures of the first ten members in the alkane homologous series. This describes Hope's knowledge of two different levels (symbolic and sub-microscopic) of representations RPs). As an important aspect for learners, she indicated how the same functional group applies to all members in the series. Calling learners' attention to the functional group as what distinguishes alkanes from other organic compounds is an element of curricular saliency (CS). She also indicated the physical state of alkanes in relation to their differences in boiling points. This is another element of curricular saliency (CS) describing physical property as an important aspect. Learners' role: None

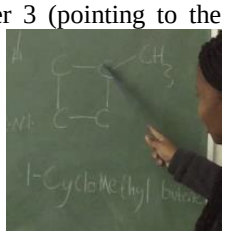
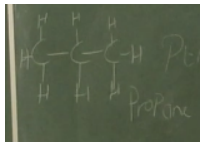
(CS) so it's just the summary. Any question on this before we move on? Ss: No response	Hope's use of TSPCK components (RP/RP/CS/CS) at a sophisticated level is given by the TSPCK map below. 
32-34 Naming Alkenes CS/RP/LP T: So, naming alkenes and alkynes is more of a similar thing, what is important is to remember and apply the IUPAC rules, (CS) so the key is to first find the longest continuous chain and then, name the chain by lowest number of carbon is which there's the double bond in the case of alkenes, or triple bond in the case of alkynes, remember that all members of alkenes end with the suffix 'ene' in their names, all members of alkynes have got 'yne', please don't forget guys so if you have got two double bonds in one molecule, let's say (*she drew five five carbon atoms with two double bonds*), (RP) it's gonna be diene, two is for di, ene for alkene, if you have got three double bonds, it's gonna be triene, you understand? Ss:yes. T: And then, the second steps you will be that you find the number the carbon atom in the main chain begin at the end nearer the double bond or the triple bond, ok. If the multiple bond is at the same distance as both from both ends, you begin naming numbering at the end nearer the first bond, number of carbon as substituted. T: Let me give an example. If for example if we have something like this (she put the structural formula for CH3CH=CHCH2CH3 on the chalkboard), what you have to do is that, you look at the longest chain that has the double bond in it, ok. And then, you number that longest carbon chain but when you number, you make sure that you start at the end where you have the double bond ok, so that the number of the first carbon which has a double bond has a lowest possible number (5:00) just that when you number the substituents remember that. When you number a substituent in an alkane, you give the substituent the lowest number  ok? Ss: yes T: So here if I start counting (from the left), I will say one, two, three, four, five. But if I start counting from this side (from the right), it would be one two three four five. And look at this, if I start counting from the right to the left, my double bond get a	Correct Comment: This section focused on what should be considered while naming alkene and alkyne. Hope's role: As an important aspect, Hope called the learners' attention to the application of IUPAC rule in finding longest continuous chain in the individual molecule of alkene and alkyne with emphasis that alkenes end with 'ene' and alkynes end with 'yne'. This is an element of curricular saliency (CS). She also drew the structure of five carbon atoms to support their explanations, reflecting her knowledge of symbolic representation (RP). She further asked learners what type of alkene was being referred to and why. Learners' role: A learner correctly referred to the double bond as characterizing the molecule as an alkene. This shows the learners' understanding of previous discussions and also, good prior knowledge Hope expected them to have in place for the discussion (LP). Hope: Hope named the molecule of pent-2-ene together with learners using the symbolic representation drawn on the chalkboard. Hope's use of TSPCK components (CS/RP/LP) at a proficient level in relation to the learners' correct response is given by the TSPCK map below.

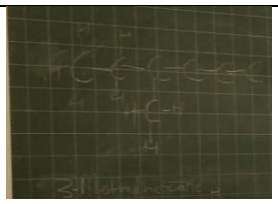
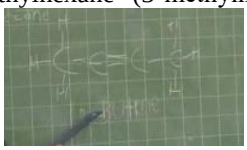
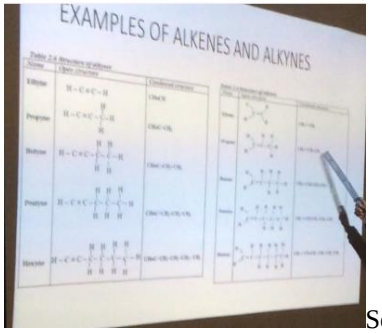
high number but if I still counting from left to right, my double bond gets a lower number ok? Ss: yes T: So, you must count in a way that gives your double bond a lower possible number. Am I clear? Ss: yes T: Ok, so in this case, what kind of a hydrocarbon is it? Ss: (murmur) T: No, wait. A hydrocarbon is an Ss: alkane….alkene T: That's an example of a hydrocarbon. What did we say an hydrocarbon is? Ss: (murmur) T: You raise your hand. We say a hydrocarbon is a compound Ss: it's a compound that is made up of carbon and hydrogen T: Good, so this is an example of a hydrocarbon (pointing to the structure above drawn on the board). What type of an example? Ok, the three types, we dealt with the first one, and so, what is this type? Ss: Alkene T: It's an alkene, why did you say it's an alkene? Raise your hand. Why did you say this an hydrocarbon is an alkene? S: it has double bond T: yes, because it has double bond. Please, every time you see a double bond, note that it's an alkene, ok? Ss: yes Naming pet-2-ene T: So, in this case, our suffix would be? SM2: ene SM4: ene T: Our suffix would be ene. How many carbons do we have? SF2: five T: Five carbons. So what would be our root?? SM5: pent T: pent, but look at this (she referred to the structure on the board), we have a double bond at carbon number two right and so, every time we have this type of unsaturated hydrocarbon, you must show where the double bond is, you see in this case, this (she referred to the structure on the board) would be pent-2-ene or some prefer writing it as 2-pentene, it's a member of alkenes, they are unsaturated hydrocarbons with at least a double covalent bond between carbon atoms however you must always avoid numbering wrongly like from the right to the left in this case, such that the carbon on which we have the double bond becomes carbon 4 and then you say the compound is pent-4-ene, we rather we rather go for the lowest numbering of carbons such that the double bond is attached to the carbon with the lowest number. Do you understand that now? Ss: yes SM7: ma'am is the whole structure an alkene because it's double bonded or single bonded? T: it's a whole structure, this thing, it's a single compound, it's just that the difference with this is that it has carbon bonded to another carbon using double bond, ok, unlike the alkane. It's just that the alkane is just straight single-single bonds but in this case you find that one of the carbons prefers bonding to another	

carbon using two of these valence electrons, is it clear if I use valence electrons? Ss: yes T: so in this case, this carbon (second carbon from the left) says ok carbon number three, I'll bring two of my electrons, and you also bring yours so that we can share them, instead of these ones (the remaining carbons in the chain with single bonds) which are like alkanes which prefer using only single bonds, OK? So, in the same of alkynes, remember alkenes and alkynes, they are named in this same way, Ok?.....	
34-35 Naming Alkynes *Questioning on but-1-yne* T: In an alkyne, we find that we have this kind of a compound (*She referred to the figure below but-1-yne*). How many carbons do we have here? SM9: 4 T: What does the triple bond between the first two carbons mean? Yes, anybody? SF9: it means that we have alkyne. T: Good, it's an alkyne because it has got one triple bond between this carbon atoms (she pointed at the structure on the board), so now we must remember to apply our IUPAC rule in naming this, that's very important, our triple bond is one the first carbon atom, if we count from the right, but on the 4th carbon atom counting from the right, we go for the smallest, so we name our molecule as but-1-yne. Any question please? There was no response from learners.	Comment: This section focused on naming but-1-yne, an alkyne. Hope's role: With reference to the structure of but-1-yne drawn on the chalkboard (RP), Hope asked learners how many carbon atoms are present and what the triple bond means in an attempt to establish their prior knowledge. Learners' role: A learner correctly indicated carbon forming four bonds and the triple bond making the molecule an alkyne. While this correct response shows that the learner understood previous related discussions, it also reflects good prior knowledge that Hope expected learners to have in place (LP). Hope's role: She acknowledge the learners' correct response and then using the structure drawn on the chalkboard (RP) explained how to name but-1-yne with emphasis on remembering IUPAC rule, an important aspect she called learners' attention to (CS). Hope's use of TSPCK components (LP-CS/RP) at a proficient level is given by the TSPCK map below.
35-36 Describing cyclohdrocarbons LP-CS/RP Hope: Sometimes, we also talk of cyclohydrocarbons, you know what I mean when I say hydrocarbons right? SM2: Alkanes Hope: And then, SM3: Alkynes Hope: Yes, alkanes, alkenes and alkynes. Now, when we talk of cyclohydrocarbons we talk of closed carbon ring of alkanes, alkenes and alkynes, what is important about the carbon atoms in such compounds is that, they form a ring just like (she drew the structure of cyclopropane on the board), this is our cyclopropane. You can see that, it's got how many carbon? SF1: 3 Hope: And then how many hydrogen? SF4: 6 Hope: So now, our cycloalkanes have the molecular formula (she put CnH_{2n} on the chalk board) but don't forget that, for our alkanes, we have got (she wrote CnH2n+2 on the chalk board), so it means that all cycloalkanes are reduced by 2 hydrogen	Comment: This section focused on describing cyclohydrocarbons where Hope first investigated learners' existing knowledge before providing explanations. Hope's role: Hope asked learners about hydrocarbons in order to investigate their existing knowledge. Learners' role: Learner SM2 and SM3 showed a good existing knowledge of alkanes and alkynes as classes of hydrocarbons (LP), the understanding Hope expected them to bring into that discussion. Hope's role: Hope explained cyclohydrocarbons pointing out the carbon atoms forming a ring as an important aspect about the compounds, an element of teacher knowledge of curricular saliency (CS). She also used the structure of cyclopropane to support her description, thereby demonstrating her understanding of a symbolic representation (RP). Hope's interactive use of TSPCK components (LP-

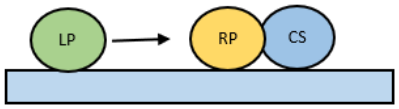
atoms in their molecules. Any question about that guys? Ss…There was no response from learners…..	CS/RP) at a proficient level of TSPCK episode is given by the TSPCK map below.
36-40 Evaluation T: Good. So, in order to name this, you use the same method. Since the longest chain consists of carbon atoms, on which carbon atom do we have the triple bond? Anybody? SM10: the first carbon atom T: So, since the triple bond is on the first carbon atom and we know that four carbons atoms is named after 'but' then this (*she pointed to the structure on the board*) would be named as but-1-yne, we describe it as an unsaturated hydrocarbon because of this triple bond neh, it's an alkyne, all alkynes contain a triple covalent bon between carbon atoms in their molecule.   T: Ok, so in this case we have how many carbons? SM9: 8 T: 8, ok. And then, where is our triple bond? SM11: on carbon number 4 T: Ok, from which side, left or right? SM11: left T: And then, from the right to the left the triple bond is on which carbon atom? SF10: 5 T: it's five so, when you are given this type of a compound to name, which side would you prefer? Ss: from the left T: why SF11: because the triple bond is attached to the lowest carbon number SF12: because it's the shortest T: Can you say that in a clear way? SF13: because we were looking for the shortest carbon chain T: You were looking for the shortest carbon chain, ok. Someone should try, there is a way that I want, yes SM2: we have to give a substituent the lowest number T: in this case we don't have a substituent SM2: then we have to give the alkyne the lowest number T: so, we want to give this triple bond the lowest possible number, ok, that is why we say we counting from the left to right and so, in this case, we have our carbon on number 4 and we have 8 carbons. So, 8 is what? SM2: oct T: oct and then what is the suffix Ss: yne T: yne. So, it's Octyne and so, it would be SM3: oct-4	Comment: This section focused on evaluating learners' understanding by giving them organic molecules to name. Learners had the opportunity to write directly on the board.

T: We call this Oct-4-yne or 4-octyne right, there are eight carbon atoms present, that suggests 'oct', it's an alkyne as we can see, there is one triple covalent bond between carbon atoms and so, it is unsaturated hydrocarbons with lesser number of hydrogen atoms compared to alkenes and alkanes neh. Is that clear now? Ss: yes	
pent-2-ene (The teacher drew this as number one and a male learner went out to the board) T: your answer is  S: (the learner wrote this T: sharp. (ii) Naming 3 methyl hexane and (iii) but-2-ene T: Who is number 2? Oh, I'll just pick. Ok, number 2 please and number three (when she finished drawing these on the board  Ok, anyone who is not busy to do number 2 (a male learner went out to do this). Yes, you in a blue jacket (another male learner went out), please do number 3 for me. (iv) cyclobutane T: (While the two boys are busy thinking about what to write as the answers to the structures, the teacher said) Girls, you are letting me down, there are no girls to assist me (The teacher drew this as the forth  and a male learner was busy thinking about the answer. (v) Propane T: The teacher thereafter drew the fifth  and then requested a female learner should do it	

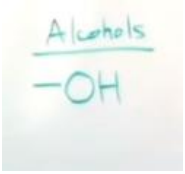
T: Please, any volunteer for number 5, this time I need a lady S: they are shy. T: Oh, they are shy, there are no ladies. Ok, let's correct the first one, let's count one two three four five. So, what type of a hydrocarbon? Ss: alkene T: So, you can see that by the double bond and then, you can see the name, it says 'pent-2-ene' is it correct? Ss: yes…yebo T: Why did you say number one is correct? Ss: murmur T: Why please? S: It's double bonded, we have five carbons and then we have two two from the left to the double bond. So, it becomes pent-2-ene. T: So, we have, he counted from the left because there is a lowest possible number for the first carbon, am I clear? Ss: yes T: And that gave him pent-2-ene. Another thing is that we have number 3 (pointing to the structure 4 above), who wrote this name?  Ss: laugh T: No, no, let's be serious. (The learner signified) T: May be you should have signed under it Ss: other laughed T: It's not funny guys. He started from here (pointing at the carbon in the figure above) and says this carbon number 1 and that gave him 1-cyclomethylbutene. Is it correct Ss: yes T: Wait, let's check, is it correct? Ss: No T: What type of a hydrocarbon is this? For example, what type of bond does it consist? S: Alkane Ss: single bond T: Single bond, so it's an alkane and the suffix? Ss: ane T: so, 'butene' is supposed to be 'butane'. So the name should be 1-cyclomethylbutane. And this,  how many carbons? Ss: three T: And this gives us? Ss: prop T: And then, what type of a hydrocarbon? Ss: Alkane T: So, it's an alkane with suffix 'ane' so it's propane. That's	

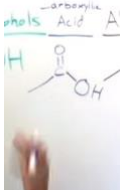
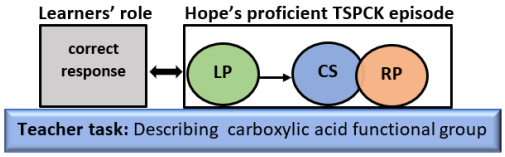
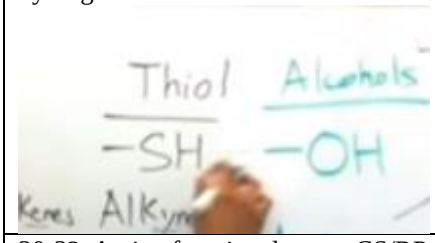
correct. And in this,  we have another carbons?
Ss: six
T: Six which gives us?
Ss: hex
T: And then, what type of hydrocarbon?
Ss: Alkane
T: It's an alkane. Does it have a substituent?
Ss: yes
T: On which carbon? Carbon number
Ss: 3
T: And so, 3 hypenmethylhexane (3-methylhexane), that's correct. And the last one,  it's how many carbons?
Ss: 2
T: Which is?
S: but
T: 'but' and then we have a triple bond which tells us the parent, the type of hydrocarbon is alkyne. It takes the suffix 'yne'. And then, he said it is 2-Butene, does it have a substituent? Which means it was just supposed to be 'Butyne'. On which carbon do we have the triple bond?
Ss: 2
T: On two, so we have 2-Butyne. (Thereafter, showing them the slides she said,) 

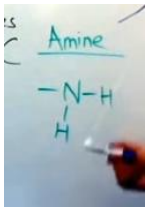
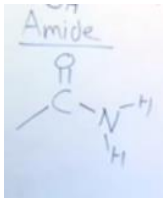
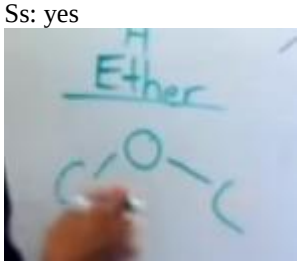
So here I have the examples of alkenes and alkynes, can you see that, so here we have the alknes on this side, and ethene, can you see that it has double bond? And this is the condensed formula, I didn't show you condensed formula while I was giving you examples, sorry for that but these are the condensed formula….END

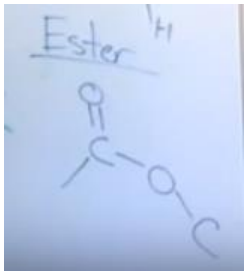
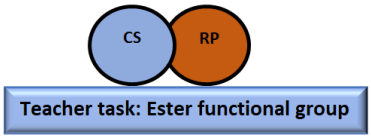
Lesson 2	
0-4 Functional Alkanes LP-CS/RP Hope: Let's talk about the functional groups for hydrocarbons. What did we call those hydrocarbons that have got single bonds between carbons? SF7: alkanes Hope: How about those with a double bond? SF8: alkenes Hope: And triple bond? SF9: Alkynes, Hope: Thanks. So, we now gonna start looking at the each of them. Now we've been talking about the IUPAC naming of these compounds, there's something in common to all the members in a particular homologous series, and that is the functional group, so for all alkanes, we've got singe carbon-carbon covalent bonds like this C-C as we have it in ethane here (*she drew the molecular structure for ethane on the chalk board*) and other members, is that right? Ss: yes	Comment: The discussion here focused on describing the alkane functional group. In-depth Qualitative Analysis: Hope's role: Hope asked learners what hydrocarbons with single carbon to carbon covalent bonds are called in relation to their previous discussions on the types of hydrocarbons. Learners' role: Learners showed good existing understanding of alkanes, alkenes and alkynes consisting of single, double and triple carbon to carbon covalent bonds respectively (LP) Hope's role: Expatiating on the learners' existing knowledge (LP), Hope drew the molecular structure of ethane on the chalk board and used it to refer to the functional group of members in the alkane homologous series as consisting of single carbon to carbon covalent bonds. This suggests Hope's understanding of what is important for learners to know, an element of curricular saliency (CS) and the use of a symbolic representation (RP). The Hope's understanding of the interactive use of TSPCK components (LP-CS/RP) at a proficient level of TSPCK episode is given by the TSPCK map below. (Correct Response – LP-CS/RP). 
4-5 Functional group Alkenes CS/RP Hope: Then, for alkene functional group, we've got two carbon atoms as well but now we have a double covalent bond (*She drew two carbons with a double between them*) (RP), at least there must one double covalent bond between two carbon atoms in a molecule, that is key feature you must always remember (CS) it is then we can call such a molecule an alkene any question on that? There was no response from learers	Comment: This section focused on alkenes functional group. Hope's role: With reference to the structure drawn on the chalkboard (RP), Hope explained alkene functional as consisting of a double covalent bond between two carbon atoms the aspect considered important for learners to understand (CS). Learners' role: None

	Hope's use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below.
5-7 Functional group Alkynes CS/RP T: Now, we have alkyne functional group, their characteristic feature which makes them different from other homologous series is the presence at least one triple covalent bond between two carbon atoms, it is important to have one triple covalent bond before we call an organic molecule an alkyne (*she faced the board and put the symbol*), here it is, just like we have a double covalent bond in the case of alkenes and a single bond in the case of alkanes. Any question please? There was no response from learners. Do we all understand? Ss: yes	Comment: This section focused on alkyne functional group. Hope's role: With reference to the structure drawn on the chalkboard (RP), Hope explained alkyne functional as consisting of at least a triple covalent bond between two carbon atoms the aspect considered important for learners to understand (CS). Learners' role: None Hope's use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below.
7-12 Haloalkanes functional group LP-CS/RP T: We've also got the functional group of haloalkanes, do you guys know of halogens? Ss: Yes T: What are they? SM1: Elements T: Like? SM1: Chlorine SF2: Fluorine T: Good idea! As you must have learned when you were being taught the periodic table, halogen is a group of elements in group 7, they are known to be very reactive chemically, like they just mentioned, they include chlorine, bromine, iodine yeah (LP). So now when we talk about the haloalkanes, we talk about saturated hydrocarbons which have got one or more halogens, so now we represent the functional group of haloalkanes as (*She put R-X on the board*) (RP), here is R, our alkyl group, X is our halogen, for example chloromethane (*she drew the structure on the board*), it's CH3Cl, it has got one carbon bonded to three hydrogens and one chlorine, do we understand? Ss: yes. T: Any question please? There was no response from learners	Comment: This section focused on the haloalkane functional group. Hope's role: In an attempt to establish learners' prior knowledge, Hope asked learners about halogens. Learners' role: Learners correctly mentioned chlorine and fluorine as examples of halogens. This shows good prior knowledge which Hope expected to have in place before discussing haloalkane functional group with them (LP). Hope's role: After acknowledging learners' correct responses, with reference to the symbolic representation on the chalkboard (RP), she described the functional group for haloalkanes as consisting of an alkyl bonded to at least an atom of halogen, an important aspect she wanted learners to understand (CS). Hope's use of TSPCK components (LP-CS/RP) at a proficient level is given by the TSPCK map below.
12-15 Alcohol functional group LP-CS/RP Hope: Ok, next is alcohol, I believe alcohol is not strange to you right? Can you give us common examples of substances that contain alcohols in our environment? SM4: Beer Ss: Laugh Hope: That's very correct, we've got so many alcoholic drinks so now in organic chemistry, it is easy to remember alcohols and their functional group because it's just a carbon chain with oxygen covalently bonded to hydrogen as OH (she put R-OH on the board), our carbon is in here (she pointed at R), and here, this hydroxyl group makes the characteristic functional group for alcohols as we can see represented it on here neh.	Comment: The discussion focused on describing alcohols functional group by first finding out what learners knew before providing an explanation. In-depth Qualitative Analysis *Hope's role*: Hope asked learners to give examples of substances that contain alcohols, relating to their environment experiences thereby demonstrating the importance of first establishing learner prior knowledge (LP). *Learners' role*: Learner S8 mentioned beer as an example of alcoholic substances thereby showing correct prior knowledge. *Hope's role*: Taking SF8's correct response into consideration, Hope explained alcohol functional

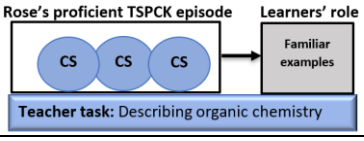
	group as consisting of hydroxyl group symbolically represented on the board for learners to see thereby showing her understanding of what learners needed to know (CS) with the use of a symbolic representation (RP). Hope's interactive use of TSPCK components (LP-CS/RP) at a proficient level mediated by a learner's correct response is shown by the TSPCK map below.
15-18 Aldehyde functional group CS/RP/LP Hope: Ok, next is the aldehyde, now aldehyde functional group, it's basically carbon with oxygen up here (s*he drew the structure on the board*), (RP) that's a double bond covalent bond between a carbon and oxygen atom (CS) right, you don't confuse that with a single bond covalent bond between carbon and oxygen and then probably think it's carbon monoxide, (LP) here our C=O here is called carbonyl group, ok and then bonded to that, is the hydrogen atom (*she pointed at the structure*), hope you got that? Learners' role: None	Comment: The discussion focused on describing aldehyde functional group where there was direct explanation of required knowledge. In-depth qualitative analysis: Hope's role: Hope explained the aldehyde functional group as consisting of carbon double covalently bonded to oxygen using its structure drawn on the board thereby describing her understanding of what learners should know (CS) and use of a symbolic representation (RP). She also cautioned learners not to confuse the carbonyl group with carbon monoxide thereby describing her awareness of a possible misconception (LP). Learners' role: None Hope's interactive use of TSPCK components (RP/CS/LP) at a proficient level of TSPCK episode is given by the TSPCK map below. (see p. 24 chap 6 for TSPCK map)
18-21 Ketone functional group CS/RP/LP T: Let's talk about ketone functional group, here it's (*she put the structure*) (RP), you see, ketone has also got carbonyl functional group but here there are two substituents attached to this carbon, the R here and another R here are bonded to this carbon, that's ketone. Guys, you've got to be very careful here so don't think aldehyde functional group is the same as that of ketone (LP), if one of the substituent is hydrogen, then it's gonna be aldehyde functional group, look at it very well, any problem? Ss: (No response) There was no response from learners	Comment: This section focused on ketone functional group. Hope's role: With reference to the structure drawn on the chalkboard (RP), Hope explained ketone functional as consisting of carbonyl group bonded alkyl groups nitrogen atom and two other atoms of hydrogen the aspects considered for learners to understand (CS). She further cautioned learners not to think aldehyde functional group is the same as ketone group. This is an element of learner prior knowledge, the understanding of a possible misconception (LP). Learners' role: None Hope's use of TSPCK components (CS/RP/LP) at a proficient level is given by the TSPCK map below.
21-25minutes: Carboxylic acid functional group Hope: So, the next one we gonna discuss is carboxylic acid functional group. Have you guys heard of acids? Ss:….(Learners echoed 'yes')…..	Hope's role: As a starting point, Hope asked learners if they had heard of carboxylic acid functional group before knowing that, carboxylic acid refers to an acidic compound and learners must have already learnt about acids in the previous Grade.

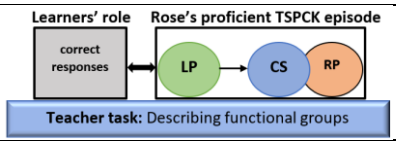
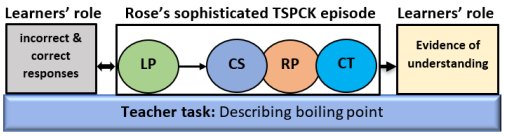
SF8: acids and bases Hope: Exactly, we have got acids and bases in organic chemistry in inorganic chemistry right (LP). In organic chemistry we also have carboxylic acids, here you think of a kind of fusion between particularly between the our hydroxyl group and carbonyl group (CS), here is our carboxylic acid functional group (*she drew the molecular structure for the carboxylic acid functional group on the chalk board*), (RP) we just put one hydroxyl group here and then I bring in the carbonyl group which is the carbon bonded to oxygen, you see can how I brought the carbonyl and OH right? Ss: yes Hope: That's our carboxylic functional group 	Learners' role: Learner SF8 referred to acids and bases as what he knew about acids. This shows the learner prior knowledge which Mark expected all learners to bring into the discussion (LP) Hope's role: Hope acknowledged the acids and bases that SF8 mentioned in relation to inorganic chemistry in order to confirm the correct prior knowledge. She referred to the fusion between the hydroxyl group and a carbonyl group as representing the carboxylic acid functional group. This is an element of curricular saliency (CS), the knowledge of what is important for learners to know. She drew the molecular structure of carboxylic acid functional group to support her explanation thereby suggesting her knowledge of the use of a symbolic representation (RP). Hope's use of TSPCK components (LP-CS/RP) in connection to a learner's correct response is given by the TSPCK map below. 
25-30 Thiols functional groups CS/RP Hope: Yeah, guys I mustn't forget thiols, these ones they are referred to as organosulfur compound, that's they are organic compounds that principally contain sulfur, their functional group is (*She put -SH on the board*), it's bonded to carbon so we can simply write that as R-SH right where our R could be CH3, our methyl or C2H5, that's our ethyl and so on, so the carbon there is bonded to SH, S is sulfur and then we have our hydrogen H. 	Comment: The discussion focused on describing thiols functional group where there was a direct explanation of required knowledge. In-depth Qualitative Analysis Hope's role: Hope referred to thiols as organosulfur compounds containing SH bonded to a carbon atom as the functional describing her understanding of what was important for learner to know (CS) using a symbolic representation (RP). Hope's interactive use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below.
30-32 Amine functional group CS/RP T: So, the next one that is more complicated it's amine, so, the amine functional group is essentially a nitrogen with hydrogen and another hydrogen and a carbon chain (*She drew the structure on the board*). The way you can think about it, it is the substituent of protein.	Comment: This section focused on amine functional group. Hope's role: With reference to the structure drawn on the chalkboard (RP), Hope explained amine functional as consisting of a nitrogen atom bonded to atoms of hydrogen the aspects considered for learners to understand (CS). Learners' role: None

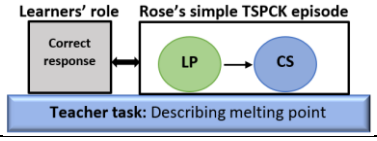
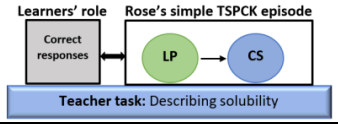
	Hope's use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below.
32-34 Amide functional group CS/RP T: Next is the amide. First of all, I'm going to draw my amine (*She drew the functional group of amine and then circled carbonyl group in the aldehyde and thereafter drew and joined the carbonyl group to the amine she earlier drew, all to form the functional group of amide*). 	Comment: This section focused on amide functional group. Hope's role: With reference to the structure drawn on the chalkboard (RP), Hope explained amide functional as consisting of carbonyl group bonded a nitrogen atom and two other atoms of hydrogen the aspects considered for learners to understand (CS). Learners' role: None Hope's use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below.
34-36 Ether functional group CS/RP T: Now, the next is ether and esters. Let's look at ether first, it's an organic molecule with its own functional group, here is the structure (*She drew the structure of oxygen bonded to two carbons on the board*), oxygen and two carbons on the two sides bonded to it so this is ether functional group (*She pointed to the structure on the board*), if we put hydrogen around this carbon, we gonna have a complete organic molecule right? Ss: yes 	Comment: This section focused on ether functional group. Hope's role: With reference to the structure drawn on the chalkboard (RP), Hope explained ether functional group as consisting of oxygen and carbon atoms as an important aspect she wanted learners to understand (CS). Learners' role: None Hope's use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below.
36-40 Ester functional grp CS/RP Hope: And now, we have ester functional group, it's more complicated than the functional group of ether, it looks like (*She drew the structure of ester functional group*), carbon in carbonyl group is bonded to one oxygen and then this O is bonded to another carbon, that's the functional group and since it contains a carbonyl group, that's (she pointed at C=O).	Comment: The discussion focused on describing ester functional group where there was a direct explanation of required knowledge. In-depth Qualitative Analysis Hope's role: Hope explained the ester functional group as consisting of a carbonyl group bonded to an oxygen atom which is in turn bonded a carbon atom with its structure drawn on the board describing her understanding of what learners should know (CS) and use of a symbolic

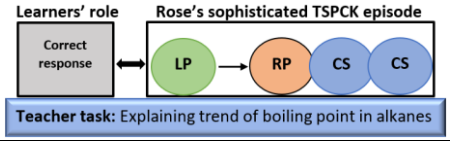
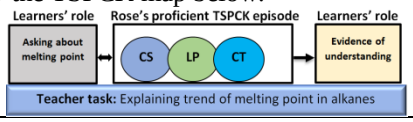
	representation (RP). Hope's interactive use of TSPCK components (CS/RP) at a simple level is given by the TSPCK map below. 

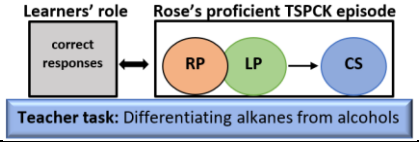
Appendix XXIX: Detailed analysis of Rose's lesson

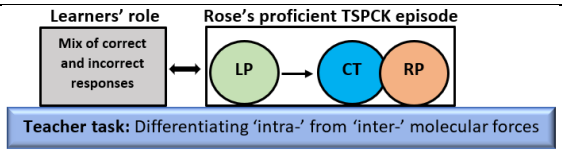
0-2min: Reminding learners of the study of organic chemistry Rose: So, it's very important for us to know that organic chemistry primarily comprises of compounds of carbon where carbon is covalently bonded to one hydrogen atom or more and it more contain other elements like oxygen, chlorine and so on, so such organic compounds undergo various chemical reactions like addition reaction right, these reactions are determined by the specific functional group associated with particular kind of organic molecules interesting chemists use these organic reactions to produce some of the materials we use in our homes like plastics, we can find that all around us, it is a product of the industrial knowledge of organic chemistry, yeah, can someone tell us more examples of products of organic chemistry? Yes anyone SF1: petroleum Rose: petroleum is a product, yes SF2: insecticides SM1: natural gas Rose: Very good and many more.	Comment: As a starting point for introducing the lesson, Rose reminded them of what the study organic chemistry means and then involved them by asking them to give some related examples. In-depth Qualitative Analysis: Rose played the role of describing organic chemistry with respect to three important aspects considered important for learners to know thereby describing her understanding of curricular saliency. These aspects included: carbon covalently bonded to hydrogen the basic knowledge of organic compounds; reactions of organic compounds as determined by the functional groups; and industrial application of the knowledge of organic chemistry. The learners' role was demonstrated in giving examples they were familiar with from their prior knowledge. The proficient interwoven of curricular saliency (CS) mediated by learners' prior knowledge is displayed by the TSPCK map below. 
2-4min: Describing functional groups Rose: Now we'll be focussing on physical properties of organic compounds for today, okay, hope we're all familiar with physical properties right. So, what are the physical properties that you can think of? SM2: boiling point SM3: mass SF3: pressure Rose: You're all correct, so we'll focus on the boiling point, melting point and solubility as the physical properties of organic compounds, one important idea which you must not forget is the functional group, remember they represent a group of atoms which we use to identify organic compounds which belong to the same homologous, for example let's say we've got (S*he drew the structure of ethane and butane on the board*), this is ethane and here is butane, they have both got single covalent bond between carbon atoms that tells us they both belong to the same alkane homologous series, alkane right? Ss: yes	Comment: The discussion centred on describing physical properties as the focus of the lesson and emphasizing functional groups as an important pre-concept. In-depth Qualitative Analysis: Rose's role: She indicated physical properties as the focus of the lesson and asked learners what physical properties are thereby describing her awareness of the importance of learners' prior knowledge (LP), a TSPCK component. Learners' role: They correctly mentioned examples of physical properties thereby demonstrating their prior knowledge. Rose's role: She focussed learners' attention on boiling point, melting point and solubility as the three physical properties to discuss. She highlighted functional groups as an important concept learners should remember, thereby describing her understanding of curricular saliency (CS). Simultaneously, used the structural formula (RP) for ethane and butane as examples of two molecules that belong to the same homologous series and containing same functional group. The proficient interwoven of TSPCK components mediated by learners' correct responses is shown by the TSPCK map below.

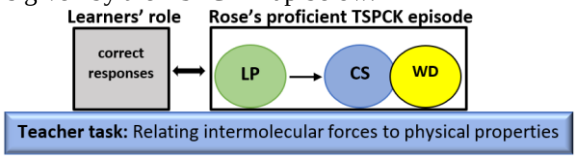
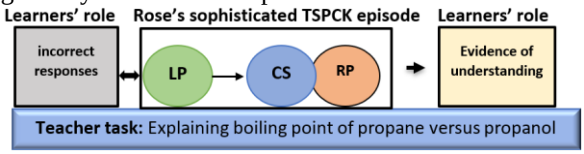
	
4-8min: Describing boiling point of liquids Rose: So, guys since you did those things already before now, let me hear from you guys what is boiling point? SM1: boiling point is like the vapour pressure equals to the atmospheric pressure Rose: Guys, remember boiling point was one of the basic stuff you learned in Grade 11 right? Ss:…(yes) Rose: So, anyone who wants to add something to what said? *(No response from learners)* Rose: In terms of phases, what can you say? Like the state of reactants what can you say? Those things like solids and gases. When you say something is boiling, what does it mean? When you boil water in a kettle as we do in our homes whenever we wanna make tea, what does it mean? SF2: It goes from liquid to gas Rose: That's right, when you heat a liquid, it changes to gas, vapour right (LP). But does that mean boiling has taken place? I think you must know that boiling point is actually a particular temperature (CS) so it would have been perfect if the boy over there had described boiling point as temperature at which the vapour pressure equals to the atmospheric pressure, ok and that girl also said when we boil water, it goes from liquid to gaseous state, very correct but, that isn't the boiling point, you don't think when you supply heat to a liquid and it changes to gas then it has reached the boiling point, no! let's say here is a kettle containing water (*she drew a kettle of water heated and particles evaporating*), you see, (RP) the moment you heat up, evaporation begins, you see water molecules gradually becoming vapours, that's evaporation, it occurs at all temperatures but water only boils when it has reached a constant temperature which we call the boiling point, (CT) do you understand that now? Ss: yes SF3: Ma'am, that means both evaporation and boiling cause water to change from liquid to vapour right? Rose: Exactly, so the boiling point is the temperature at which the vapour pressure equal to the atmospheric pressure when a liquid is heated.	Comment: This segment focused on describing the concept of boiling point of liquids. Rose asking learners questions before providing explanations. In-depth Qualitative Analysis: Rose's role: Asking learners what boiling point means and engaged them in further questioning by giving a familiar example of boiling water in a kettle as in the homes showing awareness of the importance of learner prior knowledge (LP). Learners' role: Describing boiling point in relation to vapour and atmospheric pressure, and change of state from liquid to gas. Rose's role: She Provided an explanation which indicated "a particular temperature" as the first important aspect missing from the learner SM1's response. She also distinguished 'boiling point' from 'evaporation' as the second important aspect in relation to the learner SF2's response. These signal Rose's understanding of curricular saliency (CS), two different but related important aspects necessary for learners to know. She used the symbolic representation of a kettle containing water and heated to cause a change from liquid to vapour (RP). Learners' role: SF3's response signalled understanding of Rose's explanation. Rose's understanding of interactive use of TSPCK components (LP-CS/RP/CT) at a sophisticated level of TSPCK episode in connection to the learner's correct and incorrect response is given by the TSPCK map below. 
8-10min: Describing melting point of substances Rose: So, melting point? Anyone who wants to tell us about melting point, just a very simple definition. SM4: it's the temperature at which a substance melts Rose: Oh ok, do you guys agree? Ss: yes	Comment: This segment focused on describing melting point as a concept in chemistry by asking learners' questions and providing explanations. In-depth Qualitative Analysis: Rose probed learners' prior knowledge of melting point by asking them to give a simple definition (LP)

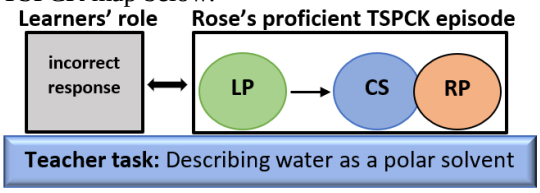
Rose: Exactly, melting point has to be a temperature, so melting point is the temperature at which a substance changes from a solid phase to a liquid phase for example just like burning a candle, it melts and then changes to a liquid state, there is a particular temperature at which a substance melts, the temperature remains constant at the point, it does not increase neither does the temperature decrease ok.	and Learner SM4's response as the temperature at which a substance melts showed good prior knowledge. She expatiated on SM4's response by giving a familiar example of a burning candle to emphasize melting point as a constant temperature (CS). The simple interwoven use of TSPCK components (LP-CS) mediated by learner's correct response is given by the TSPCK map below. 
10-14min Describing solubility LP-CS Rose: When you say something is soluble what does that mean? SF6: A substance disappears in another substance to form a solution. Rose: And then solubility? SM4: solubility is the ability of a substance to dissolve in water or any liquid Rose: When something is soluble in water or any liquid? SM4: yes Rose: So, what happens if that something is not soluble? SM4: (smile) Rose: OK guys, although most substances can dissolve in water and that's why we consider it a universal solvent but we must not think that all substances are soluble in water, some substances are more soluble than others that is, their solubility differs, hence solubility is a means of comparing the extent to which different solutes can dissolve in a particular solvent at a definite temperature, you understand that right? Ss: yes	Comment: This segment focused on describing solubility as a concept in chemistry by asking learners' questions and providing explanations. In-depth Qualitative Analysis Rose's role: Rose asked learners what it means to have something soluble and then what solubility denotes thereby showing awareness of the importance of establishing learner prior knowledge (LP). Learners' role: Learner SF6 correctly described "something soluble" as having a substance disappearing in another substance. SM4 also described solubility as the ability of a substance to dissolve. The responses showed learners' good prior knowledge. Rose's role: Expatiating on SM4's response, Rose described solubility as the extent to which substances dissolve also adding a definite temperature, an important aspect for learners to understand (CS). The simple interwoven use of TSPCK components (LP-CS) mediated by a learner's response is given by the TSPCK map below. 
14-21min: Discussing the boiling point trend in alkanes (Item 1 and 4) Rose: So as carbon chain length increases in alkanes, the boiling point increases, so temperature increases, how can we explain that guys? SF5: the molecules are available to jump out of the kettle as the chain length decreases Ss:….(Everyone smiles)….. Rose: Exactly! The point is when the chain length increases, let's see methane (She drew the structure) compared to butane (she drew the structure), in butane here, we've got more carbon atoms covalently bonded and so, longer chain length which makes their van der Waal's force stronger than that of methane, so if you've got the whole lot of these molecules bounded together, it's going to be hard for them to entangle themselves from each other when heated and for them to jump out of the cup, it means more energy must be supplied in the case of butane than methane and that increases the	Comment: This segment focused on the trend of boiling points in the homologous series of alkanes. Rose engaged learners in questioning and provided explanations. In-depth Qualitative Analysis Rose's role: She asked learners to explain the phenomenon of increase in carbon chain that increases temperature and hence, boiling point of alkanes thereby probing for learner prior knowledge (LP). Learners' role: The learner SF5 made her understanding known in indicating that, increase in temperature sets molecules on motion as seen through the escape of molecules from a kettle. Rose's role: Rose expatiated on the learner's response by drawing the structure of methane and butane thereby showing her understanding of symbolic representations (RP). Using the structures she explained higher boiling point in butane compared to methane with respect to: (i) how longer carbon chain

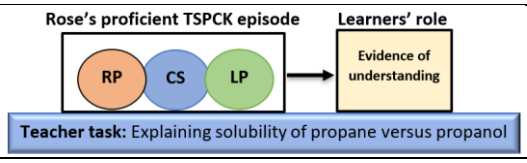
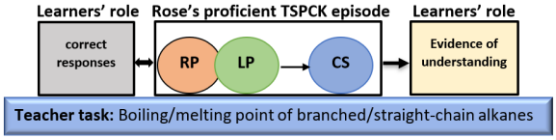
temperature and the boiling point of butane, you also need to understand that, apart from the stronger van der Waal's forces in butane, the number of carbon atoms increases their surface area, so we've got larger surface area in butane compared to methane. So the longer the chain, the larger the surface area and then the more energy needed, the higher the boiling point in the alkane homologous series.	strengthens the van der waal's forces in butane than in methane (CS); (ii) more carbon atoms increasing the surface area in butane thereby requiring more energy to be separated than in methane (CS). These suggest her understanding of two important aspects necessary for learners to understand, describe knowledge of curricular saliency. The sophisticated interwoven used of TSPCK components (LP-RP/CS/CS) mediated by the learner's correct responses is given by the TSPCK map below. 
21-27min: Discussing the melting point in alkanes SF1: Ma'am please is it the same as melting point? Rose: Good question, going up from methane, to ethane, propane and so on, as the number of carbon atoms increases, the number of electrons that surround the molecules also increases, as a result, there is increase of the molecular weight, due to that, van der Waals forces now become stronger, this raises the boiling points, and then, as the size of molecules increases due to the increase in carbon atoms, the melting point becomes higher yeah but what you should understand as the key difference between boiling point and melting point is, let me say that from your topics in Grade 10 and 11, you would remember we normally associate melting point with solids right, the temperature at which solid changes to liquid, that means the melting points of liquids are very very small, so, melting point is different in the sense that solid alkanes are more tightly packed those liquid alkanes, so, solids alkanes require greater energy to break them down, so as we go up, melting point increases and boiling point too increases, hope you now understand now? Ss:….(learners echoed yes)….. Rose: So, if I may ask you, why does the boiling point increase across the alkanes? Yes anyone? SF1: it's because as we go down the group, or up rather, the carbon chain length increases, making the intermolecular force to be stronger. Rose: Yes, so how does the strong intermolecular force raise the boiling point? SM1: strong intermolecular is hard to break by heat energy, so it requires more energy and that also increases the molecular weight and surface, which eventually raises the boiling point. Rose: You're both excellent! Any question? Anyone who needs clarification?	Comment: This segment focused on the trend of melting points in the homologous series of alkanes associated with a learner's curiosity to know. In-depth Qualitative Analysis Learners' role: Based on the Rose's explanations on the trend of boiling points in alkanes, learner SF1 was curious to know what happens to the melting point in alkanes. Rose's role: Rose first explained how the increase in the number of carbon atom increases the molecular weight thereby strengthening the van der Waal's forces in the molecule (CS). Then, she reminded learners of melting point was described as they learnt in the previous grade, the temperature at which a solid changes to liquid which implies that liquids have very low melting point thereby showing awareness of learner prior knowledge (LP). Based on that awareness, she then differentiated the melting points of liquids from solids by comparing the arrangement of their individual particles and the fact that, more energy is required to break bonds in solids than in liquids thereby demonstrating an understanding of an important aspect for learners (CS). Learners' role: In response to Rose's question, asking why the boiling increases across alkanes, learner SF1 was able to correctly relate the carbon chain length to the strength of the intermolecular forces as Rose earlier explained to them. Learner SM1 also pointed out how more energy should be supplied to raise the boiling point in molecules with longer carbon chain length. These learners' responses suggest evidence of their evidence of Rose's explanations. The proficient interwoven use of TSPCK components (CS/LP/CT) mediated by a learner's curiosity to learn and suggesting evidence of learners' understanding is given by the TSPCK map below. 
27-31min: Distinguishing alkane from alcohol Rose: So guys now, look at these two (*she drew the*	Comment: This segment focused on the difference the boiling points of alkanes and alcohols of the same

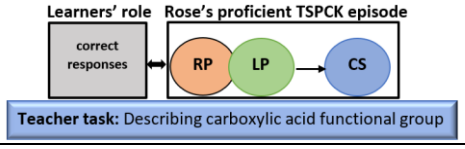
structures of propane and propanol on the board and referred to them without mentioning their names), are these same? Do they belong to the same homologous series? SF5: they are not the same Rose: What makes the difference between them? SF5: That one (Pointing at the C_3H_7OH) consists of the oxygen but the other compound does not. Rose: Any other opinion? SF7: the first structure is an alkane and it is a propane with no hydroxyl group unlike the other Rose: what about the other? SM2: ma'am the other is an alcohol, it is propanol. Rose: Good, you know that this (she pointed to the structure of propane on the board) is propane, three carbons, eight hydrogens neh, there are single covalent bonds between the carbons, it is a saturated hydrocarbon, it's an alkane neh and this (she pointed to the structure to the structure of propanol) is propanol, it's a member of alcohol, here is the hydroxyl functional group that characterises the alcohols right? Ss: yes	carbon atoms. <u>In-depth Qualitative Analysis</u> Rose's role: Using the structures of propane and propanol drawn on the board (RP), Rose investigated learner prior knowledge by asking if the two organic molecules belong to the same homologous series (LP). Learners' role: The Learner SF5, SF7 and SM2's showed good understanding by correctly distinguishing propane from propanol. Rose's role: With reference to the symbolic representations of propane and propanol (RP), Rose expatiated on the learners' correct responses by indicating the single carbon to carbon covalent in propane and hydroxyl group in alcohol as the functional groups (CS). The proficient interwoven use of TSPCK components (RP/LP-CS) mediated by learners' correct responses is given by the TSPCK map below. 
<u>31-35min: Addressing a misconception relating to molecular forces</u> Rose: Now, if you were given this as a question, say between propane and propanol, which one is gonna have the high boiling point, like if you compare the two between the propane and propanol? What's gonna be your answer and you have to give a reason for that? SM5: it's propanol Rose: why? SM5: because propanol has got a weak intramolecular force Rose: A weak intramolecular force? SM5: yes SM6: the propanol has got weak intermolecular forces Rose: A weak intramolecular force, versus weak intermolecular forces, interesting. Which one are we gonna take? Let's write it down, what do you guys mean by intermolecular forces? *There was no response?* Rose: Ok, anyone who agrees? Anyone who disagrees? *There was no response from learners* Rose: Are the intermolecular forces the same as intramolecular forces? SM1: No Rose: Why? *There was no response from learners* Adjusted May 20 Rose: Intramolecular forces are not the same as the intermolecular forces as some may think, (LP) although they are both forces when we talk about chemical substances. When we talk of intra and inter guys (she wrote 'intra' and 'inter' on the chalk board), for intramolecular forces, we look at the forces between the	<u>Comment</u>: This segment was initially meant to discuss the boiling point of propane in comparison to that of propanol but because of the mix of learners' correct and incorrect responses to the question asked, the attention was directed to explaining the difference and similarity between intermolecular forces and intramolecular forces. <u>In-depth Qualitative Analysis</u> Rose's role: Rose probed learners' prior knowledge of which one between propane and propanol would have a high boiling point Learners' role: Learners' responses showed inability to clearly differentiate intermolecular forces from intramolecular forces (LP). Rose's role: Taking the learners' inability to explain the difference between intermolecular forces and intramolecular forces into consideration, Rose first indicated to the learners that, both forces are associated with chemical substances. This shows her understanding of the similarity between them. She further differentiated the two molecular forces by emphasising 'forces within a molecule for intramolecular forces' and 'forces between molecules' for intermolecular with reference made the ionic equation of sodium chloride write on the board. This suggests Rose's understanding of conceptual teaching strategy (CT) and use of a symbolic representation (RP). Rose's interactive use of TSPCK components (LP-CT/RP) at a proficient level of TSPCK episode in connection to the learners' correct and incorrect responses is given by the TSPCK map below.

atoms found inside a single molecule, please note here we refer to forces within a molecule (CT) for example *(She the put the ionic equation of NaCl on the board)*, within NaCl, we've got ionic bond bringing Na^+ and Cl^- together, (RP) but the intermolecular forces, exist between molecules, it's the force between molecules in this case, yeah you note that we're talking about forces between molecules here unlike there (*she pointed at representation of NaCl*) where we refer to forces within a molecule, so now just like the interaction between positively charged part of a molecule with negatively charged part of a neighbouring molecule, (CT) we call this example dipole-pole interactions, you can remember that from Grade 11 right? Rose: Intramolecular forces are not the same as the intermolecular forces as some may think, (LP) although they are both forces when we talk about chemical substances. When we talk of intra and inter guys (she wrote 'intra' and 'inter' on the chalk board), for intramolecular forces, we look at the forces between the atoms found inside a single molecule, please note here we refer to forces within a molecule for example *(She the put the ionic equation of NaCl on the board)*, within NaCl, we've got ionic bond bringing Na^+ and Cl^- together, (RP) but the intermolecular forces, exist between molecules, it's the force between molecules in this case, just like the interaction between positively charged part of a molecule with negatively charged part of a neighbouring molecule, (CT) we call this example dipole-pole interactions, you can remember that from Grade 11 right?	
35-37min: Relating Intermolecular forces to physical properties Rose: So, we are focussing on intermolecular forces as they determine physical properties like the boiling point and melting point of substances, they also help us to know if one substance will dissolve in another substance. Can you name the intermolecular forces that you know? SF1: dipole-dipole interactions Rose: Yes SF2: London dispersion SM1: van der Waal's forces Rose: Good, any other one? SM5: hydrogen bonds Rose: Good, I'm glad you guys could mention all that, but the main idea is that, the type of intermolecular forces between molecules can affect the boiling point, I mean it can either lower or raise the boiling point, you would remember in your Grade 10 you were taught the kinetic theory, am I right? Ss: yes Rose: So you must have learnt in kinetic theory that, the phase of a substance depends on how strong the intermolecular forces are right, so the greater the	Comment: This segment focused on relating intermolecular forces to the physical properties (boiling point and melting point) of organic molecules. In-depth Qualitative Analysis Rose's role: Rose asked learners to name intermolecular forces they knew thereby demonstrating the importance of first establishing the learner prior knowledge (LP). Learners' role: Learners' responses showed good understanding as they correctly mentioned some kinds of intermolecular forces. Rose's role: Rose expatiated on the learners' correct responses by pointing out that, the type of intermolecular forces and its strength can affect physical properties of compounds by either lowering or raising the boiling point for instance. She explained this in relation to the learners' prior knowledge of kinetic theory (LP) thereby demonstrating an understanding of curricular saliency (CS), what should be emphasized. She also indicated the area of learning difficulty relating to the inability to know which type of intermolecular forces and their strength in correctly explaining physical properties and structures of

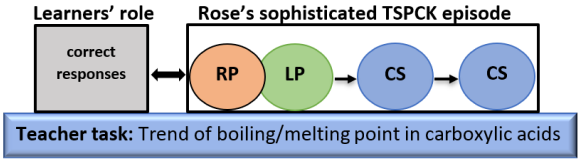
intermolecular forces, the higher the boiling points for example an ionic bond is known to be stronger than hydrogen bonding which is stronger than dipole-dipole interactions, so failure to keep that in mind may lead to difficulty in correctly explaining how physical properties of an organic compound relates to the structures of the compound because without knowing which intermolecular forces, what is the strength eish it's gonna be difficult so please take note of the what type of intermolecular forces and their strength, is that ok everyone? Ss: yes	organic compounds thereby demonstrating the understanding of what is difficult to understand (WD). The proficient interwoven use of TSPCK components (LP-CS/WD) mediated by learners' correct responses is given by the TSPCK map below. 
<u>37-40min Boiling point of alkane compared to alcohol</u> Rose: Let's go back to our discussions someone said that propanol is gonna have high boiling point compare to propane, (She pointed to the learner SM6) you said, propanol has got weak intermolecular forces, so it's gonna have high melting point and boiling point than propane right? SM5: yes Rose: Do you have a reason for saying that? SM5: (no response) *There was no response from learners* Rose: Now, one thing you must always consider is, what is the type of intermolecular forces are we talking about here and then, what is the strength of that intermolecular forces, that's important as I earlier said. So now, looking at let's look at propane, it's an alkane, alkanes are non-polar, they have got van der Waals dispersion forces right now in here (She pointed at the structure of propanol), we have got an hydroxyl group which means alcohols have got hydrogen bond but you see, by nature hydrogen bonds are weak intermolecular forces but as weak as they are, they are stronger than van der waal's forces, ok. So, now guys, which one is gonna have a high boiling point and melting point, you must give a reason for your answer, yes anyone? SF1: propanol Rose: why? SF1: it has got hydrogen bond which is stronger than van der waal's force in propane Rose: Good, so why would that make the boiling point and melting point to be higher? Yes, someone should help. SM1: There's more energy required to break a strong bond, so more energy will be needed in the case of propanol, it's boiling point will increase because of that.	<u>Comment</u>: This segment focused on comparing the boiling point of alkanes to that of alcohols. <u>In-depth Qualitative Analysis</u> Rose's role: Rose first confirmed with learner SM5 about his response that propanol has got weak intermolecular forces compared to propane. Learners' role: Learner SM5 propanol as having weak intermolecular forces compared to pentane with no further reason or explanation. Rose's role: As an important aspect for learners to know, Rose re-emphasized the importance of identifying the type and strength of intermolecular forces in determining which organic compound has got a higher boiling point and melting point thereby demonstrating the knowledge of curricular saliency (CS). In explanation this, she referred to the structure of propane and propanol thereby demonstrating her understanding of the use of symbolic representation (RP). The proficient interwoven use of TSPCK components mediated by learners' correct responses is given by the TSPCK map below. Learners' role: There was the evidence of learners' understanding as they correctly stated why propanol would have a high boiling point and melting point as Rose explained. The proficient interwoven use of TSPCK components (LP-CS/RP) mediated by learners' correct responses and suggesting evidence of learners' understanding is given by the TSPCK map below. 
2nd Lesson	
<u>0-8min: Describing water as a polar solvent</u> Rose: Now let's look at propane and propanol which one do you think is gonna be soluble in water between propane and propanol? SF8: propane Rose: You have a reason for that? SF9: propane has got weaker intermolecular forces	<u>Comment</u>: This segment focused on understanding water as a polar solvent where learners were questioned and explanations provided. <u>In-depth Qualitative Analysis</u> Rose's role: Rose probed learners' prior knowledge about which of propane and propanol would be soluble in water.

Rose: Ok, but how could that have influenced its solubility? *There was no response from learners* Rose: Do you guys know this (she pointed at the structure of water)? Ss: yes Rose: What is it? Ss: water Rose: So do you guys know about polar, non-polar, polar, non-polar Ss: (they laughed) SF2: eish, I can't remember Rose: but you can still remember in solubility like dissolves like Ss: yes Rose: Let me remind you of polar substances, let's take for instance water, it's a polar substance because it consists of a slight negative charge and a slight positive charge as you can see here (Figure x below), so these are different dipoles right however, they don't cancel out as a result, when we try dissolve polar substances in water, they will dissolve easily because water itself is a polar substance but a non-polar substance like oil we not dissolve in water, like dissolves like you remember right, we all get that? Ss: yes	Learners' role: Learner SM8 referred to propane with the reason that, propane has weaker intermolecular forces than propanol. Rose's role: Rose further probed learner knowledge and realized they could not explain how weak intermolecular forces influences solubility and hence, the need to explain water as a solvent polar (CS), an aspect considered important, thereby demonstrating her understanding of curricular saliency. She used the structure of water drawing on the board (RP) to explain the slight negative and positive charges which do not cancel out thereby make water a polar substance. The proficient interwoven use of TSPCK components (LP-CS/RP) mediated by learners' inability to describe the polarity of water and propane is given by the TSPCK map below. 
8-12min: Solubility of propane compared to propanol Rose: Now, let's go back to our discussions on whether propanol would be more soluble than propane in water. So now (she pointed at the OH in propanol) hydroxyl group in propanol makes it a polar molecule, since water is also a polar solvent as I have explained, then propanol will dissolve in water, remember the solubility rule of like dissolves like in Grade 11, so we expect a polar substance to dissolve in a polar solvent, but as we can see here, propane doesn't have any hydroxyl group, it has got weak van der Waal's forces so it cannot break through the strong hydrogen bond present in water so it is non-polar molecule, so it cannot dissolve in water. SM2: So, can we say that alkanes are insoluble in water? Rose: Let someone help us. SF4: From what ma'am just explained, water is polar, its molecules are attracted to each other by hydrogen bond so alkanes are non-polar, they cannot dissolve in water. Rose: That was a brilliant explanation, it applies to all members of alkane, do you get that now? SM2: yes	Comment: This segment focused on comparing the solubility of propane and propanol in water. In-depth Qualitative Analysis Rose's role: Using the structure of propanol, Rose referred to hydroxyl group in propanol as making it polar and soluble in water. She also reminded learners of the soluble rule of like dissolves like that they already learnt in Grade 11 thereby showing awareness of learner prior knowledge (LP). With reference to the structure of propane, she explained propane has got van der Waal's forces considered weaker than the hydrogen bond in water thereby preventing it from being soluble in water. Her explanation on what makes propanol soluble and propane insoluble in water suggests Rose's understanding of curricular saliency, an important aspect that learners needed to know (CS). Learners' role: The evidence of learners' understanding seems to emerge as learner SM2 asked if all alkanes are insoluble in water Lerner SF4 explained strong hydrogen bond brings the water molecules together thereby preventing alkanes to slip in. The proficient interwoven use of TSPCK components (RP/CS/LP) with emergence of evidence of learners' understanding is given by the TSPCK map below.

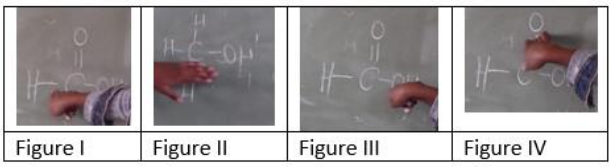
	
12-18min: Boiling/melting point of branched vs straight chain alkanes Rose: So, let's go to the next one guys. Let's quickly look at branched chains in alkanes and how it affects the melting point and boiling point, ok. So let's say (she drew the structure of 2methylbutane on the board) is our alkane, we have another one here (she drew and pointed to the structure of pentane), can you please guys, name the first compound there? Yes. SM6: 2-methyl (inaudible) Rose: 2-methyl what? SM6: 2-methylbutane Rose: You're smart, this other one? SM11: pentane Rose: So, we've got the two compounds, both having single carbon to carbon covalent bonds and that tells us they are both saturated hydrocarbons right? Ss:….(yes)…. Rose: You would also remember that 2methyl butane here is an isomer of pentane, by isomerism you think about compounds of the same molecular formula but having different structures, right? Ss: …..(yes)…. Rose: So now which of these two (she pointed at the structures of 2methylbutane and pentane on the board) is going to have high melting point and boiling point? SF4: pentane is gonna have higher melting and boiling point than 2-methylbutane Rose: yes, why? SF4: because pentane has got larger surface area Rose: Yes, pentane has got a longer straight chain length of five carbons and therefore, it has a wider surface area compared to 2-methylbutane (She pointed at its structure) which has got four carbons forming a straight chain length, you've got to understand here that, the branching of the chain makes the molecule more compact and that decreases the surface area, you see the intermolecular force in branched chain is also weaker compared to the straight chain therefore, more energy would be required to break bonds in pentane than in 2-methylbutane, hence, pentane is higher in boiling point and melting point, is that right? SF2: Ma'am does it apply to other members of alkanes and their isomers as well? Rose: Can somebody help us answer the question? SM2: I think it applies to them all since they've got same functional group, single covalent carbon bonds. Rose: Exactly! Very good, especially when you referred to the functional group. Any other question? Ss: (silence).	Comment: This segment focused on comparing the boiling and melting point of branched-chain alkanes to that of straight-chain alkanes. In-depth Qualitative Analysis Rose's role: Using the structures drawn, Rose probed learner prior knowledge about the IUPAC name for 2methylbutane and pentane. Learners' role: Learners named correctly showed their good knowledge of IUPAC naming system. Rose's role: Rose further asked learners which of pentane and 2methylbutane would have higher melting and boiling point. Learners' role: Learner SF4 referred to pentane pointing out its larger surface area. Rose's role: Rose expatiated on the SF4's correct response by describing how compact arrangement atoms in a branched alkane decreases the surface area thereby weakening the intermolecular forces leading to low melting and boiling point. This suggests Rose's understanding of what was considered important for learners to know, an aspect of curricular saliency (CS). The proficient interwoven use of TSPCK components mediated by learners' correct responses and suggesting evidence of learners' understanding is given by the TSPCK map below. (RP/LP-CS) 
18-20min: Identifying functional group of carboxylic	Comment: This segment focused on identifying the

acids Rose: Let's say we have got (Rose drew the structure of methanoic acid on the board), we've got this compound, what is its functional group? *There was no response* Rose: Does it look like an acid at all? Think SF5: Yes SM7: Carboxylic acid Rose: So what's the functional group? SM7: COOH Rose: Yes, it's COOH (she pointed at the structure of methanoic acid on the board), remember this functional group primarily consists of a carbonyl group, C=O (she pointed at the structure) and hydroxyl group for identifying alcohols right, so those are main aspects that you must remember when it comes to carboxylic functional group, any question before we move on? *There was no response from learners.*	carboxylic acid functional group as a foundation for discussing the trend of boiling point and melting point in carboxylic acid homologous series. In-depth Qualitative Analysis Rose's role: Rose used the structure of methanoic acid drawn on the board (RP) to probe learners' ability to identify carboxylic acid functional group (LP). Learners' role: Learner SM7 showed good prior understanding as he correctly referred to the carboxylic acid functional group as COOH. Rose's role: Rose expatiated on the SM7's correct response by specifically identifying the carbonyl and hydroxyl group as the main aspects important for learners to know thereby demonstrating an understanding of curricular saliency (CS). The Rose's interactive use of TSPCK components (RP/LP-CS) at a proficient level of TSPCK episode mediated by learners' correct responses is given by the TSPCK map below. 
20-24min: Boiling/melting point trend in carboxylic acids Rose: Now let's examine carboxylic acids with more carbon atoms (she drew the structure of butanoic acid on one side and the other side, she put the structure of pentanoic acid), looking at butanoic and pentanoic acid here, which one is gonna have high boiling point and high melting point? SM8: pentanoic acid Rose: Why pentanoic acid? *There was no response from SM8* Rose: Yes, anyone who wants to assist him? SF3: pentanoic acid has got a longer chain length, so it's gonna have the higher melting point and boiling point. Rose: Yes boiling point increases as the chain length increases across the carboxylic acid homologous series because compounds get bigger, the molecules become more thereby increasing the molecular mass, this increases the boiling point but here is what we need to be careful about, it's a different story when it comes to trend of melting point in the carboxylic acid homologous series, with melting point, it doesn't vary so smoothly as the chain length increases, here is the first six carboxylic acids (she drew a table consisting of six carboxylic acids, their melting points and boiling points), can those of you over there (she pointed at those occupying back seats) see this? Ss: yes Rose: Here we can see that from methanoic acid to ethanoic acid melting point increases but to propanoic acid it decreases and then it increases with butanoic acid and then decreases with pentanoic acid now the point is,	Comment: This segment focused describing the trend of boiling points in the carboxylic acid homologous series. In-depth Qualitative Analysis Rose's role: Using the structures of pentanoic acid and butanoic drawn, Rose asked learners which of the two organic compounds would have a higher boiling point and melting thereby showing understanding of the use of symbolic representations (RP) in investigating learner prior knowledge (LP). Learners' role: Learner SM8 showed good prior knowledge as he correctly referred to pentanoic acid with the reason that, it has got a longer carbon chain length. Rose's role: Rose expatiated on SM8's correct response by pointing out two different but related key aspects. First, she explained how increase in the number of carbon atoms across the carboxylic acid homologous series causes increase in the molecular mass and hence, the boiling point. Second, she referred to the location of COOH on carboxylic acids to differentiate the trend in boiling points from melting points. The Rose's interactive use of TSPCK components (RP/LP-CS-CS) at a sophisticated level of TSPCK episode mediated by learners' responses is given by the TSPCK map below.

those carboxylic acids which have got even numbers of carbons, I mean 2, 4, 6 so on like ethanoic acid, butanoic acid, hexanoic acid, they've all got the COOH on the opposite side to this CH_3CH_3 terminal group so that makes the molecules to be more closely packed leading to their higher melting points than those odd numbers of carbon atoms, can you see that?
Ss…(yes)…..
Rose: Yeah, that's unlike methanoic acid, propanoic acid, pentanoic acid, their COOH is on the same side as the R-group so we must be very careful and understand how it works whenever we think of the trend of boiling point and trend of melting point in a particular homologous series, so we're saying that the decrease in the melting point is because some are closely packed crystals, the poorly packed crystals have less dipole-dipole interactions, and therefore lower crystal binding energies, that means they require less energy to melt and so, they have a lower melting point, that sounds difficult right?
Ss: yes
Rose: Any question before we move on?
There was no response from learners



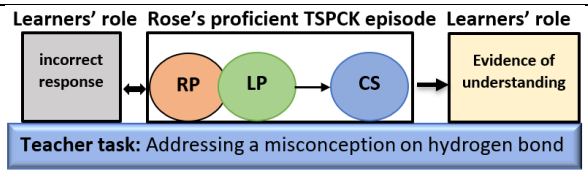
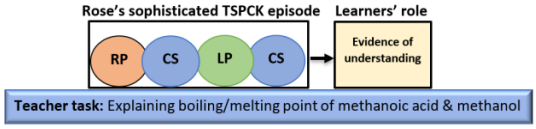
<u>24-27min: Addressing number of hydrogen bonds in methanoic acid</u>
Rose: Now let's move on, let's say (*Rose drew the structure of methanol on the board*), here is our methanol, now between methanol and methanoic acid (*Rose pointed at the structure of methanoic acid*), which one is gonna have high boiling point and melting point?
SF5: methanoic acid
SM2: methanoic acid
Rose: Oh, yeah but why?
SF5: it has got two hydrogen bonds compared to methanol
Rose: Two hydrogen bonds? Where is the other hydrogen bond?
SF5: between carbon and hydrogen
Rose: Between carbon and hydrogen, which one? Is it this one (see Figure I below)?
SF5: No ma'am between oxygen and hydrogen
Rose: yes (see Figure II below)

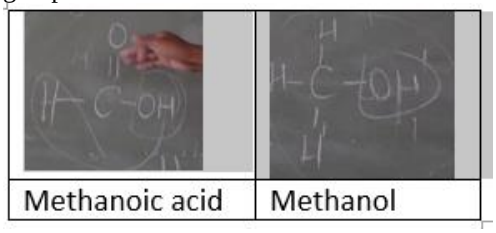
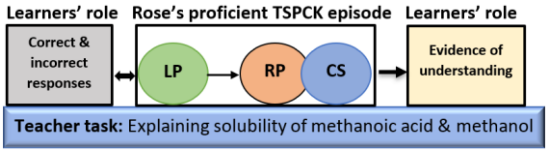

Figure I | Figure II | Figure III | Figure IV

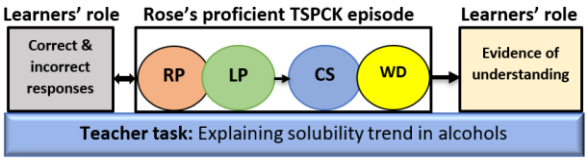
Rose: oh yes, I get where you are coming from. Ok, guys he's right, methanoic acid gonna have high boiling point than methanol but ok wait let me first clarify this (*she pointed at the double in carbonyl group*) there is no hydrogen bond as he thought, we have just got carbonyl group, but here (*she pointed at the single covalent bond between carbon and hydrogen*), we have got this (she put C-H on the board), it's a covalent bond between carbon and hydrogen however, here (she pointed at the C-OH),

<u>Comment</u>: This teaching segment focused on clarifying to the learners the number of hydrogen bonds present in a molecule of methanoic acid due to wrong assumption from a learner.
<u>In-depth Qualitative Analysis</u>:
Rose's role: Using the structures drawn (RP), Rose probed learner prior knowledge by asking them which of methanol and methanoic acid would have higher boiling/melting point (LP).
Learners' role: Learner SF5 and SM2 correctly pointed at methanoic but SF5's response revealed her misconception that, there are two hydrogen bonds in methanoic acid.
Rose's role: In addressing SF5's misconception, Rose explained using the structure (RP) what it means to have a hydrogen bond as an important aspect for learners to understand (CS) by indicating the occurrence of hydrogen bond whenever hydrogen atom is directly bonded to an oxygen atom.
Learners' role: The evidence of understanding emerged as SF5 paraphrased the explanation given by Rose.

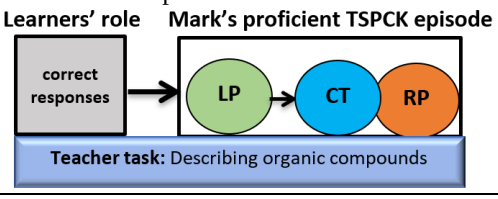
The Rose's interactive use of TSPCK components (RP/LP-CS) at a proficient level with evidence of learners' understanding is given by the TSPCK map below.
RP/LP-CS

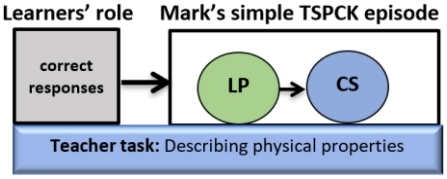
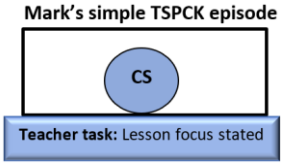
we have got carbon single bonded to hydroxyl functional group, this is where we have only one hydrogen bond, so you must be very careful, you don't take the single covalent bond between carbon and hydrogen as the hydrogen bond, hydrogen bond only exists because of the OH group here because here hydrogen atom is directly bonded to an oxygen atom, is that understood? SF5: Ma'am you're saying because hydrogen is bonded to oxygen directly that's the reason for the hydrogen bond in OH group right? Rose: Exactly! We all understand right? Ss:….(Learners echoed 'yes')	
27-31min: Boiling/melting point of methanoic acid and methanol compared Rose: So now in here (*She pointed at the structure of methanol*) (RP), we've got one hydrogen bond, but take note guys, it's as a result of our hydroxyl group right, that's our functional group for identifying members of alcohol homologous series (CS) so no one should tell us that, ma'am carboxylic acids are weak acids, they dissociate and then we have H^+, it's hydrogen bond that we have here, consisting of one hydrogen bonded to oxygen, right it does not refer to hydrogen ion, no guys, (LP) that's an hydrogen ion, it's a different story so now as our methanoic acid, it's gonna have higher boiling point than methanol the reason being that, in the case of carboxylic acids, hydrogen bonding can occur between two molecules in the case of carboxylic acids alright, so when that happens, it forms a dimer, that's like similar molecules linked together, so it's the presence of dimers that normally increases the strength of the dispersion forces in carboxylic acids, that raises their boiling point making (CS) it to be higher than that of alcohols, hope my explanation is clear to someone? Ss:…..(Learners echoed 'yes') SF2: Please, can you come again? Rose: I need someone to repeat what I have just said if you've really understood my explanation? Yes, who's gonna help? SF3: She said the occurrence of hydrogen bonding in the molecules of carboxylic acids can produce dimers and the intermolecular forces will increase, it will then increase the boiling point. Rose: Exactly, the strength of intermolecular forces increases. Does anyone still needs clarification? Ss:……(No response from learners)……	Comment: This teaching segment focused on comparing the boiling/melting point of methanol and methanoic acid. In-depth Qualitative Analysis: Rose's role: Using the structure of methanol (RP). Rose re-emphasized, the presence of only one hydroxyl functional group in the molecule also used to identify all the members of alcohols, as an importance aspect for learners (CS). She then cautioned learners about a misconception that could emerged from the assumption that the H^+ produced by carboxylic acid when dissociate is also a hydrogen bond thereby demonstrating understanding of an aspect of learner prior knowledge (LP). She also explained the formation of dimers by carboxylic acids thereby increasing the strength of their intermolecular which raises their boiling point above that of alcohols as the second important aspect for learners to understand (CS). Learners' role: The evidence of understanding seemed to emerge as learner SF3 correctly paraphrased Rose's explanation as requested by another learner SF2. The Rose's interactive use of TSPCK components (RP/CS/LP/CS) at a sophisticated level with evidence of learners' understanding is given by the TSPCK map below. 
31-34min: Solubility of methanoic acid and methanol compared Rose: Can you guys still remember what we discussed about polar substances? Ss: yes Rose: Yes, what can you remember? SM7: polar substances dissolve in water because water is polar Rose: Brilliant, yes?	Comment: This teaching segment focused on comparing solubility of methanoic acid to that of methanol. In-depth Qualitative Analysis: Rose's role: Rose asked learners what they could remember about polar substances earlier discussed. Learners' role: Learner SM7 and SM8's responses showed good understanding of the solubility rule, like dissolves like and what makes water a polar substance.

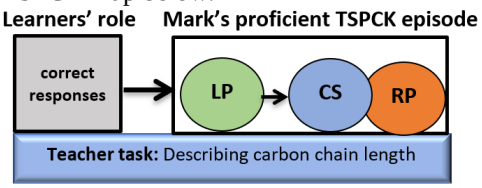
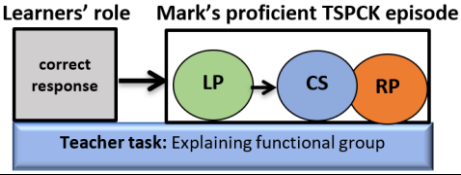
SM8: water is a polar substance with negative and positive charges Rose: So let's look at these (she referred to the structures of methanol and methanoic acid on the board), these are two organic molecules, what do you think is common to them? SF3: hydroxyl group Rose: So, which one do you think would be more soluble in water? Yes, anyone? SF4: they are gonna be soluble since they both have OH Rose: Any other opinion? (Learners kept quiet, no response) Rose: Ok guys, if you look at this (*she points to the structure of methanoic acid*), there are two extreme polar ends, here (she points to the OH end) and it also have this (she points to the C=O bond), remember O is very electronegative, you remember that right and so, it can form hydrogen bonds neh. I am simply saying that methanoic acid, just because of these two polar ends, it can form more extensive hydrogen bonds when mixed with water, in other words, it is more soluble than methanol which has got only one polar end, the hydroxyl group here.  SM6: So, methanoic acid is gonna be more soluble because of more polar ends than methanol. Rose: Exactly. Is that understood now? Ss: yes	Rose: Using the structures of methanoic acid and methanol drawn on the board, Rose asked learners what is common to the two organic molecules. Learners' role: Learner SF3 showed a good ability to identify hydroxyl functional group in methanol and methanoic acid. Rose's role: Rose further probed learner knowledge about which of methanoic acid and methanol would be more soluble in water. Learners' role: Learner SF4 could not answer Rose's question correctly as his response means the two organic molecules would be soluble in water to the same extent. Rose's role: Using the structures on the board, Rose showed learners the two extreme polar ends in methanoic acid making it more soluble in water than methanol with only one polar end. This suggests Rose's understanding of the interactive use of symbolic representations and curricular saliency (emphasis on what is important for learners to know). Learners' role: The learner SM6's comment showed his concentration in the lesson and a level of understanding of the explanations provided by Rose. The Rose's understanding of the interactive use of learner prior knowledge, symbolic representation and curricular saliency mediated by learners mixed responses and leading to evidence of a learner's understanding is given by the TSPCK map below. 
34-40min: Solubility trend in Alcohols Rose: Now, if we take propanol (she drew the structure of propanol on the board), and then we look at butanol (she drew the structure of butanol on the board), what's common to them? SM9: hydroxyl group Rose: That makes them what? SM10: Alcohols Rose: Good, so they both have the hydroxyl functional group group and so they belong to the alcohol homologous series, it's only that they have got different number carbon atoms so now which one is gonna have high solubility in water between the two? SM1: butanol Rose: Why butanol? SM1: It's got longer carbon chain Rose: Any other opinion? *There was no response* Rose: Thank you but that was wrong, in alcohols this is how it works, it is the opposite, here is what you need to know when it comes to solubility, it is like the longer the	Comment: This teaching segment focused on the solubility trend in alcohols with Rose actively engaging learners in questioning and dialogue. In-depth Qualitative Analysis: Rose's role: Using the structures of propanol and butanol, Rose asked learners to identify the common features to the two organic molecules with the purpose of establishing whether they could recognize the hydroxyl functional group. Learners' role: Learner SM9 and SM10 correctly mentioned hydroxyl functional group and referred to the two organic molecules as alcohols. Rose's role: Rose expatiated on the learners' response by relating the difference between the molecules as the number of carbon atoms and further probing learner knowledge about which of the two molecules is more soluble. Learners' role: Learner SM1 wrongly referred to butanol as more soluble in water due to its longer carbon chain than propanol. Rose's role: Rose corrected SM1's misunderstanding

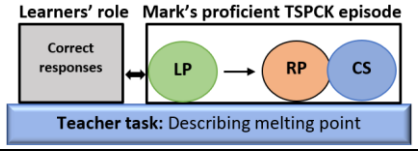
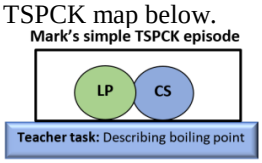
chain, the longer it takes alcohols to be soluble in water because more energy would be required to overcome hydrogen bonds so solubility decreases as the chain length increases unlike in the case of boiling point where with an increase in carbon chain, more energy is required to break the bond and therefore leading to high temperature, you must not get confused here, solubility is different from boiling and melting point, is that clear? Ss: yes Rose: Hope that's understood, any question? There was no response from learners Rose: So now, between hexanol and heptanol, which one is gonna be more soluble in water and why? SF4: It's hexanol because it has got lower number of carbon atoms and less energy would be required to overcome hydrogen bond in that case. Rose: Excellent! So, between hexanol and hexanoic acid, which one is gonna be more soluble in water? There was no response. Rose: Remember what we said about the solubility of carboxylic acids, yes? SF5: I think hexanoic acid is gonna be more soluble because it's got more polar ends than hexanol. Rose: Very good, carboxylic acids are more soluble than alcohols because they have got two oxygen atoms in addition to hydrogen in their molecules, that makes them more polar than alcohols. Any question on that? *There was no response from learners*	by indicating how longer carbon chain requires more energy to overcome hydrogen bonds thereby decreasing solubility (CS). As a gate-keeping concept, she also referred to boiling point where more energy is required to break the hydrogen bond as the chain increases thereby increasing the boiling point. She warned learners to let get confused at these two concepts of solubility and boiling point thereby her understanding of what is difficult to understand (WD). Learners' role: The evidence of learners' understanding seemed to emerge as SF4 learners correctly explained why hexanol would be more soluble in water than heptanol. Learner SF5 also distinguishes between the polarity and hence, solubility of hexanol and hexanoic acid correctly. The Rose's interactive use of knowledge components at a sophisticated level mediated by learners' correct and incorrect responses and leading to evidence of learners' understanding is given by the TSPCK map below. RP/LP-CS/WD 

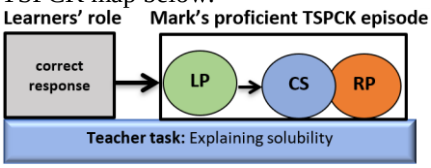
Appendix XXX: Detailed analysis of Mark's lesson

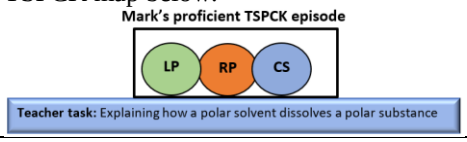
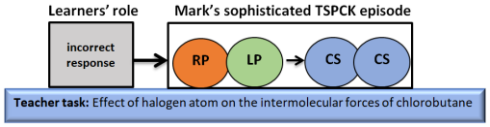
Teaching events in sequence	Comments/Qualitative in-depth analysis
LESSON 1	
0-3 minutes: Introduction (Organic chemistry) T: Organic chemistry, any idea? When we say organic chemistry, what are we talking about? Are we saying chemistry of organisms? Chemistry of life? SF1: chemistry of carbon compounds T: Yes, chemistry of carbon compounds. And? SF2: It's the study of organic compounds T: Thanks, any other opinion? Ss: (silence) T: Yeah, In chemistry, we talk about organic chemistry, it's the study of organic compounds where we've got carbon forming bonds with hydrogen as he rightly said (LP). Here we study structures and reactions of organic compound formed by carbon, hydrogen and other elements, for example here is methanol (*He drew the molecular structure of methanol on the chalkboard*), it's got carbon bonded to hydrogen and oxygen, here is propane (*He drew the molecular structure of propane on the chalkboard*) (RP), it's got carbon bonded to carbon and bonded to another carbon and hydrogens are all over but there are other compounds of carbon like calcium carbonate, yeah $CaCO_3$, it's a carbon compound but it's not an organic compound, because we can't see carbon bonded to hydrogen, it's an inorganic compound (CT) just to comment on what the first learner said, you could remember right? Ss: yes	Comment: This section introduced the lesson by describing organic compounds and differentiated them from inorganic compounds. Mark's role: In an attempt to investigate learners' prior knowledge, mark asked learners to describe organic chemistry. Learners' role: Learners correctly described organic chemistry as the chemistry of carbon compounds and the study of organic compounds, the understanding Mark expected to have in place (LP). Mark's role: Mark acknowledged learners correct responses as revealed in the description of organic chemistry as the chemistry of carbon. He called learners' attention to limiting the description of organic compounds to carbon containing carbon as some inorganic compounds also contain carbon as in their molecules. He explained by placing methanol (organic molecules) side by side with calcium carbonate in order to make learners understand the difference and similarity between the compounds. Such method describes Mark's knowledge of conceptual teaching strategy (CT) relating to variation theory in teaching science. His use of structures and chemical formula of molecules also reflect his knowledge of symbolic representations (RP). Mark's interactive use of TSPCK components (LP-CT/RP) at a proficient level in connection to the learners' correct responses is given by the TSPCK map below. 
3-5minutes: physical properties discussed T: So, today we are talking about physical properties. When we say, something is physical, what do we mean? Like in chemistry, this is one of the basic concepts right, but to start with, what does it mean when we say something is physical? SM1: we can see it T: It's physical, we can see it and what else? SM2: we can touch it T: We can touch, it is physical. So, if we can see it and touch it like the chemical we have in the lab, scientific way of understanding them, observing and touching, (LP) then how do you define physical properties? Anyone? Ss: (Silence)	Comment: This section is part of the segments introducing the lesson where the discussion focused on explaining what physical properties mean. Mark's role: Mark asked learners to explain what physical means in relation to substances. Learners' role: Learners referred to the physical things as visible and touchable, part of the prior understanding he expected them to have in pace (LP). Mark's role: Mark related physical properties to the learners' descriptions of what anything physical means. He emphasized how physical

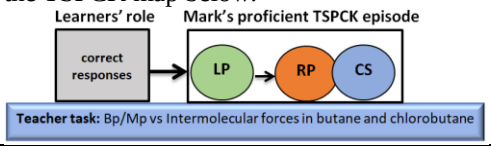
T: Ok, physical properties, those are properties we can observe without changing their identity or composition, they are tightly connected to understanding nature of chemical substances like organic molecules (CS). Like when I look at you physically, I cannot change your composition, you are still gonna be what you are to me physically, you understand that? Ss: yes T: And then another we got, we call them chemical properties, these have to deal with the internal part of a compound right. Now this one can only be observed during a chemical reaction. Now, we are talking about a physical property, the physical identities of compounds. T: So, what are physical properties? SM1: temperature T: Can you describe temperature? SM1: (silence) Ss: (silence) SM2: yes T: Ok, let's look at it this way neh temperature is related to energy. Any physical property that you can look at, from this class? Ss: silence T: Like colour, if you paint a house, is it gonna change from the form to a new form? SM1: yes	properties are connected to describing the nature of organic molecules, the understanding considered important for learners to know (CS). Mark's interactive use of TSPCK components (LP-CS) at a simple level connected to learners' correct responses is given by the TSPCK map below. 
5-6minutes: Focus of Lesson resstated CS T: that's a physical property right. So today we goona look at these three physical properties, the melting point, the boiling point and the solubility, our focus is going to be on the three, these are basic concepts in chemistry, all concepts build on them, so they are very important, (CS) right. We've also got to discuss chain length in organic molecules, functional groups and intermolecular forces, let's quickly go over them.	Comment: During this segment, Mark indicated the focus of the lesson to the learners including boiling point, melting point and intermolecular forces as they affect organic molecules. He specifically called the learners' attention to three as fundamental and linked to other concepts in chemistry. This reflects Mark's knowledge of what is important, an element of curricular saliency (CS). There was no TSPCK episode observed during this segment. 
6-10minutes: carbon chain length T: We do normally refer to chain length in organic molecules, guys from your previous lessons, what do you think we mean by that? Yes, who is gonna help us? So, guys, what do you think we mean? SM1: Carbon chain length T: Carbon chain length SM2: the number of carbon atoms that join together T: Yes, we normally refer to the carbon chain length in terms of the number of carbon atoms which covalently bond to one another and to the atoms of hydrogen, you know those are the principal atoms in organic molecules (LP). Let's say for	Comment: This section focused on describing the term carbon chain length in organic molecules. Mark's role: Mark asked learners what chain length means in organic chemistry, in an attempt to investigate their prior knowledge. Learners' role: Two learners correctly referred to chain length as describing the number of carbon atoms, the prior knowledge Mark expected them to have in place (LP). Mark's role: Mark expatiated on the learners' responses by emphasizing that carbon atoms

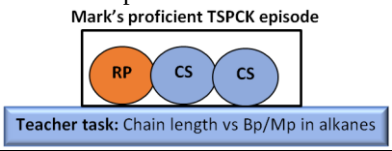
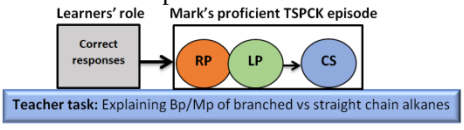
example (*He drew the structure of propane on the board*) (RP), this is propane, by chain length, I mean three carbons are covalently bonded in straight chain to hydrogen atoms, they don't just join but they are covalently bonded right (CS) we can as well have branched chain length (*He drew the structure of 2-methly propane*), yeah our methyl is the substituent. Do you understand that? Ss: yes	are covalently bonded rather than just referring to them joined together, an important aspect Mark wanted learners to take note of (CS). He also used the structures of propane and 2-methyl propane to describe straight chain and branched chain. This describes Mark's knowledge of the use of symbolic representations (RP). Mark's interactive use of TSPCK components (LP-CS/RP) at a proficient level connected to learners' correct responses is shown by the TSPCK map below. 
10-15minutes Functional group LP-CS/RP T: Yeah, what can you say about functional groups in organic chemistry? Ss: (murmuring, responses not heard) T: What are you saying guys? SF2: We use functional groups to know the name of organic compounds T: Yeah, any other opinion? Any addition? Any subtraction? Ss: (laugh!!) T: She got it, in the IUPAC naming of organic compounds, we consider functional groups right (LP). Now, functional groups are the groups of atoms that are peculiar to individual groups of organic compounds which we call the homologous series, we first identify the functional group in a molecule in order to know in which homologous series it belongs so we can name it accordingly (CS), for instance when we see single covalent bonds between one, or two or more carbon atoms bonded to hydrogen atoms, (*She drew the structure of butane on the board*) (RP), then we know, it belongs to the alkanes homologous series, so functional groups will be important as we look at the physical properties of organic compounds in their homologous series (CS). Any question on functional groups before we proceed? Ss: (Learners kept silent)	Comment: This section focused on explaining functional group. Mark's role: Mark asked learners to describe functional group in an attempt to investigate their prior knowledge. Learners' role: One learner indicated that functional groups are for naming organic compounds, part of the prior understanding that Mark expected learners to have in place (LP). Mark's role: Mark expatiated on the learner's correct response by referring to the functional groups as peculiar to identifying homologous series, and the fact that physical properties of members in a particular homologous series are connected to their functional group, an important aspect that Mark wanted learners to understand (CS). He supported his explanation with the structure of butane drawn on the chalkboard (RP). Mark's interactive use of TSPCK components (LP-CS/RP) at a sophisticated level in connection to a learner's correct response is given by the TSPCK map below. 
15-18minutes: Melting point Mark: Alright, now let's look at the melting point as one of the physical property, so now what do we mean by melting point, what happens when melting of a compound takes place? SM3: Melting happens when a solid substance changes into a liquid substance, there is a phase change. Mark: That was a nice contribution. What can you say about melting point?	Comment: The discussion centred on describing melting and melting point. Mark's role: Before providing an explanation, Mark asked learners about melting point as a physical property and what happens when a compound melts. Learners' role: Learner SM3 correctly described melting as a phase change from solid to liquid however, he did not talk about melting

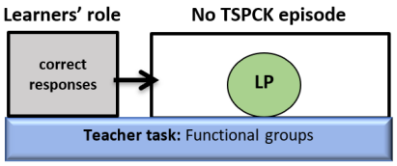
SM4: melting happens at the melting point Mark: Yeah, when something changes from solid to liquid it melts (LP) just like when you put ice in here (*He faced the chalk board and drew a cup containing ice cubes*), that's ice in the cup right, (RP) and then, you go away, the important thing happening here is that, as temperature increases, the particles gain more energy to move, so the ice begins to melt, it eventually turns into water, a liquid form (CS). So, melting is the change of state from solid to liquid, and you notice the phase change occurs because the temperature changes too, so note that it begins at a certain temperature that a substance begins to melt so we say the melting point is the temperature at which a solid changes into a liquid and so, now that you know melting point. Ss: yes	point. Likewise, learner only referred to melting as occurring at the melting point, what melting point means was not coming out clearly (LP). Mark's role: Mark expatiated on the learners' correct responses regarding melting as the phase change. He referred to the structure of a cup of ice drawn on the chalk board to illustrate this. This describes his understanding of the use of symbolic representation (RP). Most importantly, he described melting point as the temperature at which melting takes place. The emphasis Mark put on the "certain temperature" while describing melting point talks to his understanding of what is important for learners to understand, an element of curricular saliency (CS). Mark's interactive use of TSCK components (LP-RP/CS) at a proficient level in connection to the learners' correct responses is given by the TSPCK map below. 
18-20 minutes: Boiling point T: Now, somehow similar to melting point, we can describing boiling point right. we have a liquid becoming a gas, that's a vapour as you must have learnt in Grade 12 while learning about kinetic theory and states of matter (LP), so now we're saying that as the temperature increases so water begins to convert into vapour, so what is important here is that, boiling point is the particular temperature (CS) at which a liquid into changes to gas, so these two, the melting point and boiling point are important in our discussions today ok.	Comment: In relation to the previous discussions, this section focussed on describing the boiling point. Mark's role: Mark described boiling point as the particular temperature at which a liquid becomes vapour, the aspect he emphasized as important for learners, an element of curricular saliency (CS). He also connected this understanding to the kinetic theory which he indicated learners must have learned in the previous grade. This shows the prior knowledge (LP) he expected learners to have in place. Learners' role: None Mark's interactive use of TSPCK components (LP/CS) at a simple level is given by the TSPCK map below. 
20-24 minutes: Solubility T: and then solubility. When something is soluble, what does it mean guys? SM2: it has something to do with something that dissolves in a solvent Mark: Yeah, it's got something to do with a substance	Comment: This section focussed on describing the solubility of substances in a solvent. Mark's role: Mark investigated learners' prior regarding what it means for a substance to be soluble. Learners' role: One learner referred to the

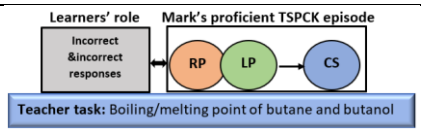
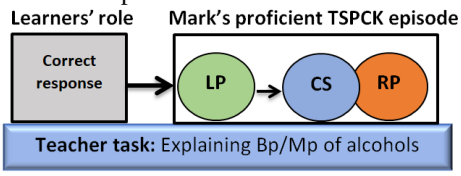
dissolving in another substance right, (LP) so, solubility guys neh, it's the ability of a given substance to dissolve in another substance, it's amount of a given substance which gets to dissolve in a unit volume of another substance, a liquid substance so, it can't just be something, it is the property of a substance to dissolve, it's also the amount of a substance that dissolves (CS) now let's say for instance I've got this cup of a liquid substance (*He drew a cup with particles of substances*) and then I decide to add let's say *(He drew a solid substance)*, so now this (He referred to the solid) substance may be completely or partially soluble in this (He referred to the substance in the cup) (RP) in other words, this substance that dissolves another one, we call it a solvent and the one that is dissolved, we call it a solute, you get that right? Ss: yes T: yeah, in Grade 11 you must have heard of like dissolves like right? Ss: yes T: What's it about it? SF1: It's like water is a polar substance and it dissolves another polar substance T: another polar substance like? (The learners were quiet) Ss: yes T: yeah, in Grade 11 you must have heard of like dissolves like right? Ss: yes T: What's it about it? SF1: It's like water is a polar substance and it dissolves another polar substance T: another polar substance like? (The learners were quiet)	disssolution of a substance which was part of the prior knowledge Mark expected learners to have in place (LP). Mark's role: Mark first confirmed the learner's response and then expatiated on the learners' prior knowledge by specifically referring to solubility as the 'property of a substance to dissolve' an important aspect he wanted learners to understand, an element of curricular saliency (CS) rather than 'something' that a learner indicated. To support his explanation, he drew a diagram of a cup containing a solid dissolving in solvent, showing his knowledge of the use of a symbolic representation (RP). Mark's interactive use of TSPCK components (LP-CS/RP) at a proficient level in connection to learner's correct response is shown by the TSPCK map below. 
24-30 minutes: Polar solvent T: Let's briefly talk about this before we move on. You see, there are three basic rules around this 'like dissolves like', we have them as (He wrote the three rules on the board as in the Figure 1 below), these are things you've learned in Grade 11, we must always remember them as we move on guys (LP), yeah. Can you see this from the back? Ss: yes Mark: A polar solvent dissolves a polar compound, why? their molecules merge easily, they've both got similar forces, let's see, an ionic solute (*He wrote the chemical formula and ionic equation of sodium chloride on the board*), (RP) it's has got sodium and chloride ion, remember we add table salt to our food in our homes, what happens? It dissolves easily in water because, there is an attractive between Na^+ and Cl^- right, since water is also polar, it consists of positively charged pole, it has also got the negative pole because oxygen is more electronegative than hydrogen, right? So, Na^+ in the salt crystal gets attracted to the negative end of water, Cl^- gets attracted to the positively end of water, once	Comment: This section focussed on understanding polar substances and their polarity characterized by on Mark's explanations. Mark's role: He stated the solubility rules which he indicated to the learners that they served as a reminder of what they had learned in the previous grade. Such an indication describes Mark's knowledge of what prior understanding learners must have in place, an element of learner prior knowledge (LP). In explaining how a polar solvent dissolves a polar substance, he used the chemical formula of sodium chloride to show how the electrostatic force is overcome by the water molecules. This describes his knowledge of the use of a symbolic representation (RP). He further emphasized how attractive forces

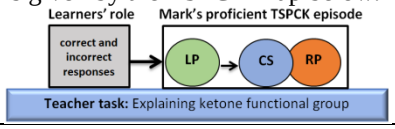
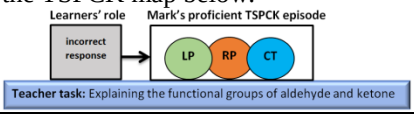
the attraction between water molecules overcome the attractive force between salt ions, then salt dissolves in water, this is the main idea that you must take note of guys, (CS) hope you got the whole idea? Ss: yes T: We will need it like ok. Ss: yes T: That's fine for now guys, we will need that basic idea later in this lesson, ok.	holding molecules of a substance together must be overcome by water for dissolution to take place. Such an emphasis shows what is important for learners to understand, an element of curricular saliency (CS). Learners' role: None Mark's interactive use of TSPCK components (LP/RP/CS) at a proficient level is given by the TSPCK map below. 
30-36 minutes: Butane/Chlorobutane T: So, let's discuss factors that affect the melting point and boiling points of organic compounds. If you can look at the forces holding, you know intermolecular forces? Ss: yes T: Let's just say forces holding the chain right, say you have butane (*he drew the structure on the board*) and then we have chlorobutane (*he drew the structure on the board*) now (RP) when you think about forces holding these ones, which one has got the stronger force here? SM7: chloro-butane would have a high melting and boiling point T: meaning butane has got a weak intermolecular force compared to chloro-butane? SM7: yes T: Why? SM7: let's say the chloro-butane which has got the carbon chain with chlorine. Since we know that, as the carbon chain increases, it requires more energy to break the bond so the chlorine affects the chain. Yeah, the chlorine affects the chain such that the longer the chain, the stronger the bond. T: So, if I replace this Cl with H does it affect the chain? SM7: (No response) SF2: no Mark: We already said chain length is how many carbon atoms form a straight chain right? Ss: Yes Mark: So, here is butane (*He referred to the structure on the board*) with four carbon atoms, here is chlorobutane (*He referred to the structure on the board*) having four carbon atoms bonded to hydrogen atoms, can we all see this? Ss: yes T: The difference between them is Cl atom, we can say it has replaced one hydrogen atom in butane so, you don't begin to think because we've got a chlorine atom instead of hydrogen atom, the chain length has increased, no guys, carbon chain length neither increases nor decreases because of Cl but what you must understand here is that, the functional group of alkanes is C-C right, but the functional group of this (He referred to chlorobutane), is C-X, (CS) because Cl, it's a halogen is present, so the presence of halogens in saturated hydrocarbons make the compounds haloalkanes, so now,	Comment: This section focused effect of halogen atom in the molecule of an alkane taking butane and chlorobutane as an example. Mark's role: With respect to the structures of butane and chlorobutane drawn on the chalkboard (RP), Mark asked learners which of the two molecules has stronger intermolecular forces. Learners' role: The learner who responded to the question had the misconception that, the carbon chain in chlorobutane is longer because of the chlorine than the carbon chain in butane contrary to the understanding of no difference in the carbon chain length which Mark expected learners to have in place (LP). Mark's role: Acknowledging the learner's response, Mark first explained how the chlorine atom in chlorobutane makes no difference in the carbon chain length compared to butane. In his explanation, Mark indicated the single carbon-carbon covalent bond as the functional group of butane whereas a halogen bonded to an alkyl group represents the functional group for chlorobutane. This is an element of curricular salience, the knowledge of what is important (CS). Then, he explained how the two molecules react different due to the difference in their functional. This knowledge of how functional groups relate to organic reactions is another important aspect, an element of curricular saliency (CS) adding depth to Mark's explanations. Mark's interactive use of TSPCK components (RP/LP-CS/CS) at a sophisticated level in connection to a learner's incorrect response is given by the TSPCK map below. 

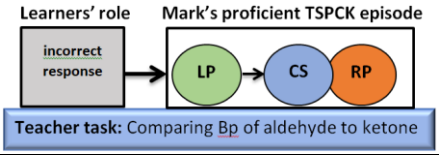
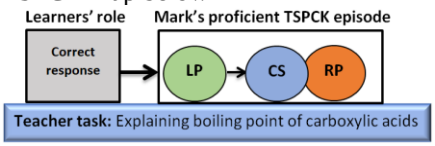
because butane and chlorobutane do not have the same functional groups, they cannot react the same way, (CS) so haloalkanes are more highly reactive chemically than alkanes, why? because C-X bond is weaker than C-C or C-H, but guys the only exception is C-F where the bond is stronger because fluorine is more electronegative than other halogens and since stronger bonds are difficult to break, then we say only C-F is less reactive, however you can only say when the size of chlorine increases, then our C-X bond is gonna be weaker since bond length increases as the halogen gets increased in its size, is that understood now? Ss:yes	
36-40 minutes InteForc Butane/Chlorobu LP-RP/CS T: So, now let's go back to our discussions on the intermolecular forces. Here we are talking about the intermolecular forces that exist between the groups right, now we know that this butane, it's gonna have which intermolecular force? SF3: van der waal forces T: van der waal forces that's right (LP), and what is gonna be here in chlorobutane? SF5: dipole-dipole T: diplople-dipole, then which of the two forces is stronger? Ss: dipole-dipole T: So if dipole-dipole force is present in chlorobutane and van der waals is present in butane, which of these two compounds is gonna have high melting and boiling point? Ss: Chlorobutane T: Chlorobutane right, remembered we earlier said melting point is a given temperature at which melting of a substance occurs right, and so if this chlorobutane (*He referred to the structure on the board*) (RP) has got stronger intermolecular forces, it gonna take more time and more energy to break the forces for it to melt right so that means it gonna have higher melting point and boiling point than butane which has got a weak intermolecular forces compared to chlorobutane (CS).	Correct Comment: This section focussed on understanding how the intermolecular forces in butane and chlorobutane affect the boiling point and melting point of the two molecules when compared. Mark's role: In order to first establish learners' prior knowledge, Mark asked them to identify the type of intermolecular forces found in butane and chlorobutane. Learners' role: Learners correctly mentioned van der waal's forces and dipole-dipole forces as the intermolecular forces in butane and chlorobutane respectively the knowledge Mark expected learners to have in place (LP) Mark's role: After acknowledging the learners' correct responses, Mark referred to the structures drawn on the chalkboard (RP) to explain how it would take more time and energy to break the stronger intermolecular forces in chlorobutane compared to that in butane thereby making the former having higher melting point and boiling point than the latter, an aspect considered for learners to understand (CS). Mark's interactive use of TSPCK components (LP-RP/CS) at a proficient level in connection to the learners' correct responses is given by the TSPCK map below. 
Lesson 2	
0-4 minutes Chain in Alkanes B/Mpt RP/CS/CS Mark: Then, another factor, we are now talking about the chain. Here we've got heptane as we can see (*He drew the structure of heptane*), let's look at pentane as well (*He drew the structure of pentane*) (RP) they both belong to the same homologous series of alkanes right, because of the single	Comments: This section focussed on explaining the how carbon chain in alkanes affect the trend of boiling point and melting point in the homologous series. Mark's role: Mark principally explained the concept by drawing the molecular structures of pentane and heptane (RP). In the structures, he

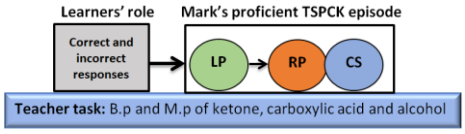
carbon to carbon covalent bonds, that's their functional group (CS), but heptane has got a longer chain, it has got seven carbon atoms so, we can say it's got a higher molecular weight because it contains more atoms than pentane which has got only five carbon atoms, what we say is, melting point and boiling point increase as the carbon chain length becomes longer, you also see that, heptane with a longer chain length has got a higher molecular weight, so as the melting and boiling point increase, the molecular weight increase in the alkane homologous series (CS), so heptane is gonna have higher melting and boiling point than pentane.	referred to the common functional group consisting of single covalent bonds between carbon atoms in the two organic molecules. This is an element of curricular saliency, pointing out functional group as an important aspect for learners to take note of (CS). Then, he related the variation in the boiling point to the differences in the carbon chain length which also affects the molecular weight. This aspect also describes Mark's knowledge of curricular saliency (CS). Learners' role: None Mark's interactive use of TSPCK components (RP/CS/CS) at a proficient level is given by the TSPCK map. 
4-6 minutes Branched alkanes M/B.pt13 *Explaining influence of chain length: 2-mthyl propane Vs butane* T: And then, let's just leave consider this (He drew the structure of butane on the board), it's butane right? Ss: yes T: What's its molecular formula, anybody? SM2: C_4H_{10} T: Exactly, it's butane with the molecular formula C4H10 (LP). Yeah, let's see this one as well (*He drew the structure of 2-methyl propane on the board*), what are you gonna call this (*He pointed at the structure of 2-methyl propane*) if this (*He pointed at structure of butane*) (RP) is butane? SF3: 2methyl T: 2methyl what? SF3: propane. T: So, comparing the two, then which one is gonna have the highest m.p and b.p between the two? Take note that they have the same formula, and they are structural isomer. That's isobutane, that is 2methylpropane. SM4: butane T: Butane, why? SF5: it doesn't have branches T: it doesn't have branches? When we talk about branches, because this one (he referred to the structure of 2methylpopane) has a branch, we talk about surface area is shorter, you see this one (he pointed at the structure of butane), has a longer surface area, so since we are talking about surface area, we can compare surface area to the length, the longer the chain, the higher the melting point and boiling point; (CS) the greater the surface area the higher the melting point and boiling point.	Comment: This section focused on the trend of boiling point and melting point in the branched alkanes. Mark's role: With reference to the structure of butane drawn on the chalkboard (RP), Mark asked learners if it was butane and also for them to indicate its molecular formula in an attempt to investigate learners' prior knowledge. Learners' role: Learners correctly referred to the structure to be that of butane and also C_4H_{10} as its molecular formula, the understanding Mark expected them to have in place (LP). Mark's role: After confirming the learners' correct prior knowledge, he expatiated on the responses in explaining how the boiling point and melting point of butane would be higher than that of 2-methylpropane due to the longer surface area in butane and longer chain length, an important aspect he wanted learners to understand (CS). Mark's interactive use of TSPCK components (RP/LP-CS) at a proficient level in connection to the learners' correct responses is shown by the TSPCK map below. 

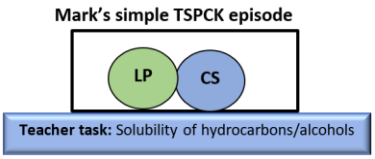
6-8minutes: Influence of functional groups – Questioning T: And then we've got the functional groups, it also affects the m.p and the b.p. right, obviously we have got different functional groups and they function in different ways. You all know functional groups? Can you name the functional groups? SM1: alkanes T: alkanes Ss: alkenes, ketone T: ketones Ss: aldehydes, carboxylic acid T: carboxylic acid Ss: esters, alcohols T: So, they are functional groups right? Ss: yes T: Good those are functional groups right, I'm happy.	Comment: This section focussed on the Mark's interaction with learners on identifying functional groups of organic molecules where learners demonstrated good prior knowledge. Mark's role: Mark asked learners questions about functional groups in order to establish their prior knowledge. Learners' role: Learners responded correctly by mentioning examples of organic compounds with specific functional groups, the knowledge Mark expected them to have in place (LP). Mark's role: Mark acknowledged learners prior knowledge. 
8-13 minutes: Comparing the boiling point and melting point of butane and butanol Mark: Now, each of those homologous series is identified by a functional group. Let's say (*In the molecular structure of butane on the chalk board, Mark replaced H on the first carbon with OH such that butane becomes butanol*) yeah, now let's compare it to the butane here (*He drew the molecular structure of butane again*) (RP), so is this gonna affect the melting point and boiling point? What can we say about the melting point and boiling point of butanol and butane here? SM8: Butane is stronger than butanol so it's gonna have higher melting point and boiling point. Mark: What do we mean by butane is stronger? SM8: ….There was no response from SM8…. SM9: I think the melting point and the boiling point of butanol are gonna be higher than that of butane Mark: the melting point and the boiling point of butanol are gonna be higher than butane according to him, the reason being? SM9: Butanol has got strong intermolecular forces Mark: Indeed, butanol is gonna have high melting point and boiling point because it has strong intermolecular forces ok (LP). The hydroxyl functional group is the key, it's our OH (*He pointed at the molecular structure on the board*) commonly identified with the alcohols homologous series, (CS) so butanol has melting and boiling point stronger than butane.	Comment: This segment focused on comparing the boiling point and melting point of butane to that of butanol. In-depth Qualitative Analysis Mark's role: With reference to the structures of butane and butanol on the board (RP), Mark asked learners if the hydroxyl group in butanol was going to make its boiling point and melting point different from that of butane. Learners' role: Learner SM8 wrongly stated that, butane is stronger than butanol and hence, butane would have high melting point and boiling point. However, Learner SM9 correctly responded by stating higher melting point and boiling point in butanol than in butane. The learner also added that, butanol has stronger intermolecular forces than butane, the reason for the difference in melting point and boiling point (LP). Mark's role: Mark further confirmed the learner's correct prior understanding by re-stating the learner's response. With reference to the molecular structure of butanol, Mark referred learners to the presence of hydroxyl which is known to be the functional group of all alcohols. This seems to describe Mark's understanding of hydroxyl functional as an important aspect of alcohols. This is an element of curricular saliency (CS). Mark's interactive use of TSPCK components (RP/LP-CS) in connection to learner' correct and incorrect responses is given by the TSPCK map below.

	
13-16 minutes: Alcohols melting and boiling point Mark: So, let's say in this example, you have got butanol right, and pentanol, they are both groups of alcohols, you are thinking, which one is gonna have higher melting point and boiling point between butanol and pentanol? SM2: pentanol Mark: the reason being? SM2: the longest chain Mark: the longest chain? Ss: yeah Mark: since we are talking about the chain, the longer the chain, the higher the melting point and the boiling point in homologous series of alcohols right (LP) so in the pentanol here (*He drew and referred to the structure of pentanol*), (RP) with six carbon atoms, the melting point and boiling point is gonna be higher (CS) than the butanol here (He referred to the structure on the board), it's got a lower number of carbon atoms.	Comment: The discussion focused on describing the boiling point and melting point of alcohols by asking learners a question before providing explanations. In-depth Qualitative Analysis *Mark's role*: Mark asked learners which of butanol and pentanol would have higher melting and boiling point thereby demonstrating the importance of first establishing learner prior knowledge (LP). *Learners' role*: Learner SF2 correctly referred to pentanol with the reason that, it has longer carbon chain than butanol. *Mark's role*: Using the structures drawn on the board, Mark expatiated on SM2's correct response but explaining that, the longer the carbon chain in alcohols, the higher the melting and boiling point, important aspect learners needed to know thereby demonstrating her understanding of what learners needed to know (CS) with the use of a symbolic representation (RP). Mark's interactive use of TSPCK components (LP-CS/RP) at a proficient level in connection to a learner's correct response is shown by the TSPCK map below 
16-18 minutes: Ketone functional group Mark: We've also got the functional groups of ketone and aldehyde. Let's first talk about ketone. How do we spot the ketone? if I say that, that is the ketone passing there, how are you gonna recognise the ketone? SM1: it has got carbon with a double bond and OH group Mark: We can find it in carboxylic acids, OH group is common to all alcohols, so if I see a ketone, yes? SM2: Ketone has got oxygen double bonded to carbon. Mark: Oxygen double bonded to carbon? (LP) We say that a functional group which has got one carbon double-bonded to one oxygen, it's our carbonyl group (CS) (*Mark put C=O on the board*) neh and then, in ketone functional group, let's see (*Mark drew the functional group of ketone on the board*), (RP) the carbon in our carbonyl group is bonded one side to	Comment: This section focused on ketone functional group where Mark interacted with learners before providing explanations. Mark's role: In order to investigate learners' prior knowledge, Mark asked them how to recognise ketone functional group. Learners' role: While a learner wrongly referred to ketone functional group as consisting of carbonyl and hydroxyl group, another learner referred to it as consisting of carbonyl group, the knowledge Mark expected learners to have in place (LP). Mark's role: In his response to the first learner, Mark indicated that carbonyl group is found in carboxylic acids and hydroxyl group in

a carbon, right and on the other side to another carbon neh.	alcohols. However, he did not make it clear to the learners that, not only alcohol functional group contain hydroxyl group. Using the structure of carbonyl group (RP), he explained how it is bonded in the ketone functional group, an important aspect he wanted learners to understand (CS). Mark's interactive use of TSPCK component (LP-CS/RP) at a proficient level in connection to the learners' correct and incorrect responses is given by the TSPCK map below. 
18-22 minutes: Aldehyde functional group Mark: What about the functional group of aldehyde guys? What makes them different from ketones? SM2: Names end with al Ss:….(Laugh!!) Mark: Well you could say all aldehydes have their names end with al, accepted. Who wants to tell us about their functional group? Ss:….(No response from learners)…… Mark: Now here is the functional group (*He faced the board and drew the symbolic structure of aldehyde functional group*) (RP), it has got a carbonyl group that's C=O here, it's bonded to one hydrogen atom here and then to an alkyl group, we can represent it as -CHO and as he rightly said, all the compounds in the aldehyde homologous series have their names end with al (LP) for instance propanal, butanal and so on. So we get the difference between the functional group of ketone and aldehyde right? (CT) Ss: yes	Comment: This section focussed on understanding the aldehyde and ketone functional groups. Mark's role: In an attempt to investigate the learners' prior knowledge, Mark asked them how the functional group of aldehyde is different from that of ketone. Learners' role: Rather than referring to the functional groups, a learner responded by indicating that all members of aldehyde have their names end with 'al' (LP). Mark's role: In expatiating on the learners' response and provide the answer required, Mark drew the structure of aldehyde functional group on the board (RP) and emphasized how carbonyl group is bonded different in each case of aldehyde and ketone as an element aspect he wanted learners to understand. Such a method of place a concept side by side with another concept to show the difference and similarity symbolizes knowledge of conceptual teaching strategy (CT). Mark's interactive use of TSPCK components (LP/RP/CT) at a proficient level in connection to the learners' incorrect response is shown by the TSPCK map below. 
22-25 minutes B.pt of aldehyde and ketone LP-CS/RP Mark: OK, so if we have a ketone and then we have an aldehyde, which one do you think is gonna have high boiling point? SF2: Aldehyde Mark: Why? SF2: It's got a carbonyl group Ss….(Laugh!!) Mark: You guys are laughing because she forgot both aldehyde and ketone have got a carbonyl functional group,	Comment: This section focussed on comparing the boiling point of aldehyde and ketone Mark's role: In an attempt to investigate the learners' prior knowledge, Mark asked them which of aldehyde and ketone would have a higher boiling point. Learners' role: A learner wrongly referred to the aldehyde as having higher boiling point due to its carbonyl functional group rather than referred to ketone, the understanding Mark wanted them to have in place (LP).

you mustn't forget that whenever you think of aldehydes and ketones (LP) so here ketones are going to be having higher boiling point because around carbonyl group, that's our C=O (*He wrote that on the chalkboard*) (RP), right, as we can see here there are two alkyl groups which are donating electron thereby making ketones to be polar (CS), do we have any question? Ss:….(No)……	Mark's role: Mark called the learners' attention to the fact that, both aldehyde and ketone have the carbonyl functional group in addressing the learner's inadequate prior knowledge. With reference to the symbolic representation of carbonyl group (RP), he explained higher boiling point of ketone as a result of the two alkyl groups donating electrons, the important aspect he wanted learners to understand. This is an element of curricular saliency (CS). 
25-29 minutes: Boiling point of carboxylic acids Mark: Another important group of compounds is carboxylic acid, what's their functional group? SF3: RCOOH Mark: You got it right, here is carboxylic acid functional group (LP) (*He put the symbolic structure on the board*), it consists of carbonyl group C=O and hydroxyl group, (RP) OH so when it comes to their trend of boiling points in carboxylic acids, the boiling point increases down the group, as the number of carbon atoms in the molecules increases, the molecules get bigger and that raises the boiling point. (CS)	Comment: The discussion focused on describing the boiling point of carboxylic acids by asking learners a question before providing explanations. In-depth Qualitative Analysis *Mark's role*: Mark asked learners about the functional group for carboxylic acids. thereby demonstrating the importance of first establishing learner prior knowledge (LP). *Learners' role*: Learner SF3 mentioned correctly mentioned RCOOH as the functional group for carboxylic acid. *Mark's role*: Taking SF3's correct response into consideration and with reference to the structure on the board, Mark emphasised the hydroxyl and carbonyl group in carboxylic acids and further explained as the carbon atoms increase, the molecules get bigger thereby increasing the boiling point thereby showing her understanding of what learners needed to know (CS) with the use of a symbolic representation (RP). Mark's interactive use of TSPCK components (LP-CS/RP) at a proficient level mediated by a learner's correct response is shown by the TSPCK map below 
29-33minutes: Functional group of Ketone/ Alcohol and carboxylic acid (boiling and melting point compared) Mark: So, now between ketone which has got a carbonyl functional group and in the case of carboxylic acid, which one is gonna have high boiling point and melting point? Ss: ketone….carboxylic acid….ketone (Chorus answers from learners) Mark: In deed, carboxylic acid is gonna have higher boiling	Comment: This section focused on comparing the boiling point and melting point of ketones, carboxylic acids and alcohols. Mark's role: In an attempt to establish the learners' prior knowledge, Mark asked them which of ketone and carboxylic acid would have higher boiling point and melting point. Learners' role: Learners gave a mix of correct

point and melting point than ketone right (LP), so now between alcohol and carboxylic acid which one is gonna have high boiling point and melting point? SF6: Alcohol Mark: I know you guys are smart, it's about hydrogen bond here, it's here in alcohol (*Mark pointed at the structure of ethanol on the board*), it's also here (*He pointed at the structure of ethanoic acid*) (RP) right but you see, carboxylic acid has also got a carbonyl group in addition to its hydroxyl group, whereas alcohols has only got hydroxyl group, so the boiling point of carboxylic acid is gonna be higher than that of alcohols, (CS) even more than ketones and aldehydes.	and incorrect answers by referring to ketone as well carboxylic acid rather than mentioning only carboxylic acid, the understanding Mark expected them to have in place (LP). Mark's role: Mark acknowledged carboxylic acid as having high boiling point and melting point than ketone but without explaining why. He further asked learners which of carboxylic acid and alcohol would have high boiling point and melting point. Learners' role: A learner correctly referred to alcohol Mark's role: In explaining how the boiling point of carboxylic acids is higher than that of alcohols, using the structures of organic molecules (RP), Mark called learners' attention to the presence of presence of carbonyl group and hydroxyl group in carboxylic acid unlike in alcohols where only hydroxyl group is present. The type of functional groups demonstrated Mark's knowledge of what was important for learners to take note of, an element of curricular saliency (CS). Mark's interactive use of knowledge of TSPCK components (LP-RP/CS) at a proficient level in connection to the learners' correct and incorrect responses is given by the TSPCK map below. 
33-37 minutes: Solubility of hydro/Alcohols T: And now guys, let's talk about the solubility of some of these organic compounds. We earlier described solubility right? Ss: yes T: We're talking about basic principle, like dissolves like, just like positive attracts negative, even here we're saying like dissolves like so substances with the same properties are more likely to dissolve one another right. So, let's talk about forces right. So, you find that another substance, one will be strong enough to dissolve another substances, in order for the dissolving to happen there has to be an equal distribution of the forces like similar strength of the forces, it is the same as fighting, you don't just go and fight a big learner obviously who is gonna beat the hell out of you. Ss: laugh T: So, like same thing, like dissolve likes and we look at water as a universal solvent, right Ss: yes T: Water is a polar substance. So according to our rule, like dissolves like, unlike will dissolve unlike, for instance,	Correct Comment: This section focused on evaluating learners' understandings of the concepts learned during the teaching. Mark's role: He reminded learners of the concepts of solubility of substances in water, Learners' role: No identifiable Mark's role: By drawing the structure of ethane (RP) on the chalkboard as an example of alkane, Mark explained why hydrocarbons which are nonpolar would not dissolve in water which is polar substance, an important aspect he wanted learners to understand. He also referred to the presence of hydrogen bond in alcohols which makes them bond easily with water thereby making them soluble. This is an element of curricular saliency (CS). Mark's interactive use of knowledge of TSPCK components (RP/CS) at a simple level is given by the TSPCK map below. response

hydrocarbons which are nonpolar wouldn't dissolve in water which is polar, if you look at alkanes like ethane (*He drew the structure*) (RP), it has got single covalent carbon-hydrogen bonds right, so there's equal sharing of electrons between adjacent atoms here such that, no charge separation exists, that makes hydrocarbons to be nonpolar, their molecules won't be able to have charge interaction with water as a result, there are insoluble and we therefore say they are hydrophobic, but alcohols will dissolve in water because they are polar and water is also polar, so those that can dissolve in water they are hydrophilic, hope you wouldn't confuse hydrophilic with hydrophobic? Ss: No T: Now, we got other hydrocarbons neh like methane, methane a gas right, wow. Methane is a gas right Ss: yes T: Like if we say methane here we are talking about solubility like the water is hot one thing that you should know is that solubility and temperature, temperature affects solubility like some substances, they will not dissolve but immediately when they start heating up, they loose power just like we said with melting point, they bond, they break and then they become soluble. right Ss; yes T: So, like we say that temperature and solubility of gases they are inversely proportional right so but they are soluble too and because you are talking about dissolving there didn't see it but they do dissolve in liquid and gases take for example, let's say we dissolve gases in water, we talked about pressure right? So, the pressure applied will determine the solubility are we together? Ss; yes T T: Regarding alcohols, they can bond easily they tend to be soluble in water because of the functional group, the OH. So, these groups, the hydroxyl, they can form bond with water and they tend to dissolve in water but other hydrocarbons cannot dissolve in water.	
37-40 minutes: Evaluating learners' understanding T: Now, I'm gonna ask you for the last time, what's the m.p? I can see it in your eyes when I say it, I can see it SM2: the temperature at which a solid changes to a liquid T: why can't you say the temperature at which a liquid changes to solid? SF2: something melts T: and because something melts, we are talking about the state of matter, solid, liquid, gases, plasma, you know Ss: yes T: So, now what you are saying is you know particles in a solid are closely packed to one another right, just as you are sitting together, you are so close, like no movement. And then, particles of a liquid, they cannot move, they just vibrate and gases can move freely right? Now, when you talk about m.p, solubility and everything right, I just talked about changes from solid to liquid neh. Now, it happens that when you get to the liquid part, they are just vibrating, which limits the movement, it limits the movement, now when you come	Comment: This section focused on evaluating learners' understandings of the concepts learned during the teaching. Mark's role: Asking learners questions Learners' role: Providing answers to the questions. LP

to solubility, with limit in the movement, what happens? With such limited movement, what happens? SM1: hmm T: Have you done something like dissolving a blue substance in a black substance, but it dissolves and doesn't become black, it becomes blue with a bit of black SM1: yes, just like in titration T: Titration? SM1: yes T: Yhoo, you guys you are moving, you are moving. Like I'm talking about the motion of the liquid which limits the ability to Ss: soluble T: the ability to dissolve right. So, can I get for the last time, like the longer the chain Ss: the higher the melting point	

Appendix XXXI: Ruth's lesson plan

(Topic Specific PCK Lesson Plan)

Subject	Physical Science
Grade	12
Topic covered	Organic chemistry
Specific Concept	Functional groups and IUPAC naming of organic compounds
Allocated time	1hr 20minutes (40minutes per lesson)

CATEGORY A: ASPECTS RELATED TO CURRICULUR SALIENCY

10. **Purpose: (What do you intend learners to know in this lesson? You can list this a set of specific outcomes)**
    At the end of the lesson, learners should be able to:
    - Define what is meant by a functional group
    - Identify the functional group present in organic compounds that belong to the same homologous series e.g. alkane, haloalkanes, alkenes, alkynes, alcohols, carboxylic acids, esters, ketone, aldehydes, amide and ether.
    - Understand and state the IUPAC
    - Use the IUPAC rule in naming organic compounds in the same homologous series such as: alkanes, alkenes, alkynes, alcohols.
11. **List the most immediate concepts needed prior to teaching the concepts you intend to teach. Indicate how these genuinely affect your lesson.**
    - **Arrangement of elements in the period table**: It is important that learners first understand the position of elements like carbon, hydrogen, oxygen and chlorine in the periodic table as it relates to their valence electrons. For learners to understand organic chemistry very well, they must have known how to represent these elements symbolically and how the group in the periodic table influences their chemical properties.
    - **Chemical bonding**: Learners must have previously learnt about chemical bonding especially covalent bond because the knowledge will make them to remember and understand when we draw the structures of how carbon forms simple bonds single, double and triple covalent bonds such as C-C, C=C, C-H to explain homologous series and functional groups of alkanes, alkenes and alkynes.

12. **Summarize your understanding of the most important *content knowledge* of this lesson**

    Functional groups: A functional group is a group of atoms which gives molecules their reacting characteristics. The functional groups are important in organic chemistry because their presence in organic molecules determines the chemical properties including reactions of the organic molecules. They are also used to categorize organic compounds into various homologous series meaning all compounds in a particular homologous series have the same functional group. They are also used in giving organic compounds in the same homologous series similar names. The functional groups that will be covered in this lesson include for the homologous series of: alkane (C-C), alkene (C=C), alkyne (C=C), haloalkanes (R-X), alcohols (R-OH), carboxylic acids (R-COOH), esters (R-COO-R), ketone R1(CO)R2, aldehydes (R-CHO), amide and ether.

- **IUPAC naming of organic compounds**: The International Union of Pure and Applied Chemistry (IUPAC) has put forward a system of nomenclature which relates the name of the compound to its molecular structure. In this system, every name consists of a root, a suffix and as many prefixes as necessary. The basic rules for naming organic compounds include the following: Take the longest continuous carbon chain as the root hydrocarbon and name it according to the number of carbon atoms it contains, adding the appropriate suffix to indicate the principal substituent group; Number the carbon atoms in the root hydrocarbon from the end which will give the lowest number to the suffix, and then the prefix; Indicate the other substituents by prefixes preceded by numbers to show their positions on the carbon chain; When two different alkyl groups are substituted to one organic compounds, they should be named based on the one that came first alphabetically, e.g. 4-ethyl-2-methylHexane. In this lesson, organic compounds will be named together with the learners by drawing their molecular structure.

CATEGORY B: ABOUT LEARNER PRIOR KNOWLEDGE

13. List common misconceptions and errors by learners specific to the concepts intended for this lesson.

- Learners may think that the hydroxyl group (OH) in alcohols is the same as the hydroxide ion (OH^-) in inorganic compounds like NaOH because they both have similar symbol OH.
- Learners might think that all compounds of carbon are organic compounds.
- Learners might think that substituent groups are also part of the longest continuous chain thereby include the groups in their numbering when naming.
- Learners may think that the hydroxyl group (OH) in alcohols is the same as the hydroxide ion (OH^-) in inorganic compounds like NaOH because they both have similar symbol OH.

14. List specific parts of your lesson that you think may turn out difficult for learners to understand. Provide reasons for your analysis.

Please note that potential difficult areas are not necessarily 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.

- Organic compounds which belong to different homologous series but have similar functional groups can be difficult for learners to distinguish such as the functional group for aldehyde and ketone functional groups, they have both got a carbonyl group in their structures so learners might confuse them when teaching by showing them the molecular structures.
- When given the molecular structures, it can be difficult for learners to correctly give the IUPAC name of organic compounds that contain more than one substituent groups e.g. alkyl CH_3 and ethyl C_2H_5 because this requires good understanding of first finding the longest continuous carbon chain.
- Learners may encounter difficulties when either a double or triple bond and a substituent group are both present in an organic molecule, learners find it difficult to know which one between a bond or substituent group should be considered first in naming.

CATEGORY E: USE OF REPRESENTATIONS

15. List representations that you would use for teaching the concepts intended for this lesson.

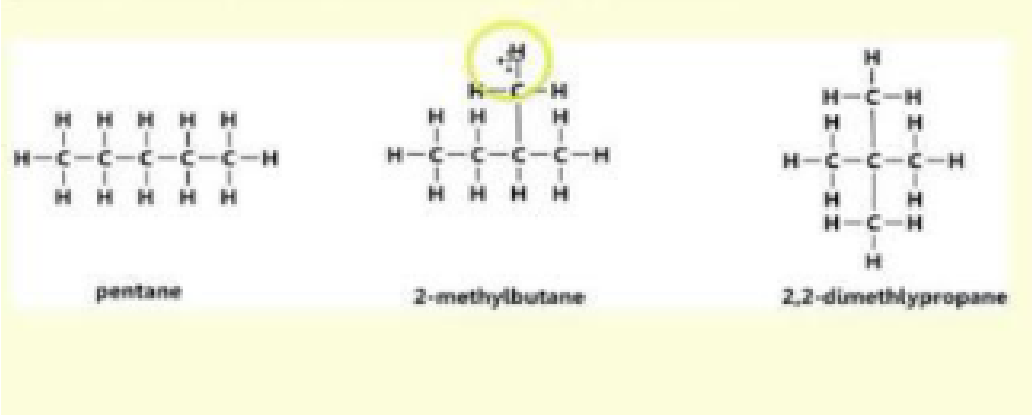
I will use different forms of representations like:

- symbolic representations,
- structural formulas, molecular formulas,
- sub-microscopic and

- macroscopic representations in teaching the concepts.

In this lesson, we will use only two types of representation. The symbolic, sub-microscopic and representation.
For symbolic representation, we will be having the molecular formulas for the isomers. For sub-microscopic, we will be having the structural formulas of the compounds.
Having both symbolic and sub-microscopic representations will help the learners to get a better picture of the concept.

Isomers for C5H12



16. <u>Summarize strategies that would be employed in teaching the concept:</u>

The focus of this lesson would be on the functional groups and IUPAC naming of organic compounds. Before explaining each concept, I will ask learners to first say what they know about the concept. This will assist me to know if they have appropriate prior understanding. I will use structures to explain functional groups and nomenclature so that learners can see for themselves what elements are involved and how carbon is bonded to hydrogen. I will also engage learners in some practical demonstrations on how to identify functional groups of organic compounds. Then, I will explain the IUPCA naming of organic compounds with learners. I will state the rules for naming organic compounds with focus on the hydrocarbons using the molecular formulae and structures to promote learners' understanding. I will give learners examples and allow them to name some compounds as an example. At the end of the lesson, I will ask learners questions in order to evaluate the understanding.

CATEGORY D: PRE-ASSESSMENT AND LESSON INTRODUCTION

17. Assessing the learners before the beginning of the lesson and how the lesson will unfold.

- As form of a pre-assessment, the learners will be asked two questions about the specific concept that will be covered in the lesson. These questions are only to check what they already know about the concept because they are not empty vessels and considering the fact that they did area before, they really do know something. The questions will be as follows: 1. What are intermolecular forces and mention their types. 2. What do you think isomers are
- I will then hand them the worksheets which has the exercise and the notes. I will help them to understand what is on their sheets by explaining and giving them a chance to explain.
- We also do some examples on isomerism and the physical properties in relation to the structure of organic molecules.

CATEGORY F: LEARNER ENGAGEMENT

18. Ensuring learners participation.

Learners are expected to participate in the lesson, this is important because as a teacher you get to see the learners misunderstanding or the level of their understanding. It is so important for a teacher to ensure that learners become curious to learn and keep them engaged. I will ensure this by making sure that the lesson is interactive. I will ask learners questions, listen to their answers. The lesson will be an open one, where learners can voice their thoughts.

CATEGORY G: SUPPORTING RESOURCES

19. Resources to be used during the lesson

- Black board
- Worksheets
- Textbook
- Chalk

CATEGORY H: CONCLUSION

20. Closure

In conclusion, the learners will be asked a question in order to see if learning did take place during the lesson. From a worksheet they will have to do the exercise at home as practice. Here are the questions:

- What is the relationship between the surface area and the boiling point?

Appendix XXXII: Inter-rater calculation for learner achievement tests

Observer A	Rater_1
Observer B	Rater_2

	Observer A		
Observer B	1	2	
2	1	2	3 (55.0%)
1	0	2	2 (45.0%)
	1 (45.0%)	4 (55.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.87

Observer A	Rater_2
Observer B	Rater_3

	Observer A		
Observer B	3	2	
3	2	0	2 (50.0%)
2	1	1	2 (50.0%)
	3 (50.0%)	1 (50.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.235 to 1.000

Observer A	Rater_1
Observer B	Rater_3

	Observer A		
Observer B	3	1	
1	1	2	3 (60.0%)
3	0	2	2 (40.0%)
	1 (40.0%)	4 (60.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.87

[a] Quadratic weights

Appendix XXXIII: Ruth's learner Rasch Person Measure (Pre-test)

TABLE 17.1 Pre-achievement test (Ruth) ZOU660WS.TXT Apr 13 2018 7: 7
INPUT: 30 Person 17 Item REPORTED: 30 Person 17 Item 2 CATS MINISTEP 4.2.0

Person: REAL SEP.: 1.26 REL.: .69 ... Item: REAL SEP.: 1.21 REL.: .77

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
1	9	17	1.52	.63	1.01	1.8	1.22	1.8	.17	.60	46.7	75.4	Ru01
6	8	17	1.44	.63	.66	-.4	.53	.0	.74	.60	86.7	75.4	Ru06
3	7	17	.92	.63	.79	-1.2	.74	-.7	.68	.60	86.7	75.4	Ru03
8	7	17	.92	.63	.79	-1.6	.74	-1.0	.68	.60	86.7	75.4	Ru08
4	7	17	.92	.60	1.43	-.7	1.41	-.2	.35	.58	53.3	71.3	Ru04
5	7	17	.92	.59	.90	-.7	.95	-.2	.59	.56	80.0	69.9	Ru05
2	6	17	.53	.59	.67	1.7	.57	1.3	.68	.54	93.3	70.5	Ru02
9	5	17	.21	.60	.61	-1.7	.50	-1.1	.69	.52	93.3	71.8	Ru09
7	4	17	-.89	.63	.58	-1.8	.45	-1.1	.68	.50	86.7	74.7	Ru07
10	3	17	-1.80	.74	.58	-.9	.37	-.6	.61	.44	86.7	83.9	Ru10
11	3	17	-1.80	.74	.69	-.6	.49	-.4	.57	.44	86.7	83.9	Ru11
16	3	17	-1.80	.74	.64	.5	.42	.7	.59	.44	86.7	83.9	Ru16
12	3	17	-1.80	.74	.81	.3	.90	.2	.49	.44	86.7	83.9	Ru12
15	3	17	-1.80	.74	1.19	-.8	1.35	.4	.33	.44	86.7	83.9	Ru15
14	2	17	-2.43	.87	.52	.9	.25	.6	.58	.39	93.3	89.0	Ru14
21	2	17	-2.43	.87	.52	-.8	.25	-.4	.58	.39	93.3	89.0	Ru21
13	2	17	-2.43	.87	.88	-.8	1.04	-.4	.40	.39	93.3	89.0	Ru13
25	2	17	-2.43	.87	1.44	.9	1.27	.6	.24	.39	80.0	89.0	Ru25
27	2	17	-2.43	.87	1.38	1.2	1.42	.8	.15	.39	80.0	89.0	Ru27
28	2	17	-2.43	.87	1.25	1.3	1.21	1.6	.03	.39	80.0	89.0	Ru28
30	2	17	-2.43	1.14	.45	-.6	.12	-.6	.51	.31	93.3	93.2	Ru30
18	2	17	-2.43	1.14	.45	-.6	.12	-.6	.51	.31	93.3	93.2	Ru18
23	2	17	-2.43	1.14	.45	-.6	.12	-.6	.51	.31	93.3	93.2	Ru23
17	1	17	-3.40	1.14	1.45	.8	1.10	.5	.16	.31	93.3	93.2	Ru17
19	1	17	-3.40	1.14	1.34	.9	1.48	1.2	.04	.31	93.3	93.2	Ru19
20	1	17	-3.40	1.14	1.29	.8	1.41	.7	.12	.31	93.3	93.2	Ru20
24	1	17	-3.40	1.14	1.36	.9	1.42	1.6	-.01	.31	93.3	93.2	Ru24
22	1	17	-3.40	1.89	1.36	.8	1.34	.4	-.01	.31	93.3	93.2	Ru22
26	1	17	-3.40	1.89	.88	.8	1.22	.7	-.01	.31	93.3	93.2	Ru26
29	1	17	-3.40	1.89	1.23	.9	1.31	1.6	-.01	.31	93.3	93.2	Ru29
MEAN	3.6	17.0	-2.01	.94	.99	-.1	1.06	.1			85.9	83.9	
P.SD	3.3	.0	1.74	.37	.47	1.1	.92	.9			11.2	8.2	

Appendix XXXIV: Ruth's learner Rasch Person Measure (Post-test)

TABLE 17.1 Post-Learner achievement test (Ruth) ZOU157WS.TXT Apr 13 2018 7:25
INPUT: 30 Person 17 Item REPORTED: 30 Person 17 Item 2 CATS MINISTEP 4.2.0

Person: REAL SEP.: 1.65 REL.: .84 ... Item: REAL SEP.: 2.23 REL.: .91

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
2	14	2.74	.99	1.29	1.0	1.46	1.3	-.23	.72	64.7	92.9	Ru02
3	14	2.74	.99	1.26	.9	1.38	.7	.60	.72	88.2	92.9	Ru03
10	14	2.74	.99	.18	-1.6	.08	-.7	.89	.72	100.0	92.9	Ru10
12	14	2.74	.99	.18	-1.6	.08	-.7	.89	.72	100.0	92.9	Ru12
13	14	2.74	.99	.18	-1.6	.08	-.7	.89	.72	100.0	92.9	Ru13
14	14	2.74	.88	.68	-.3	.35	-.4	.82	.73	94.1	90.8	Ru14
15	14	2.74	.88	.68	-.3	.35	-.4	.82	.73	94.1	90.8	Ru15
21	14	2.74	.88	.68	-.3	.35	-.4	.82	.73	94.1	90.8	Ru21
7	13	1.87	.88	.91	.1	1.29	.6	.72	.73	94.1	90.8	Ru07
11	13	1.87	.88	.41	-1.0	.18	-.8	.88	.73	94.1	90.8	Ru11
16	13	1.87	.88	.41	-1.0	.18	-.8	.88	.73	94.1	90.8	Ru16
17	13	1.87	.88	.41	-1.0	.18	-.8	.88	.73	94.1	90.8	Ru17
18	13	1.87	.88	.41	-1.0	.18	-.8	.88	.73	94.1	90.8	Ru18
19	13	1.87	.88	.41	-1.0	.18	-.8	.88	.73	94.1	90.8	Ru19
20	13	1.87	.88	.41	-1.0	.18	-.8	.88	.73	94.1	90.8	Ru20
24	13	1.87	.77	1.03	1.9	1.16	1.6	.08	.71	58.8	86.8	Ru24
1	12	1.20	.77	1.09	1.7	1.03	1.2	.44	.71	70.6	86.8	Ru01
6	12	1.20	.77	1.13	.4	1.35	1.1	.64	.71	82.4	86.8	Ru06
8	12	1.20	.77	.99	.1	.60	-.2	.74	.71	82.4	86.8	Ru08
9	12	1.20	.77	.54	-1.0	.28	-.9	.85	.71	94.1	86.8	Ru09
23	12	1.20	.77	.54	-1.0	.28	-.9	.85	.71	94.1	86.8	Ru23
4	11	.67	.70	1.39	1.0	1.14	.4	.58	.68	76.5	83.2	Ru04
5	11	.67	.70	1.20	.6	.87	.1	.64	.68	76.5	83.2	Ru05
22	11	.67	.70	.90	-.1	1.36	1.5	.64	.68	88.2	83.2	Ru22
25	11	.67	.70	.70	-.7	.44	-.6	.78	.68	88.2	83.2	Ru25
26	11	.67	.65	.71	-.9	.46	-.5	.74	.64	82.4	80.1	Ru26
27	11	.67	.60	.68	-1.4	.50	.2	.65	.53	82.4	74.8	Ru27
28	11	.67	.60	.89	-.4	.77	.3	.53	.49	82.4	74.6	Ru28
29	10	-0.22	.60	1.20	.9	1.02	.5	.42	.49	70.6	74.6	Ru29
30	10	-0.22	.62	.93	-.2	.67	.2	.48	.45	76.5	76.2	Ru30
MEAN	12.43	1.57	.81	.97	-.2	1.10	.0			86.7	86.9	
P.SD		1.20	.12	.90	1.2	1.88	1.0			10.6	5.8	

Appendix XXXV: Ruth's learner Rasch Person Measure (Stacked data)

TABLE 17.1 Post-achievement test ANCHORED (Ruth) ZOU594WS.TXT Apr 14 2018 14: 3
INPUT: 30 Person 17 Item REPORTED: 30 Person 17 Item 2 CATS MINISTEP 4.2.0

Person: REAL SEP.: .82 REL.: 2.78 ... Item: REAL SEP.: 1.75 REL.: .86

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
2	17	2.82	.81	2.79	2.5	4.41	1.9	-.17	.56	70.6	88.3	Ru02
3	17	2.82	.81	1.38	.8	.71	.2	.49	.56	82.4	88.3	Ru03
12	17	2.82	.81	.62	-.7	.29	-.3	.71	.56	94.1	88.3	Ru12
13	17	2.82	.81	.62	-.7	.29	-.3	.71	.56	94.1	88.3	Ru13
15	17	2.82	.81	.62	-.7	.29	-.3	.71	.56	94.1	88.3	Ru15
7	17	2.82	.74	.95	.0	.74	.1	.62	.59	82.4	85.9	Ru07
10	17	2.82	.74	.95	.0	.74	.1	.62	.59	82.4	85.9	Ru10
11	17	2.82	.74	.95	.0	.74	.1	.62	.59	82.4	85.9	Ru11
14	17	2.23	.74	1.02	.2	1.38	.7	.55	.59	82.4	85.9	Ru14
16	17	2.23	.74	.41	-1.5	.24	-.6	.81	.59	94.1	85.9	Ru16
17	17	2.23	.74	.41	-1.5	.24	-.6	.81	.59	94.1	85.9	Ru17
19	17	2.23	.74	.41	-1.5	.24	-.6	.81	.59	94.1	85.9	Ru19
20	17	2.23	.74	.41	-1.5	.24	-.6	.81	.59	94.1	85.9	Ru20
21	17	2.23	.74	.41	-1.5	.24	-.6	.81	.59	94.1	85.9	Ru21
24	17	2.23	.74	.41	-1.5	.24	-.6	.81	.59	94.1	85.9	Ru24
1	17	2.23	.68	2.08	2.2	2.25	1.3	.16	.59	58.8	83.0	Ru01
6	17	1.73	.68	1.87	1.9	2.00	1.2	.25	.59	70.6	83.0	Ru06
8	17	1.73	.68	1.28	.8	1.39	.7	.47	.59	82.4	83.0	Ru08
9	17	1.73	.68	1.11	.4	.81	.1	.58	.59	82.4	83.0	Ru09
18	17	1.73	.68	.65	-.9	.50	-.4	.73	.59	94.1	83.0	Ru18
23	17	1.73	.68	.69	-.7	.61	-.2	.71	.59	94.1	83.0	Ru23
4	17	1.30	.64	1.00	.1	.77	-.1	.61	.59	82.4	80.2	Ru04
5	17	1.30	.64	1.36	1.1	1.26	.6	.45	.59	70.6	80.2	Ru05
22	17	1.30	.64	.98	.1	1.06	.3	.58	.59	82.4	80.2	Ru22
26	17	1.30	.64	.80	-.5	.62	-.3	.68	.59	82.4	80.2	Ru26
25	17	1.30	.61	.69	-1.1	.52	-.7	.72	.58	88.2	77.6	Ru25
27	17	1.30	.59	1.04	.2	1.77	1.1	.46	.53	82.4	73.8	Ru27
28	17	1.30	.60	1.25	1.0	1.57	.8	.37	.51	70.6	75.0	Ru28
30	17	-0.51	.60	1.49	1.8	1.91	1.1	.26	.51	70.6	75.0	Ru30
29	17	-0.51	.63	1.47	1.5	1.45	.7	.28	.49	64.7	77.6	Ru29
MEAN	17.0	1.90	.71	1.00	.0	.98	.2			83.5	83.3	
P.SD	.0	1.01	.07	.55	1.2	.87	.7			10.1	4.2	

Appendix XXXVI: Ruth's learner Item measure (Pre-test)

TABLE 13.1 Pre-achievement test (Ruth) ZOU660WS.TXT Apr 13 2018 7: 7
INPUT: 30 Person 17 Item REPORTED: 30 Person 17 Item 2 CATS MINISTEP 4.2.0

Person: REAL SEP.: 1.26 REL.: .69 ... Item: REAL SEP.: 1.21 REL.: .77

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
12	0	30	3.63	1.84	MAXIMUM MEASURE				.00	.00	100.0	100.0	Item12
13	0	30	3.63	1.84	MAXIMUM MEASURE				.00	.00	100.0	100.0	Item13
15	0	30	3.63	1.84	MAXIMUM MEASURE				.00	.00	100.0	100.0	Item15
1	5	30	3.55	.79	.89	-.1	.30	-.2	.41	.34	92.6	92.5	Item1
3	6	30	2.44	.68	1.13	.4	1.81	.9	.31	.42	88.9	88.8	Item3
11	7	30	2.32	.59	.76	-.7	.61	-.3	.60	.52	92.6	84.4	Item11
16	7	30	2.32	.59	1.13	.5	.78	.0	.49	.52	77.8	84.4	Item16
4	8	30	1.83	.59	.87	-.3	1.11	1.3	.50	.52	92.6	84.4	Item4
8	9	30	1.33	.57	1.16	.6	1.15	1.5	.43	.55	85.2	83.7	Item8
7	9	30	1.33	.57	1.38	1.2	1.49	1.0	.38	.55	77.8	83.7	Item7
14	10	30	1.01	.55	.43	-1.2	.27	-1.6	.80	.58	96.3	82.9	Item14
9	11	30	0.58	.53	.93	-.1	1.25	.6	.60	.60	88.9	82.2	Item9
10	11	30	0.58	.52	1.48	1.2	1.39	1.9	.30	.61	66.7	81.4	Item10
17	11	30	0.58	.52	.36	-1.8	.27	-1.3	.86	.61	96.3	81.4	Item17
5	12	30	-0.78	.50	.44	-1.4	.34	-1.2	.84	.62	96.3	80.4	Item5
2	13	30	-1.83	.47	1.32	1.3	1.44	1.6	.47	.63	63.0	75.9	Item2
6	14	30	-2.84	.49	.88	-.5	.61	-.4	.64	.58	77.8	76.5	Item6
MEAN	7.8	30.0	.46	.75	.96	-.2	1.06	.1			85.9	83.9	
P.SD	4.9	.0	1.81	.42	.37	1.4	.72	1.3			10.6	5.2	

Appendix XXXVII: Ruth's learner Item measure (Post-test)

TABLE 13.1 Post-achievement test (Ruth) ZOU157WS.TXT Apr 13 2018 7:25
INPUT: 30 Person 17 Item REPORTED: 30 Person 17 Item 2 CATS MINISTEP 4.2.0

Person: REAL SEP.: 1.65 REL.: .84 ... Item: REAL SEP.: 2.23 REL.: .91

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
15	30	6.55	.00	MAXIMUM MEASURE				.00	.00	100.0	100.0	Item15
13	30	6.55	.00	MAXIMUM MEASURE				.00	.00	100.0	100.0	Item13
12	30	6.55	.00	MAXIMUM MEASURE				.00	.00	100.0	100.0	Item12
6	30	-0.48	.41	.99	.0	.86	-.5	.48	.45	60.0	68.8	Item6
17	30	-0.98	.45	1.14	.7	1.25	.9	.38	.49	70.0	76.2	Item17
14	30	-0.67	.45	1.02	.2	.92	-.2	.49	.49	76.7	76.2	Item14
16	30	-0.98	.50	.95	-.1	1.18	.5	.51	.50	83.3	82.9	Item16
11	30	-0.98	.53	1.15	.6	.86	-.1	.44	.49	80.0	84.8	Item11
5	30	-0.98	.53	.52	-1.7	.34	-1.6	.81	.49	93.3	84.8	Item5
8	30	-0.98	.61	.40	-1.8	.19	-1.5	.82	.45	96.7	87.9	Item8
7	30	-0.98	.61	.40	-1.8	.19	-1.5	.82	.45	96.7	87.9	Item7
10	30	-2.23	.61	1.43	1.7	1.46	1.1	.00	.45	76.7	87.9	Item10
9	30	-2.23	.68	1.32	1.3	1.38	1.8	-.08	.42	86.7	90.1	Item9
4	30	-2.59	.68	.50	-1.2	.18	-1.1	.73	.42	93.3	90.1	Item4
3	30	-2.59	.79	1.47	.9	1.09	1.8	-.16	.36	93.3	93.2	Item3
2	30	-2.59	.79	.65	-.6	.18	-.7	.60	.36	93.3	93.2	Item2
1	30	-3.41	1.06	1.20	.5	1.22	.6	.09	.27	96.7	96.6	Item1
MEAN	30.0	.00	.64	.98	-.1	1.20	.1			86.7	86.9	
P.SD	.0	2.18	.16	.39	1.0	1.23	1.1			10.4	7.1	

Appendix XXXVIII: Rasch Item measures for Ruth's TSPCK episodes

TABLE 17.1 Ruth's TSPCK episodes Analysis ZOU455WS.TXT Aug 21 2018 11:12
INPUT: 28 Items REPORTED: 28 Items 2 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.28 REL.: .65 ... Item: REAL SEP.: 2.15 REL.: .82

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
20	5	3.02	.97	MAXIMUM MEASURE				.00	.00	100.0	100.0	concept20
28	5	3.02	.38	MAXIMUM MEASURE				.00	.00	100.0	100.0	concept28
4	5	.72	.38	1.36	.9	.60	.1	.51	.58	60.0	83.0	concept4
25	5	.72	.38	1.36	.9	.60	.1	.51	.58	60.0	83.0	concept25
1	5	-1.16	.38	1.36	.9	.60	.1	.51	.58	60.0	83.0	concept1
2	5	-1.16	.38	.62	-.8	.28	-.3	.69	.58	100.0	83.0	concept2
3	5	-1.16	.38	.62	-.8	.28	-.3	.69	.58	100.0	83.0	concept3
5	5	-1.16	.38	.62	-.8	.28	-.3	.69	.58	100.0	83.0	concept5
8	5	-1.16	.38	.78	1.8	.90	1.1	-.32	.58	60.0	83.0	concept8
15	5	-1.16	.38	.78	1.8	.90	1.1	-.32	.58	60.0	83.0	concept15
18	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept18
19	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept19
21	5	-1.16	.44	.48	1.6	.50	1.3	.30	.77	60.0	89.0	concept21
22	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept22
23	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept23
24	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept24
26	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept26
27	5	-1.16	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept27
6	5	-2.58	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept6
7	5	-2.58	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept7
9	5	-2.58	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept9
10	5	-2.58	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept10
11	5	-2.58	.44	.15	-.9	.13	-.7	.98	.77	100.0	89.0	concept11
12	5	-2.58	.19	.79	-.3	.49	.0	.71	.64	80.0	78.0	concept12
13	5	-2.58	.19	.79	-.3	.49	.0	.71	.64	80.0	78.0	concept13
14	5	-2.58	.19	.90	1.8	1.13	1.2	-.15	.64	40.0	78.0	concept14
16	5	-2.58	.19	.79	-.3	.49	.0	.71	.64	80.0	78.0	concept16
17	5	-2.58	.24	.31	.7	.83	.3	.32	.42	80.0	79.7	concept17
MEAN	5.0	-1.27	1.40	.87	-.1	1.30	.0			85.9	85.0	
P.SD	.0	1.52	.14	.94	1.3	2.70	1.1			18.7	4.2	

Appendix XXXIX: Rasch Item measures for Hope's TSPCK episodes

TABLE 17.1 Hope's TSPCK episodes Analysis ZOU863WS.TXT Aug 21 2018 11:44
INPUT: 31 Item REPORTED: 31 Item 2 CATS MINISTEP 3.90.2

Person: REAL SEP.: 2.15 REL.: .74 ... Item: REAL SEP.: 3.64 REL.: .93

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
18	5	3.05	1.97	MAXIMUM MEASURE				.00	.00	100.0	100.0	concept18
8	5	.74	1.38	.63	-.8	.28	-.3	.67	.57	100.0	83.0	concept8
9	5	.74	1.38	1.36	.9	.60	.1	.50	.57	60.0	83.0	concept9
10	5	.74	1.38	1.36	.9	.60	.1	.50	.57	60.0	83.0	concept10
20	5	.74	1.38	1.36	.9	.60	.1	.50	.57	60.0	83.0	concept20
21	5	.74	1.38	.63	-.8	.28	-.3	.67	.57	100.0	83.0	concept21
27	5	.74	1.38	.63	-.8	.28	-.3	.67	.57	100.0	83.0	concept27
28	5	.74	1.38	.63	-.8	.28	-.3	.67	.57	100.0	83.0	concept28
29	5	.74	1.38	1.25	1.8	.76	1.6	-.19	.57	60.0	83.0	concept29
30	5	.74	1.38	1.25	1.8	.76	1.6	-.19	.57	60.0	83.0	concept30
31	5	.74	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept31
2	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept2
3	5	-1.17	1.47	1.38	1.8	.49	1.6	.23	.77	60.0	89.3	concept3
4	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept4
5	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept5
6	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept6
7	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept7
11	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept11
12	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept12
15	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept15
16	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept16
17	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept17
19	5	-1.17	1.47	.16	-.9	.12	-.6	.96	.77	100.0	89.3	concept19
22	5	-1.17	1.24	1.19	.5	.70	.2	.64	.67	60.0	80.1	concept22
23	5	-1.17	1.24	1.19	.5	.70	.2	.64	.67	60.0	80.1	concept23
24	5	-1.17	1.24	.98	1.6	.98	1.4	-.09	.67	60.0	80.1	concept24
25	5	-1.17	1.24	.52	-.9	.31	-.2	.80	.67	100.0	80.1	concept25
26	5	-1.17	1.24	.52	-.9	.31	-.2	.80	.67	100.0	80.1	concept26
1	5	-2.60	1.24	.52	-.9	.31	-.2	.80	.67	100.0	80.1	concept1
13	5	-2.60	1.24	.52	-.9	.31	-.2	.80	.67	100.0	80.1	concept13
14	5	-2.60	1.28	.81	1.4	1.41	.7	.19	.46	60.0	81.1	concept14
MEAN	5.0	-.56	1.40	.89	-.1	1.15	.1			86.7	85.0	

Appendix XL: Rasch Item measures for Rose's TSPCK episodes

TABLE 17.1 Rose's TSPCK episodes Analysis ZOU262WS.TXT Aug 21 2018 12:24
INPUT: 20 Item REPORTED: 20 Item 2 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.45 REL.: .77 ... Item: REAL SEP.: 2.07 REL.: .81

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
4	5	.92	.95	.87	-.5	.45	-.6	.84	.71	100.0	81.8	concept4
5	5	.92	.35	.67	-.7	.31	-.2	.66	.55	100.0	81.8	concept5
1	5	-1.19	.35	1.21	.6	.55	.1	.52	.55	60.0	81.8	concept1
2	5	-1.19	.35	.21	.6	.55	.1	.52	.55	60.0	81.8	concept2
7	5	-1.19	.35	.21	.6	.55	.1	.52	.55	60.0	81.8	concept7
8	5	-1.19	.35	.67	-.7	.31	-.2	.66	.55	100.0	81.8	concept8
9	5	-1.19	.35	.67	-.7	.31	-.2	.66	.55	100.0	81.8	concept9
10	5	-1.19	.35	.67	-.7	.31	-.2	.66	.55	100.0	81.8	concept10
11	5	-1.19	.35	.62	1.6	.90	1.1	-.36	.55	60.0	81.8	concept11
12	5	-1.19	.35	.62	1.6	.90	1.1	-.36	.55	60.0	81.8	concept12
13	5	-1.19	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept13
14	5	-1.19	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept14
15	5	-1.19	.36	.50	1.4	.81	.9	.37	.73	60.0	87.3	concept15
17	5	-1.19	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept17
19	5	-1.19	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept19
3	5	-2.36	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept3
6	5	-2.36	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept6
16	5	-2.36	.36	.18	-1.0	.15	-.7	.96	.73	100.0	87.3	concept16
18	5	-2.36	.20	.57	-.8	.36	-.1	.79	.64	100.0	78.1	concept18
20	5	-2.36	.27	.30	.7	.75	.3	.36	.45	60.0	80.7	concept20
MEAN	5.0	-1.27	.37	.90	-.1	1.40	.1			85.3	83.8	

Appendix XLI: Rasch Item measures for Mark's TSPCK episodes

TABLE 17.1 Mark's TSPCK episodes Analysis ZOU796WS.TXT Aug 21 2018 13: 0
INPUT: 23 Item REPORTED: 23 Item 2 CATS MINISTEP 3.90.2

Person: REAL SEP.: 1.67 REL.: .68 ... Item: REAL SEP.: 2.14 REL.: .82

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
3	5	3.55	1.95	.72	-.8	.30	-.3	.82	.53	100.0	81.7	concept3
14	5	3.55	1.32	.60	-.7	.30	-.2	.71	.53	100.0	81.7	concept14
23	5	3.55	1.32	1.22	.6	.60	.1	.49	.53	60.0	81.7	concept23
2	5	.92	1.32	1.22	.6	.60	.1	.49	.53	60.0	81.7	concept8
7	5	.92	1.32	1.22	.6	.60	.1	.49	.53	60.0	81.7	concept9
22	5	.92	1.32	.60	-.7	.30	-.2	.71	.53	100.0	81.7	concept10
1	5	-1.19	1.32	.60	-.7	.30	-.2	.71	.53	100.0	81.7	concept1
4	5	-1.19	1.32	.60	-.7	.30	-.2	.71	.53	100.0	81.7	concept4
5	5	-1.19	1.32	1.39	1.0	1.65	1.1	-.34	.53	60.0	81.7	concept5
6	5	-1.19	1.32	1.39	1.0	1.65	1.1	-.34	.53	60.0	81.7	concept6
8	5	-1.19	1.32	.60	-.7	.30	-.2	.71	.53	100.0	81.7	concept8
9	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept9
11	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept11
12	5	-1.19	1.23	1.09	1.2	1.75	1.0	.30	.67	60.0	83.8	concept12
13	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept13
15	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept15
16	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept16
17	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept17
18	5	-1.19	1.23	.22	-1.2	.20	-1.1	.98	.67	100.0	83.8	concept18
19	5	-1.19	1.23	1.09	1.2	1.45	1.0	.30	.67	60.0	83.8	concept19
20	5	-1.19	1.23	1.41	1.6	1.22	1.9	-.02	.67	60.0	83.8	concept20
21	5	-1.19	1.11	.75	-.4	.53	-.1	.70	.57	80.0	75.2	concept21
10	5	-2.36	1.21	1.11	.4	.73	.3	.34	.38	80.0	79.7	concept10

Appendix XLII: Interrater for Correlation analysis

Observer A	Rater_1
Observer B	Rater_2

	Observer A		
Observer B	1	2	
2	1	2	3 (55.0%)
1	0	2	2 (45.0%)
	1 (45.0%)	4 (55.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.96

Observer A	Rater_2
Observer B	Rater_3

	Observer A		
Observer B	3	2	
3	2	0	2 (50.0%)
2	1	1	2 (50.0%)
	3 (50.0%)	1 (50.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.235 to 1.000

Observer A	Rater_1
Observer B	Rater_3

	Observer A		
Observer B	3	1	
1	1	2	3 (60.0%)
3	0	2	2 (40.0%)
	1 (40.0%)	4 (60.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.96

[a] Quadratic weights

Appendix XLIII: Interrater for learner views analysis

Observer A	Rater_1
Observer B	Rater_2

	Observer A		
Observer B	2	1	
1	1	2	3 (60.0%)
2	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 0.82

Observer A	Rater_1
Observer B	Rater_3

	Observer A		
Observer B	3	1	
1	2	0	2 (50.0%)
3	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_2
Observer B	Rater_3

	Observer A		
Observer B	3	2	
2	1	2	3 (60.0%)
3	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 0.82

[a] Quadratic weights

Appendix XLIV - Identified Rose's TSPCK episodes matching the test items

Test Item	*Test Item Description*	*Corresponding content*	*Time (min)*	*TSPCK Episode*	*Category of TSPCK episode*	*Rasch Item measure*
Item 1	Pattern across alkanes	Boiling point in Alkanes	14-21 Lesson1	LP-RP/CS/CS	sophisticated	-2.36
Item 2	Reason for answer in item 1	Boiling point in Alkanes	14-21 Lesson1	LP-RP/CS/CS	sophisticated	-2.36
Item 3	Pattern across alcohols	Boiling point of Alkane/Alcohol	37-40 Lesson1	LP-CS/RP	proficient	-1.19
Item 4	Reason for answer in item 3	Boiling point of Alkane/Alcohol	37-40 Lesson1	LP-CS/RP	proficient	-1.19
Item 5	Pattern across alkanes and alcohols	Boiling point of Alkane/Alcohol	37-40 Lesson1	LP-CS/RP	proficient	-1.19
Item 6	Reason for answer in Item 5	Boiling point of Alkane/Alcohol	37-40 Lesson1	LP-CS/RP	proficient	-1.19
Item 7	Reason for higher boiling point of hexane than hexanol	Boiling point of Alkane/Alcohol	37-40 Lesson1	LP-CS/RP	proficient	-1.19
Item 8	Reason for lower boiling point of methanol than hexanol.	Boiling point of Alkane/Alcohol	37-40 Lesson1	LP-CS/RP	proficient	-1.19
Item 9	Comparison boiling point of carboxylic acids to alcohols	Boiling/melting point in methanoic acid and methanol compared	27-31 Lesson2	RP/CS/LP/CS	sophisticated	-2.36
Item 10	Reason for the answer in item 9	Same as item 9	Same as item 9	RP/CS/LP/CS	sophisticated	-2.36
Item 11	Arranging hexane, hexanol and hexanoic acid according to solubility	Solubility in methanoic acid and methanol compared	31-34 Lesson2	LP-RP/CS	proficient	-1.19
Item 12	Reason for answer in item 11	Same as item 11	Same as item 11	LP-RP/CS	proficient	-1.19

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

Appendix XLV - Identified Mark's TSPCK episodes matching the test items

Test Item	*Test Item Description*	*Corresponding content*	*Time (min)*	*TSPCK Episode*	*Category of TSPCK episode*	*Rasch Item measure*
Item 1	Pattern across alkanes	Boiling/melting versus chain length in Alkanes	0-4 Lesson2	RP/CS/CS	Proficient	-1.19
Item 2	Reason for answer in item 1	Same as item 1	0-4 Lesson2	RP/CS/CS	Proficient	-1.19
Item 3	Pattern across alcohols	Boiling/melting point in alcohols	13-16 Lesson2	LP-RP/CS	Proficient	-1.19
Item 4	Reason for answer in item 3	Same as item 1	13-16 Lesson2	LP-RP/CS	Proficient	-1.19
Item 5	Pattern across alkanes and alcohols	Boiling/melting point in butane and butanol compared	8-13 Lesson2	LP-RP/CS	Proficient	-1.19
Item 6	Reason for answer in Item 5	Same as item 5	8-13 Lesson2	LP-RP/CS	Proficient	-1.19
Item 7	Reason for higher boiling point of hexane than hexanol	Same as item 5	8-13 Lesson2	LP-RP/CS	Proficient	-1.19
Item 8	Reason for lower boiling point of methanol than hexanol.	Boiling/melting point in alcohols	13-16 Lesson2	LP-RP/CS	Proficient	-1.19
Item 9	Comparison boiling point of carboxylic acids to alcohols	Boiling/melting point in ketone, carboxylic acid and alcohol compared	29-33 Lesson2	LP-RP/CS	Proficient	-1.19
Item 10	Reason for the answer in item 9	Same as item 9	29-33 Lesson2	LP-RP/CS	Proficient	-1.19
Item 11	Arranging hexane, hexanol and hexanoic acid according to solubility	Solubility in hydrocarbons and alcohols compared	33-37 Lesson2	RP/CS	Proficient	0.92
Item 12	Reason for answer in item 11	Same as item 11	33-37 Lesson2	RP/CS	Proficient	0.92

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

Appendix XLVI – Identified Ruth's TSPCK episodes matching the test items

Learners' Achievement test		Ruth's contents and TSPCK episodes covered corresponding to test items				
Test Item	*Test Item Description*	*Corresponding content*	*Time (min)*	*TSPCK Episode*	*Category of TSPCK episode*	*Rasch Item measure*
	Identify functional group on the given organic molecule					
Item 1	Ethanoic acid	Carboxylic functional group	20-23 Lesson1	RP/LP-CS/CS	sophisticated	-2.58
Item 2	Ethyl ethanoate	Ester functional group	23-27 Lesson1	RP/LP-CS/CS	sophisticated	-2.58
Item 3	Ethanal	Aldehyde functional group	29-33 Lesson1	LP-RP/CT/WD	sophisticated	-2.58
Item 4	2-Butanol	Alcohol functional group	16-18 Lesson1	RP/LP-CT/CS	sophisticated	-2.58
Item 5	2-Bromobutane	Haloalkane functional group	11-13 Lesson1	RP/LP-CS	proficient	-1.16
	Draw simple organic molecule containing the functional group of					
Item 6	Cycloalkane	Naming cycloalkanes	28-30 Lesson2	CS/RP	simple	0.72
Item 7	Ketone	Ketone functional group	27-29 Lesson1	RP/LP-CS	Proficient	-1.16
Item 8	Ether	Naming ethers	32-36	LP-CS/RP	Proficient	-1.16
Item 9	Thiol	Thiols functional group	18-20 Lesson1	LP-RP/CT/WD	sophisticated	-2.58
Item 10	Aldehyde	Aldehyde functional group	29-33 Lesson1	LP-RP/CT/WD	sophisticated	-2.58
	Name of the structure of the given compound of					
Item 11	2,5 dimethyl 3-bromohexane	Naming haloalkanes	18-23 Lesson2	RP/LP-CS	Proficient	-1.16
	Write structural formula for					
Item 14	Dichloromethane	Naming haloalkanes	18-23 Lesson2	RP/LP-CS	Proficient	-1.16
Item 16	Diethyl ether	Naming ethers	32-36	LP-CS/RP	Proficient	-1.16
Item 17	1-butene	Naming alkenes	23-25	LP-RP/CS	Proficient	-1.16

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-Representations; CT-Conceptual teaching strategies

Appendix XLVII - Identified Hope's TSPCK episodes matching the test items

Test Item	*Test Item Description*	*Corresponding content*	*Time (min)*	*TSPCK Episode*	*Category of TSPCK episode*	*Rasch Item measure*
	Identify functional group on the given organic molecule					
Item 1	Ethanoic acid	Carboxylic functional group	21-25	LP-CS/RP	proficient	-1.17
Item 2	Ethyl ethanoate	Ester functional group	36-40	CS/RP	simple	0.74
Item 3	Ethanal	Aldehyde functional group	15-18	CS/RP/LP	proficient	-1.17
Item 4	2-Butanol	Alcohol functional group	12-15	LP-RP/CS	proficient	-1.17
Item 5	2-Bromobutane	Haloalkane functional group	7-12	LP-CS/RP	proficient	-1.17
	Draw simple organic molecule containing the functional group of					
Item 6	Cycloalkane	Naming cycloalkanes	36-37	LP-CS/RP	proficient	-1.17
Item 7	Ketone	Ketone functional group	18-21	CS/RP/LP	proficient	-1.17
Item 8	Ether	Ethers	34-36	CS/RP	simple	0.74
Item 9	Thiol	Thiols functional group	25-30	CS/RP	simple	0.74
Item 10	Aldehyde	Aldehyde functional group	15-18	CS/RP/LP	proficient	-1.17
	Name of the structure of the given compound of					
Item 11	2,5 dimethyl 3-bromohexane	Naming haloalkanes	7-12	LP-CS/RP	proficient	-1.17
	Write structural formula for					
Item 14	Dichloromethane	Naming haloalkanes	7-12	LP-CS/RP	proficient	-1.17
Item 16	Diethyl ether	Naming ethers	34-36	CS/RP	simple	0.74
Item 17	1-butene	Naming alkenes	32-34	LP-CS/RP	proficient	-1.17

Note: LP-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; RP-