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**DEVELOPMENT AND VALIDATION OF  
INSTRUMENTS TO ASSESS CONTENT  
KNOWLEDGE AND TOPIC SPECIFIC  
PEDAGOGICAL CONTENT KNOWLEDGE OF  
TEACHERS OF ORGANIC CHEMISTRY**

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Thesis presented for the degree of

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## ABSTRACT

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In 1986, Shulman described Pedagogical Content Knowledge (PCK), as the transformation of Content Knowledge into various forms which help students to understand the concepts. In a later study, Shulman (1987) identified the construct of PCK as one of the knowledge bases of teachers. Many researchers have proposed models to characterise this transformation of Content Knowledge (CK), one of the most recent of which describes the construct of Topic Specific PCK (TSPCK) (Mavhunga, 2012). This study attempts to evaluate the extent to which teachers of organic chemistry are able to transform their CK to TSPCK.

The introduction of the National Curriculum Statement in South Africa in 2006 led to changes in the curriculum for all subjects; in particular there was an increase in emphasis on organic chemistry at Grade 12 level. The current research forms part of a larger project to investigate how teachers' knowledge of their subject matter affects the way they teach across several different contexts. It is premised on the assumption that PCK develops with experience and results from the transformation of CK.

Two instruments based on the Mavhunga (2012) model were designed to assess Grade 12 teachers' TSPCK in organic chemistry. Her model proposes that topic specific PCK results from the transformation of CK; thus Content Knowledge is considered to be a prerequisite to develop TSPCK. Thus two instruments are required, one each to evaluate CK and TSPCK. A pilot study was conducted with a small group of teachers and the findings were used to refine the instruments. Expert teachers at local schools were consulted and assisted in the development process of the instruments, the final versions of which were administered to a larger cohort of 44 science teachers from diverse schools. The CK instrument was assessed as a conventional test on organic chemistry while the TSPCK instrument was scored using a specially designed rubric. The research methodology used a mixed methods approach to transform data collected into numerical clusters as well as to carry out a qualitative analysis. The data was analysed to yield raw scores which were later subjected to Rasch analysis. This measurement model was used to validate the instruments and also to convert raw scores into interval data. According to the Rasch

analysis, both instruments met the criteria of validity and internal consistency. The findings from the CK instrument revealed that the majority of teachers performed well. Teachers with university training achieved higher scores than those trained at technikons and colleges. Performance on the TSPCK instrument was not as strong as for CK; teachers with little experience revealed less complete levels of TSPCK than those with more experience. A reasonable correlation between levels of CK and TSPCK was confirmed by a value of  $r = 0.68$  ( $p < .0005$ ) for the correlation coefficient derived from a scatter plot of CK versus TSPCK. This implies that an estimated 46% of the variance in TSPCK is accounted for by the variance in CK and provides evidence for the assumption that CK is a prerequisite for TSPCK.

The main findings from this project revealed that low levels of CK are likely to result in lower levels of TSPCK while high levels of CK are likely to result in high levels of TSPCK. On the other hand the study also revealed that high levels of CK do not necessarily translate into high levels of TSPCK. An unanticipated outcome of the study was that in some cases, lower than average levels of CK can translate into high levels of TSPCK. The Rasch analysis also enabled the refinement of the CK instrument and the rubric developed to score the TSPCK instrument. The refinements will allow the researchers to use the valuable data collected during the course of this particular study as part of a data set for any future study. The instruments developed for this study have the potential to be used for a large-scale implementation to obtain a more nuanced picture of the level of PCK in organic chemistry in the teaching cohort in South Africa.

## PUBLICATION

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Davidowitz, B., & Vokwana, N. (In press). Developing an instrument to assess grade 12 teachers' topic specific PCK in organic chemistry. In M. Askew, J. Loughran, M. Rollnick, & H. Venkatakrisnan (Eds.), *Windows into mathematics and science teachers' knowledge*. USA & Canada:Routledge.

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## DEDICATION

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Through it all I have learnt to trust in God, to God be glory, without our heavenly father, the centre of my life, none of this would be possible. God has carried me through my entire life and I still do not know how to thank Him for such a favour on me. I would like to express my deep appreciation to my mother (Mrs Thobeka Vokwana); the bible says “train up a child in the way he should go: and when he is old, he will not depart from it”. Your efforts from 1993 to 1994 when preparing me for Grade 1 and during Grade 1, the Xhosa novels you used to read for me, are precious memories that I will cherish for the rest of my life and I believe they cultivated a firm foundation to my academic life. To my father (Mr Siphiwo Vokwana) your tireless support is invaluable, without you everything would remain a vision. The Lusanda SDA church, you guys have kept me sane through the whole process, and I am dedicating this thesis to you as well. Finally, since most of the people acknowledged in this study are women, I believe that they represent a small sample of the women we have in this country and so in this month of women, I am dedicating this thesis to all the hard working women in South Africa.

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## LIST OF ABBREVIATIONS

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CK	Content Knowledge
PCK	Pedagogical Content Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge
SMK	Subject Matter Knowledge
NCS	National Curriculum Statement

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# CHAPTER 1

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## 1. Introduction to the study

*In this chapter, I will give an overall view of the study and as I introduce the study I will also include the rationale behind the study, the theory which framed the research, and the research questions which the study intended to answer. I will also briefly summarise the manner in which the research instrument was designed and describe the background of the researcher who conducted this study as well as terms which were meaningful in this study.*

### 1.1. Background

Several years after South Africa achieved a new democracy in 1994, the Department of Education made major changes by introducing outcomes-based education. New curricula and syllabi were implemented at primary and secondary level in all subjects including Mathematics and Physical Sciences<sup>1</sup> (DoE, 1998). Since a relatively small percentage of learners who graduated from secondary schools entered tertiary education, the focus of secondary education was adjusted to satisfy a much wider range of constituencies than was the case in the previous dispensation. The new curriculum was phased in over thirteen years at both primary and secondary levels, resulting in the National Curriculum Statement, NCS, for Grades 1-12 (Western Cape Department of Education, WCED, 2006). Since the focus of this project is grade 12 organic chemistry, I will describe some of the changes specific to this topic.

With the introduction of the NCS in 2006, there was a shift in focus in the topic of organic chemistry for Grades 10-12 compared to the earlier curriculum known as NATED 550<sup>2</sup>.; For example topics such as amines, amides, ketones and arenes were added to the organic chemistry content for the new curriculum. In addition to the concepts in the NCS curriculum, learners are now taught to understand the links between the chemical and physical properties of compounds. Learners are also

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<sup>1</sup> Physical Science is one of the subjects offered for the National Senior Certificate examination and comprises topics in Chemistry and Physics.

<sup>2</sup> NATED is NATIONAL EDucation and 550 is the government policy promulgation number. The full title is NATED 550 (2001/08)

expected to understand the types of organic reactions, such as elimination, addition and substitution reactions. In addition, they are expected to name and be able to recognise and understand the reaction conditions for each type of reaction. Once the NCS curriculum had been implemented, questions based on organic chemistry concepts, which formerly comprised 11 % of the Grade 12 final examinations, made up 32% of the chemistry paper.

In addition, to the factors mentioned above it is acknowledged that organic chemistry is a difficult topic for students to conceptualise both at secondary and tertiary level. The difficulties inherent in the topic are not readily apparent at secondary level as the subject is taught at the introductory stage but more visible difficulties arise at tertiary level (Hassan, Hill & Reid, 2004). There are general challenges associated with the concepts of organic chemistry at all levels which contribute in making it difficult for students to grasp and one of these is the way in which organic molecules are represented. In some cases the textbooks use two-dimensional structures to represent three-dimensional molecules and students may fail to make this link in their learning. In organic chemistry learners are introduced to several types of reactions such as addition, elimination and others, whereas in other topics of chemistry they deal with less complicated reactions such ionic reactions (Hassan et al., 2004). This is a challenge in organic chemistry and physical models can play a role in understanding chemical reactions and in learning organic chemistry in general.

As I have mentioned the increased emphasis on organic chemistry after NCS was implemented means that teachers will have to devote more classroom time to this topic. New content means that teachers will be required to improve their Content Knowledge (CK) in organic chemistry and that they will also have to develop ways of transforming that knowledge into various forms that students can understand - what Shulman (1986) referred to as Pedagogical Content Knowledge (PCK).

Central to students' learning is the teachers' responsibility to ensure that learning is taking place. Teachers are steering the ship and hence it is easy to blame them when students fail. The annual report for 2009/2010 produced by the Eastern Cape Department of Education (ECDoE, 2010) noted two key outputs of the overall programme, namely target outputs and actual outputs. The actual output for the performance measures for pass rates in Grade 12 for Physical Science as quoted in

the report was 28.69% measured against a target output of 48.8%. This represents a significant difference of 19.9% between the two targets, which is equivalent to a decline of 41.1%. It may be assumed that one of the reasons for this ongoing poor performance at schools may be the lack of appropriate qualifications and knowledge of educators (CDE, 2007). One of the important roles of a teacher is to try to unpack or decompress the concepts to enable students to understand them (Ball, Thames & Phelps, 2008).

Shulman (1986) described Pedagogical Content Knowledge as the transformation of subject matter *per se* into various forms which help students to comprehend it. In a later study Shulman (1987) identifies the construct of PCK as one of the knowledge bases of teachers. This implies that amongst important factors which bring about effective teaching is whether teachers have developed PCK, which can be viewed as the skill of manipulating teachers' knowledge of subject matter into ways which will improve learners' understanding of a specific topic. It also implies that when teachers manage to use this skill effectively in their classrooms, the learners' comprehension of the topic may improve.

Kind (2009), writing on perspectives of PCK, describes nine models presented by other researchers. She notes that the majority of these models can be considered as integrative in that they favour combining CK and PCK. Only three models use the principle that PCK transforms CK. According to Gess-Newsome and Lederman (1999) in integrative models PCK is not a separate knowledge component; it includes teacher knowledge as a whole comprising CK, pedagogy and context. On the other hand, transformative models define PCK as new knowledge which results from transforming CK, pedagogy and knowledge of context for the purpose of instruction in the classroom. I have chosen to use a more recent transformative model (Mavhunga, 2012) since it has more power to explain how PCK develops (Kind, 2009).

Many models have been employed to characterise the transformation of pure content knowledge to Content Knowledge for teaching as manifested in the classroom. For example Cochran, DeRuiter and King (1993) proposed a model of PCK comprising teachers' integrated understanding of four components; namely knowledge of students, contexts, subject matter knowledge and general pedagogical knowledge.

Based on the work of Cochran et al. (1993) as well as Geddis and Wood (1997), Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) developed a model which shows the integration of teachers' internal knowledge domains to produce the visible product of these domains in the classroom, which they refer to as manifestations. Examples of these include Topic Specific Instructional Strategies and Assessment. The Rollnick et al. (2008) model is useful in that it separates the teacher's internal thought processes from what can be observed directly in the classroom, as it allows the distillation of the overall teaching strategy produced in action, as informed by the teacher's knowledge domains. Mavhunga (2012) extended the Rollnick et al. (2008) model to include the construct Topic Specific Pedagogical Content Knowledge (TSPCK) which is comprised of teachers' understanding of:

- Students' prior knowledge
- Curriculum saliency (deciding what is important for teaching and sequencing)
- What makes a topic easy or difficult to teach
- Representations including powerful examples and analogies
- Conceptual teaching strategies

Chapter 4 contains a broader description of the categories emerging from this model.

Other useful tools in capturing PCK are the Pedagogical and Professional experience Repertoires (PaP-eRs) and Content Representations (CoRes) developed by Loughran, Mulhall and Berry (2004). CoRes were initially developed by small groups of experienced science teachers working in teams, leading to the identification of Big Ideas for teaching particular topics, and subsequently, to the development of framing questions, while PaP-eRs are narrative accounts of practice designed to bring to life the ideas in the CoRes. The Big Ideas for a particular subject area such as organic chemistry highlight a number of key concepts commonly viewed by practitioners as important for students to learn in order to understand the topic (Loughran et al., 2004).

Whilst models of PCK and tools such as CoRes and PaP-eRS allow researchers to identify PCK in their research data, the process is time-consuming as most of the research is based on case studies. In addition, it is not possible to generalise the data to large cohorts of teachers in a specific context. Another option available to researchers would be to use specially designed instruments to probe teachers' CK

and PCK. While a study based on a questionnaire has been reported in the literature (Tepner & Dollny, 2011) it is not appropriate for the South African context as their questionnaire is not topic specific with respect to CK and PCK in organic chemistry. This aim of this study was to design of two instruments consisting, one on Content Knowledge of organic chemistry and the other on Topic Specific PCK, to capture the manner in which teachers transform their CK of organic chemistry.

## **1.2. Rationale**

It is unquestionable that when the South African government decided to amend the curriculum in 2006 (WCED, 2006), they meant to improve the state of education and were responding to one of the rights listed in the Bill of Rights which is contained in the Constitution of 1996, namely the “right to quality education for all”. The ways in which the educational governing bodies have attempted to fulfil this dream have been a matter of discussion among the people, in the press, communities and churches. The shift in emphasis on organic chemistry at Grade 12 level has meant that physical science teachers need to adjust their time in the classroom to accommodate these increased demands for teaching this topic.

This study does not seek to answer or provide quick solutions to the problem; however it is crucial that the knowledge and expertise of the teacher is also taken into consideration amongst other factors which play a role in student learning in any subject. The most common type of teaching in South Africa is the transmission mode (Rogan, 2004), where teachers stand in front of the classroom and teach, while students listen and take notes, with little interaction between teachers and students. The belief that influences this approach by most of the teachers is based on their understanding that a good class is one in which students sit quietly and listen to the teacher and only answer questions posed by the teacher. Even those members of the public outside the classroom situation, such as parents, still believe that a teacher is the person guiding the learning of the students and it is therefore a teacher’s responsibility to ensure a better learning environment for students, commonly judged by the manner in which students perform in important examinations. Teachers therefore play a central role in students’ learning and it is important to have some insight into the extent to which they transform their Content Knowledge for teaching.

Schools in the Eastern Cape and all other provinces in South Africa are faced by multiple factors that lead to underperformance, which has become the norm in the education system each year at different schools. One of these factors may be lack of Content Knowledge in the teachers. There are schools that were once among one of the best performing schools in the Eastern Cape, for example Mvelo High School (featured in a SABC 1 programme, Cutting Edge<sup>3</sup>, in October 2010), St Matthew's High School and many others which appear to have lost their qualified teachers in mathematics and science. This could be attributed to a lack of preparation of skillful teachers to replace those who retired or left the profession. Thus, as older teachers step down; the new teachers who are joining the profession are struggling to develop good teaching skills that are effective for learning. It is therefore very important to look at the role PCK can play in the transformation of subject matter knowledge for teaching. A sound understanding of subject matter is very important for teachers to know which teaching strategies are best suited for students' learning. Teachers need to develop their PCK in order for them to develop different strategies of teaching.

The current study will investigate the role of Content Knowledge, CK, and teachers' transformation of their CK for students to understand the concepts. In 1986, Shulman defined pedagogical content knowledge, PCK, as an act of transforming the Content Knowledge from teachers' personal understanding into various forms that could help students to comprehend the topic. The research undertaken attempts to evaluate the extent to which science teachers are able to transform their CK to PCK. Thus, the study was designed to evaluate CK and the levels of PCK for grade 12 teachers who are teaching organic chemistry. PCK can be defined as simultaneous amalgamation of teachers' Content Knowledge and the manner in which these teachers manipulate their CK for learners to comprehend. PCK includes teachers' ability to choose the most suitable and useful representations and conceptual teaching strategies that will bring effective learning of concepts to students. PCK, generally, has been explicitly characterised by researchers (Davidowitz & Rollnick, 2011; Geddis & Wood, 1997; Mavhunga, 2012) with respect to its transformative nature of teachers' understanding of a specific topic into a variety of forms of processed knowledge which students can easily understand. The study is based on the assumption that PCK develops with

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<sup>3</sup> Cutting Edge is broadcast weekly by the South African Broadcasting Corporation and focuses on presenting in-depth coverage of topical news events.

experience and, since PCK results from the transformation of CK, the level of CK which teachers possess is hypothesised to be a prerequisite for the development of this construct.

According to Mavhunga (2012), when knowledge of a specific subject matter is reasoned through the five knowledge components of transformation, it yields transformed Content Knowledge. As mentioned in section 1.1, these components of transformation include learner's prior knowledge, curricular saliency, what is difficult to teach, representations and teaching strategies. Mavhunga (2012) argues that this transformation is specific to each topic and it might be different when another topic is transformed through the same components. Hence she proposed the idea of PCK as being topic specific, namely Topic Specific PCK (TSPCK). One of the guiding assumptions in this study was that CK is a prerequisite to development of PCK. Therefore two instruments were developed, one probing teachers' knowledge of subject matter (CK instrument) and the other probing their PCK in organic chemistry (Topic Specific PCK instrument).

While case studies of selected teachers would allow a richer description of the actual situations in the classroom, instruments such as the one developed for this study provide the potential to evaluate any targeted interventions of teachers' TSPCK and are useful in that they can be administered to large groups of teachers. In her January 2012 address where she presented the Grade 12 results the Minister of Education, Mrs Angie Motshekga, mentioned a new strategy which would boost the matric results even more, namely PCK (Department of Basic Education, DoBE, 2012), thus:

.. we have a strategy in place ...our focus will be on four areas:....(4) focusing teacher development efforts on subject matter and pedagogical content knowledge.  
(DoBE, 2012)

This implies that in the near future, as there would be an increasing interest in PCK, there might be a need to develop a module on PCK for inclusion in teacher education programmes. It would be important to have a sense of where the teachers stand in terms of this construct and instruments like the one developed in this study might be very useful in obtaining this kind of insight. It could be risky to make general claims with regard to insights on PCK in general, therefore several topic specific instruments assessing particular constructs will ensure that findings would be specific to each

topic covered in the science curriculum. These claims would be fair and therefore closer to the reality of how each topic is taught.

As mentioned before, PCK in general is associated with teachers' experience, in that the more experienced a teacher, the higher the chances of having a well-developed PCK. It made sense therefore to base this study on teachers in practice, especially in a case like this project where the aim is to evaluate and capture PCK as novices are likely to possess little knowledge of this construct (Cochran & Jones, 1993; Geddis, Onslow, Beynon & Oesch, 1993). The sample for this project was drawn from physical science teachers teaching organic chemistry topics at Grade 12 level in different schools across the country. The project involved both qualitative and quantitative approaches, which included the design, validation, testing and implementation of instruments designed to assess CK and PCK in a key topic of physical science, namely organic chemistry.

### **1.3. An outline of the research design of the instruments**

In this project, two instruments were designed to assess the Topic Specific PCK of Grade 12 teachers in organic chemistry as well as their level of understanding of the concepts which are taught in the current curriculum. The aim of developing these instruments was to investigate the extent to which teachers transform their Content Knowledge in organic chemistry. It is argued in this study that the level of CK possessed by teachers and how they transform that knowledge, as well as their experience in teaching, might indicate an important link between their level of understanding of the content and PCK.

The first instrument, designed to evaluate teachers' CK, is based on the Big Ideas which were distilled from the Grade 12 chemistry curriculum by a group of expert teachers. The tasks were designed similarly to those in a standard test of concepts in organic chemistry. The instrument to evaluate the teachers' PCK is based on the categories of Topic Specific PCK of the Mavhunga (2012) model used by this study and other researchers (see Chapter 4) The rationale for designing two instruments lies in the notion of the transformation of CK to produce knowledge for teaching. Our instruments would allow testing of the hypothesis that teachers require a reasonable

level of CK to be able to develop PCK in a specific topic. The design of the instruments went through several iterations, during which feedback from a pilot study as well as from a group of expert teachers led to refinement of the instruments.

The CK data were scored according to the responses which teachers gave to the questions posed. A rubric was used to assign scores from 1 (limited response) to 4 (exemplary response) to the open-ended responses which teachers gave in the TSPCK instrument. A score of zero was assigned for blank responses. The rubric yielded numeric clusters which were subjected to Rasch, (Bond & Fox, 2007; Boone & Rogan, 2005) analysis and the details of how these were analysed will be provided in chapter 5. The scores derived from the Rasch analysis of CK and TSPCK instruments were used to construct a scatter plot of CK versus TSPCK to test the hypothesis of a possible link between these two constructs. The findings will be presented in chapter 6.

#### **1.4. Positionality and the researcher**

It was in January 2011, while attending the 40th convention of the South African Chemical Institute (SACI), that my interest in science education was triggered by presentations from two academics, Associate Professor Bette Davidowitz from the University of Cape Town and Doctor Margaret Blackie from Stellenbosch University. I cannot remember exact details of their presentation but I was moved by their topic, namely organic chemistry. This was one of the subjects which at some stage in my studies I decided to just learn by heart, and only work to pass it as I could not understand it at all. The problem took its toll from my second year until Honours level. One idea which caught my attention at this conference, in a way these presenters could not have known, was that they were answering questions which had long troubled me as I had not realised why I had never understood the topic of organic chemistry. I was intrigued and became interested in “digging a bit deeper” as it was my belief that possibly I was not the first and would not be last person to have this problem. In my excitement I thought that I had found the solution to the problems in the education system. My subsequent engagement in the field of science education research taught me that my experience with organic chemistry is part of the big puzzle which is research in chemistry education. No single study would yield an

answer. There is more research to be done and I realised that in the many pieces which make up this puzzle, I would be looking at only one part.

At the conference I met a professor from the University of Witwatersrand who referred me to the Sasol Inzalo scholarship programme (Sasol Inzalo Foundation, 2013) which subsequently provided very generous funding for my studies. At this stage I was working for a petroleum company in Mossel Bay, the PetroSA GTL refinery plant. I decided to resign from my job and start research for a Master's degree. At the beginning I was not sure whether I would be awarded the Sasol Inzalo scholarship, but I was eager to further my postgraduate studies and I decided that if I was not awarded the sponsorship I would do a Master's degree part-time at the University of Cape Town (UCT), which was more convenient than WITS University as it was closer to Mossel Bay. While being interviewed by the director of the SASOL Inzalo Foundation, I applied to study at UCT. One of the delegates at the SACI conference who gave a presentation on organic chemistry, a lecturer at the University of Cape Town, became my supervisor.

One of my first challenges was that I had to forego the expectation that I had entered the field of science education to be a messiah. Another challenge was making a transition from pure chemistry to chemistry education. I did my undergraduate studies and also BSc (Hons) in chemistry. It should be noted that there is currently no formal course in science education at UCT which would have allowed me to close the gap between my experience in pure chemistry and research in education. It was at this point that my supervisor suggested the formation of a reading group. Through reading and engaging with my supervisor, the concept of Pedagogical Content Knowledge, put forward by Shulman (1986), became a construct of interest since I was beginning to have an understanding that had my high school teachers of organic chemistry laid a good foundation in this topic I would have never struggled the way I did. PCK is used as a lens to look at how teachers transform their Content Knowledge in a variety of ways which could help learners to comprehend a specific topic and hence this became the first step of my investigation. In the case of this study the Content Knowledge under study was organic chemistry by science teachers at grade 12 level. While gathering the data for this project, I met the Director of Axiom Education Foundation, a non-profit organisation in the rural Eastern Cape. He offered me an opportunity to work at Axiom Education, and I will be joining the foundation after I

finish my Master's degree. This organisation helps both teachers and learners to improve their understanding in Mathematics, Science and Languages. This experience will help me in exploring further in the real world what I have learnt in the years I have spent carrying out research for my Master's degree.

### **1.5. Background to development of research questions**

Amongst different researchers who have paid attention to PCK since Shulman introduced the concept, there is a common agreement that this type of teacher knowledge, complex as it is, is normally associated with accomplished teachers. It is also understood that it comes through effort of trial and error in teachers. It is also believed that novice teachers have limited PCK compared to accomplished teachers. Bishop and Denley (2007) described the knowledge of accomplished teachers as an attribute that makes one wonder what it is exactly that these teachers know that gives them flexibility in their teaching, as they seem to be able to read the class situation at hand and are able to adjust their plans through on-the-spot decisions. When the situation does not proceed as planned, teachers have to find a way around any problem. Experienced teachers seem to know exactly what to do in order to accomplish their goals. On the other hand, a novice teacher faced with the same situation would find it difficult to take the lesson back on track when everything does not go according to plan. Bishop and Denley (2007) noted that if it were possible to make a list of strategies of accomplished teachers, this might benefit the novice. However, such a list would not capture the entire picture as:

Clearly these teachers are manipulating their knowledge in ways that most other teachers are not. If all the highly accomplished science teachers knew the same things, it would of course be ideal if we could simply write down what it is that they know. (Bishop & Denley, 2007, p.13).

According to Bishop and Denley (2007) the important issue is not only the level of knowledge or what the accomplished teachers know that play a large role but what they do with what they know, which brings essence to their teaching and results in learning. It is therefore believed that one cannot ignore the level of PCK which the accomplished teachers possess which is, however, only manifested in their action in a classroom environment. One might think that, since this knowledge is manifested in the classroom it might therefore be captured through interviews, questionnaires,

recorded videos and so on. There is, however, more involved. Bishop and Denley (2007) described the complex nature of PCK as:

..... maybe this is why there has been so much difficulty in 'freezing' PCK to define it – it has been described as an 'elusive butterfly'. Perhaps one reason for the problems is that PCK can only be 'seen' in action it is a dynamic construct which is not amenable to static representation. (Bishop & Denley, 2007, p. 8).

They used the metaphor of a spinning top to argue that PCK is a dynamic construct consisting of several components generated in practice through the capability of the teachers to combine or blend their individual knowledge bases. They further argued that the individual components need to be combined together and operate simultaneously to produce PCK.

As has been described in the paragraphs above, PCK is not one type of knowledge that one can pinpoint exactly. The objective of collection of different research instruments is to unravel this complexity. The aim of my research instruments is to catch a glimpse of how these accomplished teachers think, through their way of articulating their teaching in answering the tasks in the instruments. Their responses to the questions posed might yield good examples to help others, both beginning teachers and others who might need those good examples to catalyse development of their PCK. The findings of this study might be the first step in understanding teachers' possession of this PCK. It might also help other teachers who have been teaching for years but still show limited knowledge of how to transform CK to enable meaningful learning. This study forms part of a larger research project to investigate how teachers' knowledge of their subject matter affects the way they teach across several different contexts. It is for this reason that for this study I designed and evaluated an instrument to assess the Topic Specific Pedagogical Content Knowledge, TSPCK, of a sample of grade 12 teachers in organic chemistry. The research questions which the study attempted to answer were the following:

1. Is it possible to design a valid and reliable instrument for determining Topic Specific PCK of organic chemistry teachers at Grade 12 level?
2. Is there a correlation between CK and TSPCK?
3. Is there a relationship between teachers' TSPCK and level of education or years of experience?

## **1.6. Thesis Outline**

This thesis consists of seven chapters. In this first chapter I have introduced my thesis and given a brief description of the manner in which my study was designed. I have also included my background as a researcher for this study. In chapter 2, I discuss the literature which has been reviewed as framework to this study. In this chapter I consider the construct of Topic Specific PCK as developed by Mavhunga (2012). In particular I discuss the components of TSPCK which make the transformation of CK possible and also include other models which form part of the Mavhunga model. Following chapter two will be a chapter discussing the methodology which was followed to design an instrument to gather data as well as the manner in which the research was conducted using a mixed methods approach. Ethical issues related to the study will also be discussed in this third chapter. Chapter 4 will discuss the design of both CK and PCK instruments as well as the rubric which was used to score the PCK instrument. The following chapter describes the data analysis and the manner in which instruments were scored and includes the refinement of the rubric. In chapter 6, I will discuss the quantitative data which was analysed using the Rasch model (Bond & Fox, 2007) and will include the findings. The final chapter gives a brief discussion of the implications of this study. Following these chapters will be a list of my references and the appendices.

## **1.7. Terms relevant to the study**

Two terms are used frequently in the thesis, namely instrument and content knowledge.

This study will describe the design of instruments to assess teachers' TSPCK in organic chemistry. As stated previously there are two instruments, one to probe content knowledge and the other to assess levels of TSPCK. The term, questionnaire, is used in those contexts where reference is made to published work in which the authors use this term.

While several terms have been used to describe the content of specific disciplines, the term subject matter knowledge represents an overall conception of four components among which is listed content knowledge, described as the “facts and concepts of the subject matter” (Cochran & Jones, 1998). This is the definition of content knowledge, CK, used in this thesis.

University of Cape Town

## CHAPTER 2

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### 2. Literature Review

*The construct of Topic Specific Pedagogical Content Knowledge, TSPCK, was used to conceptualise my study. In the literature which I review, I discuss the TSPCK model which was constructed by Mavhunga (2012), focusing particularly on the components of TSPCK which make the transformation of Content Knowledge, CK, possible. The model views the transformation of specific topics of CK through five knowledge components namely, learner prior knowledge, curricular saliency, what is difficult to teach, representations and conceptual teaching strategies. In my study I used these knowledge components to analyse and portray PCK of experienced science teachers in a specific topic, namely organic chemistry. Mavhunga (2012) argues that PCK resulting from the transformation through the five knowledge components would be similar to that seen in experts and so PCK resulting from this transformation would be premised within a specific topic and hence called Topic Specific PCK.*

*The TSPCK instrument which has been designed for my study was based on these five components of transformation in a specific topic and aimed at investigating the transformation of this topic by a cohort of teachers. Hence this model was found suitable to conceptualise my study because it deals with transformation of CK of a specific topic. Since Mavhunga's (2012) model also acknowledges the work done by other researchers in capturing the development of PCK, I will refer not only to the Mavhunga model but also acknowledge the other models from which it is derived.*

#### 2.1. Introduction

This study acknowledges the concept of PCK as an act of transforming Content Knowledge from teachers' personal understanding into various forms that could help students comprehend the topic. Shulman (1986) identified Content Knowledge as a knowledge that teachers should possess in the subjects they are teaching. The particular point of view which is important for this project was the process of transformation of CK for effective teaching, suggesting that CK alone is not sufficient for teaching but it is only when transformed to PCK that it yields positive effects in

learning of students. This concept was one of the foundations which framed this study.

A number of researchers became interested in Shulman's (1986) powerful theoretical idea of PCK and many attempted to define the concept according to how they viewed and understood it. Cochran, DeRuiter and King (1993) constructed a model of Pedagogical Content Knowing as a dynamic process which continues to develop throughout a teacher's career. This model describes knowledge categories which are the sources for development and growth of PCK. The knowledge domains which continued to grow were pedagogy, subject matter, students and context, thereby producing growth in the level of PCK of teachers. In this model, Content Knowledge forms part of the knowledge categories which inform the development and growth of PCK. Geddis and Wood (1997) focused particularly on the relationship between Content Knowledge and PCK, thus further elaborating on the knowledge possession which informs the transformation of CK. For example, in their focus on teaching as a process of transformation of Content Knowledge, Geddis and Wood (1997) observed that this process emerged from knowledge of learners' prior concepts, subject matter representations, instructional strategies, curriculum materials and curricular saliency. Magnusson, Krajcik and Borko (1999) describe the construct of PCK as the knowledge base of teachers which guides learners to effective learning of a specific topic. Their model shows the knowledge components which they argue lead to PCK.

Several researchers have demonstrated a correlation between CK and PCK. For example Rollnick et al. (2008) inferred manifestations of teachers' knowledge domains through classroom observations. Based on their study, they constructed a model to capture and portray PCK. In revising the Rollnick et al. (2008) model, Davidowitz and Rollnick (2011) found that teachers' beliefs also interact with teachers' internal knowledge domains as described by Cochran et al. (1993) in developing PCK. Mavhunga's (2012) model of Topic Specific PCK builds on these studies and will be the theoretical construct for my study as it emphasises the importance of Content Knowledge which is transformed to produce TSPCK in teachers.

It should be noted that PCK has been described as being topic specific by a number of researchers, including Mavhunga, (2012), Magnusson et al. (1999), Veal and

MaKinster (1999). I have focused on this construct aspect in particular as I am building up a case for investigating transformation of CK in a specific topic. I will therefore take the reader through the models which are incorporated in the Mavhunga (2012) model, showing how the model builds on previous research to frame this study and draw attention to how CK relates to Topic Specific PCK.

## **2.2. Teaching Organic Chemistry**

Organic chemistry has long been regarded as a difficult topic in the curriculum at both secondary and tertiary levels (Green & Rollnick, 2006; Hart, 1925; Katz, 1996). For example, many years before Shulman (1986) proposed the idea of PCK, Hart (1925) reflected on his teaching of organic chemistry and came to the conclusion that a teacher who is not capable of putting him/herself in the shoes of a learner is not fit to teach. In his paper he recalls the story of a colleague who described how he had been taught about the preparation of oxygen gas which was described as a colourless and tasteless gas. All that was on the colleague's mind was a question of what a gas was, not to mention that the gas was oxygen. The teacher was explaining how this gas would be prepared; however, to the colleague it appeared to be a foreign language. Hart (1925) noted that the failure to make the necessary links for learners was also common to the teaching of organic chemistry at the time. On reflection he was not surprised to find that students hated organic chemistry. He decided to change his approach to teaching organic chemistry which was more complex. If a teacher is able to consider a specific topic from the learner's point of view, it means that the teacher will be able to take into account important knowledge components such as learner's prior knowledge, including misconceptions, and therefore will have an understanding of which concepts are difficult to learn and which concepts are central. Hart (1925) argues that a good teacher would put himself in the learner's position and therefore teach the topic as if all the students had little prior knowledge. According to Mavhunga (2012) this would require a teacher with good understanding of the transformation through the five knowledge components of her model. In a study which explored the role of the nature of the discipline in improving understanding, Green and Rollnick (2006) determined that there are topics which are linear while others are non-linear. Organic chemistry is an example of a linear sub-discipline where comprehension of basic concepts is essential in order to

build a secure knowledge base. It means that if there are gaps in building up some of these concepts then there will be a problem in the knowledge base as a whole.

### **2.3. PCK as transformation of content knowledge**

The idea of PCK was introduced by Shulman in his 1986 paper and is further elaborated in his paper in 1987. PCK is defined as an amalgam of knowledge that makes possible the transformation of knowledge into powerful, teachable forms which students could easily understand (Shulman, 1987). The amalgam of knowledge referred to in the statement above is that of content and pedagogy, and PCK is regarded as teachers' special form of professional understanding (Shulman, 1987). PCK provides a platform for CK blended with pedagogy as a prerequisite for the journey of teacher preparation. In describing PCK Shulman (1986) takes into consideration the ways in which teachers teach their subject, having identified what they know about the subject, students and curriculum they are dealing with and therefore how teachers transform their knowledge of a particular topic. According to Shulman (1987, p. 8), there are seven categories on which teacher knowledge for teaching should be premised. These include:

- (i) Content knowledge (CK)
- (ii) General pedagogical knowledge,
- (iii) Curriculum knowledge,
- (iv) Pedagogical content knowledge (PCK),
- (v) Knowledge of learners and their characteristics,
- (vi) Knowledge of educational contexts,
- (vii) Knowledge of educational ends, purposes and values, and their philosophical and historical backgrounds.

Among the seven categories above, PCK and CK are designated as two different knowledge bases for teaching; PCK is defined as amalgam of content and pedagogy. This means that CK has a significant role or impact on PCK as it forms part of the constructs which define PCK. A series of studies conducted by Shulman, provided evidence that;

..... knowledge, understanding and skill we see displayed haltingly and occasionally masterfully among beginners are demonstrated with ease by the expert.

(Shulman, 1987, p. 5)

Shulman's observation is very interesting as it allows an understanding of what experts have or do which makes them labelled as those who easily demonstrate the knowledge, skills and understanding described above.

A number of researchers have shown interest in PCK especially researchers in the field of science education, for example Bishop and Denley (2007), Park and Oliver (2008). PCK is not only knowledge that teachers should have; it allows teachers to reason about their Content Knowledge, and it enables them to be flexible in using their CK, adjusting it according to the conceptions and misconceptions of their learners. This process allows teachers to develop an understanding of conceptual representations and instructional strategies which address the difficult topics so that learners can comprehend that specific topic.

Shulman (1986) elaborates the importance of PCK, stating that:

Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners, because those learners are unlikely to appear before them as blank slates.

(Shulman, 1986, p. 9 & 10).

The benefits included in the possession of PCK are further demonstrated by Shulman's view that:

Within the category of pedagogical content knowledge, I include, for most regularly taught topics in one's subject area, the most useful forms of representations of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others.

(Shulman, 1986, p. 9).

The last two quotes appear in the majority of studies of PCK which have been conducted following the publication of Shulman's papers in 1986 and 1987, for example Bishop and Denley (2007), Geddis et al., (1993), Gess-Newsome and Lederman (1999) and Park and Oliver (2008). These studies emphasise the importance of CK and PCK and show the way in which they are closely related to each other. It is almost not possible to mention PCK without further explaining the

term using CK to define it. Many ideas and models of PCK are built upon this understanding and hence it is very important for this study to acknowledge the construct of general PCK even though my study is based on PCK in a specific topic.

#### **2.4. Models of PCK developed by other researchers**

Most models of PCK proposed by other researchers focus on how to gain access to teachers' PCK. These studies have investigated how PCK is developed in novices and whether there is a possible way of gaining access to PCK of those regarded as experts; see for example Cochran et al. (1993), Geddis and Wood (1997) and Rollnick et al. (2008). In this regard these researchers expand the notion of PCK. A discussion of some of these models is presented below.

Cochran et al. (1993) expanded the concept of PCK in terms of a model of Pedagogical Content Knowing (PCKg). They described PCK from a constructivist point of view which could be useful in teacher education preparation. They proposed a model of PCK comprising teachers' integrated understanding of four components: namely, knowledge of students, contexts, subject matter knowledge and general pedagogical knowledge. Other researchers modified the definition of PCK as described by Shulman (1986). For example, Veal and MaKinster (1999), proposed a taxonomy of PCK as a hierarchy consisting of three levels which they found to be inter-related. These researchers defined PCK as translation of Content Knowledge into sections which a particular group of students could easily grasp, using instructional strategies in that particular context. All these attempts were working towards giving a clear picture of how PCK develops, the outputs of PCK and how CK is transformed.

##### **2.4.1. Knowledge categories of PCK**

The model of Cochran et al. (1993), as has been mentioned, categorised knowledge involved in PCK into knowledge of pedagogy, subject matter, students and context. The model defines PCK as a dynamic process from which teachers' understanding of the four knowledge components grows according to the exposure they have in a classroom environment. The researchers defined this process as Pedagogical Content Knowing, PCKg. It means that PCK is not established over a day or through

college but comes with experience in the classroom as a teacher reflects on his or her teaching. In addition, trial and error processes allow the growth and development of his or her teaching. PCKg is therefore a continuous process of knowing and hence the PCKg model is a modified version of PCK which defines PCK as a developmental process of knowing in a teacher preparation. It is likely that as pedagogical content knowledge increases so does the teachers' ability to make use of their own comprehension to create strategies that focus on teaching specific topics for students to construct a useful understanding in a given context.

Although Cochran et al. (1993) defined the concept of PCK from a constructivist point of view; PCKg still deals with the importance and benefits of teachers who have a better knowledge about their students, since every learner has his/her own preconceptions. It is crucial for teachers to have an understanding of all these preconceptions and knowledge constructed by students for effective learning. Teaching should focus on the learning in context, paying attention to teaching specific content with respect to that certain group of students in a certain context that suits them. Geddis et al. (1993) and Shulman (1986) also mentioned the importance of having knowledge of students for better transformation of subject matter for effective teaching.

The constructivist notion of PCK is based on the integration of teacher knowledge domains, which implies that it is only when teachers know the subject matter, students, pedagogy and environmental contexts that they are able to construct knowledge of a specific topic. For example, before teachers construct effective instructional strategies for students' understanding they need to go through a process of knowing the students' pre/misconceptions, what representations can address students' problems, as well as the nature of the curriculum. Magnusson et al. (1999) argued that a subject specialist and a teacher could be distinguished clearly with respect to these questions and noted:

What shall I do with my students to help them understand this science concept? What materials are there to help me? What are my students likely to already know and what will be difficult for them? How best shall I evaluate what my students have learned?  
(Magnuson et al., 1999, p. 95).

In the model of PCKg developed by Cochran et al. (1993), there is an emphasis on teachers developing and allowing growth of their four domains of teacher knowledge

from limited to exemplary through experience and reflective trial and error practices. It might also be an indication that if these are internal teacher knowledge domains there must be ways or indications of their presence that can be seen when a teacher is in a classroom environment. For example in Geddis et al. (1993), the differences in teacher knowledge domains, namely the students' prior knowledge and knowledge of curriculum, were visible in the way two novice teachers and an expert dealt with a specific topic in a classroom context. The findings from Geddis et al. (1993) were used by Rollnick et al. (2008) to develop their model of PCK which proposes that the level of teacher knowledge domains can be seen in a classroom environment through manifestations which can be observed directly. This model will be discussed in section 2.4.3.

#### **2.4.2. Transformation of Content Knowledge into Pedagogical Content Knowledge**

Geddis and Wood (1997) extended Shulman's (1986) idea of pedagogical content knowledge and further elaborated on this construct by identifying components which impact on the transformation of Content Knowledge, namely learner's prior knowledge, effective teaching strategies, alternative representations of subject matter, curricular saliency and what is difficult for students to learn. These authors use the term Curricular Saliency to refer to teachers' understanding of the place of a topic in the curriculum and the purpose(s) in teaching, their decisions to leave out certain aspects of a topic and their awareness of how a topic fits into the curriculum. The transformation of Content Knowledge emerges from the transformation of the knowledge components given above. In a case study of two teachers, a novice and an expert, Geddis et al. (1993) found that all the components above play a role in the transformation of Content Knowledge. It is assumed that novices are likely to have limited knowledge of the components described above compared with experts, although this might not always be the case. PCK gives a teacher an understanding of what possible misconceptions there are within the learner, and therefore they can prepare the appropriate teaching strategies as well as relevant representations needed. PCK is concerned about students' learning and it helps teachers to deal with the difficulties students experience in learning a particular topic. Thus novice teachers may not address learners' difficulties because they have limited

pedagogical content knowledge to transform their knowledge of content into various forms that learners can comprehend. It could be assumed that a teacher chooses specific representations having considered other important aspects of teaching, such as how content might be ordered or represented to take specific account of particular intentions, students and context and so on. The transformation of subject matter is therefore topic specific. In any subject, there might be difficult topics which would require teacher's ability to transform the subject matter into a form that is accessible to students. It takes a well-developed teacher with good skills to be able to achieve this (Shulman, 1986).

Geddis et al. (1993) found that expert teachers revealed developed PCK although they found it difficult to articulate a reason for the way in which they transform their knowledge, thus making it difficult to say what they know in terms of PCK. On the other hand, it is difficult for novices to cover the curriculum requirements of a topic while at the same time making sure that the students understand the content. Novice teachers look at these topics at a superficial level and do not go into depth with respect to the curriculum (Geddis et al. 1993).

In my opinion, the risk of teachers translating exactly what is in the textbook without paraphrasing and expanding concepts is that students might find it difficult to make sense of the particular topic. They may then study only to pass exams by memorizing the content or practising previous examination papers but struggle to link the concepts of these topics to the outside world contexts. Expert teachers deal with learner difficulties by applying their knowledge of other different topics relative to the whole curriculum, and that is called curricular saliency. Teachers can only have a good understanding of curricular saliency once they learn and understand which topics are the most important, the amount of time that should be spent on these topics and the order in which they should be taught.

Teachers exercising their PCK also have an opportunity to understand what makes a particular topic difficult/easy to learn. This was the fundamental explanation of PCK (Shulman, 1986, p. 9 &10), who reasoned that transformation of content knowledge occurred through awareness of effective teaching strategies, representations of subject matter and also understanding of the curriculum as a whole. All these types

of knowledge are needed for effective transformation of Content Knowledge into forms that students could understand (Geddis et al., 1993).

Assessment tasks might increase the awareness of teachers not only in how to manage their classrooms, classroom activities, homework etc. but also may encourage them to consider ways in which they can offer better transformed subject matter for students to learn and understand the concepts which will be assessed in homework, classwork and examinations.

### **2.4.3. CK and the development of PCK**

The work by Cochran et al. (1993) described above is one of the starting points in the Rollnick et al. (2008) model, namely the concept of the four domains of teacher knowledge which are included in PCK. Cochran et al. (1993) only explored the knowledge underlying teacher preparation to produce PCK but the model still left a question of how these teacher domains have been integrated into PCK. It was not clear how these domains together would produce effects that are visible in the classroom. The domains of teacher knowledge are internal constructs of teachers but surely there should be a way in which the end products in teachers who possess these domains of teacher knowledge can be observed or assessed. It is important that these knowledge domains are made accessible so that it can assist those who still need help in developing their knowledge of these four teacher domains.

Rollnick et al. (2008) developed a model for PCK to investigate the influence of CK of teachers on the development of their PCK. The model was aimed at inferring the influence or impact of domains of teacher knowledge on their PCK from manifestations of teacher knowledge which are observable in classrooms. Rollnick et al. (2008) used the four components of teacher knowledge domains that were developed by Cochran et al. (1993) to construct their model, which is shown in the diagram below, Figure 2.1. It shows that the four components, knowledge of subject matter, students, general pedagogical knowledge and knowledge of context, are the main domains of teacher knowledge that play an important role in combining to produce PCK in order to produce observable products in classrooms, which they called manifestations of teacher knowledge.

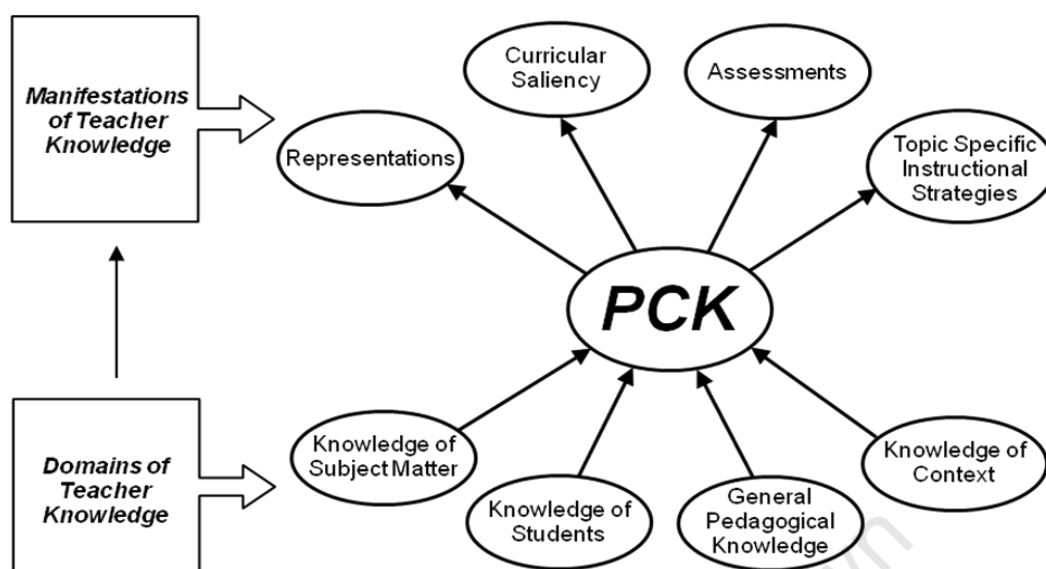


Figure 2.1 Rollnick et al. (2008) model of PCK

It is clear then that if the teachers' levels of understanding of the four internal domains were to be examined, researchers would have to look at manifestations of these domains in the classroom. Rollnick et al. (2008) explored manifestations of teacher knowledge using examples from two case studies which were conducted with two secondary level teachers and one tertiary level teacher who was teaching in an access programme. All these teachers were teaching in specific topics.

Rollnick et al. (2008) captured the four manifestations namely, representations, curricular saliency, assessment and topic-specific instructional strategies and used these to portray the level of understanding of CK in teachers and its influence on teachers' PCK. The two secondary level teachers both revealed lack of understanding of the subject with little confidence in their CK, which translates to lower levels of PCK. On the other hand, a teacher portraying well-developed CK, managed to pose different strategies of representing concepts in the specific topics, amount of substance and chemical equilibrium.

It has been shown that sometimes teachers do not find it easy to articulate their practice (Loughran et al., 2004; Shulman, 1987) despite revealing good CK. Content Representations, CoRes, (Loughran et al., 2004) proved to be a good tool for capturing teachers' PCK. CoRes originate from a designed activity with a group of expert teachers which makes it possible to identify the Big Ideas for teaching specific

topics. Rollnick et al. (2008) found that CoRes made it possible for teachers' use of representations, topic-specific strategies and curricular saliency to be uncovered during the interviews carried out with the teachers mentioned above.

In a later study by Davidowitz and Rollnick (2011), the model described in Figure 2.1 was used to portray and capture PCK as well as the influence of teacher beliefs. The modified model by Davidowitz and Rollnick (2011) will be discussed next with beliefs as a central issue playing a role in the way in which teachers teach.

#### **2.4.4. Influence of beliefs on PCK**

A number of researchers have built their research based on the domains of teacher knowledge on the Cochran et al. (1993) model, showing the potential of these domains in teacher preparation. The model by Davidowitz & Rollnick (2011) elaborates on the influence which teacher beliefs also exert on the teachers' knowledge. These researchers argue that:

Beliefs can be powerful mechanisms supporting the formation of constructive personal theories, which in turn inform practice.

(Davidowitz & Rollnick, 2011, p. 357).

Davidowitz & Rollnick (2011) argued that it is important for the PCK of those teachers referred to as experts to be captured and portrayed for the use by others, especially novice teachers. The manner in which expert teachers transform their Content Knowledge into a form which students can comprehend as well as their beliefs could be helpful in revealing the fruitful results of transformed subject matter. It is important that expertise of good teachers be passed on to novices who may find strategies which might help them speed up the development of their PCK especially in courses as challenging as organic chemistry, which is regarded as difficult for students to comprehend (Green & Rollnick, 2006; Hart, 1925; Katz, 1996).

The expert teacher's beliefs had a crucial influence in the manner in which he taught organic chemistry at second year university level. By observing the lecturer during formal teaching and tutorials, Davidowitz and Rollnick (2011) found that the lecturer made explicit to the students his belief that an understanding of key concepts which underpin the discipline would make life less complex for them. Thus he endeavoured to ensure that they understood the fundamentals very clearly before introducing to

them the main part of the course. It is likely that there are beliefs in every teacher which motivate his/her actions in the classroom. The paper by Davidowitz and Rollnick (2011) acknowledges that organic chemistry is considered as one of the more difficult topics experienced by students. Associated with this difficulty is the poor link between the levels of organic chemistry from the different levels of chemistry, namely grade 12, first and second year chemistry. A teacher with well-developed PCK like the lecturer observed in their study recognises these difficulties and uses valuable teaching time to attend to the issues that might arise because of these problems.

Since Davidowitz and Rollnick (2011) found a link between teacher knowledge and beliefs about teaching, they modified the Rollnick et al. (2008) model as shown in Figure 2.2 below.

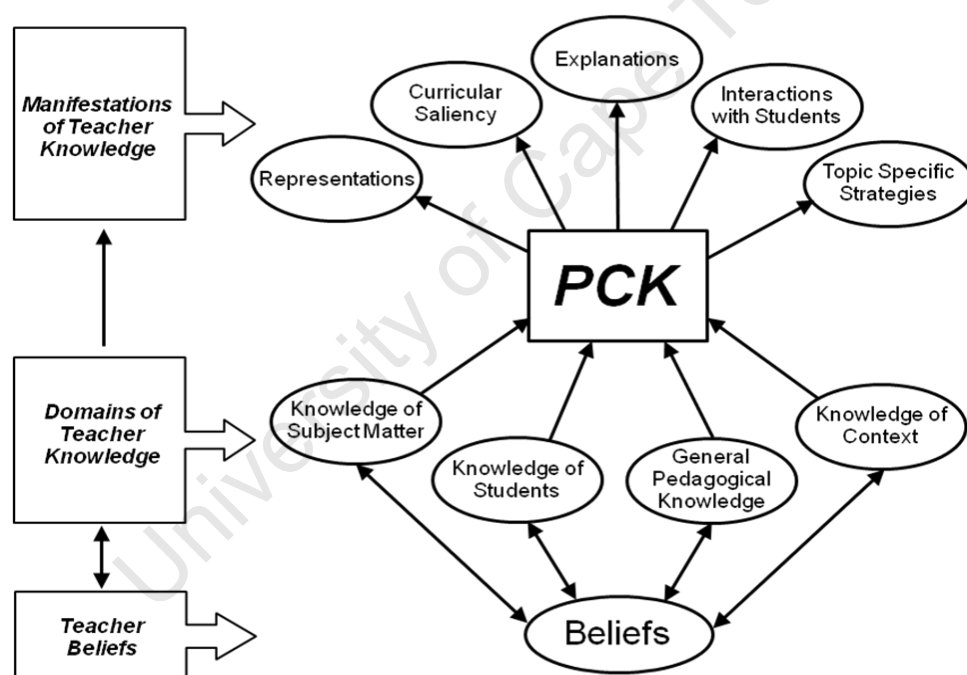


Figure 2.2 A modified PCK model, Davidowitz & Rollnick (2011)

Beliefs are regarded as crucial and influential in the way a teacher teaches and are shown to underpin the domains of teacher knowledge. Five categories were observed as being the manifestations of the lecturer's PCK. In addition to the categories of explanations, interactions with students and topic specific strategies observed by Rollnick et al. (2008), two new categories, explanations and interactions with students were observed in the study of the expert lecturer (Davidowitz &

Rollnick, 2011). Beliefs can be regarded as the driving force behind any move a teacher makes in teaching in a particular way. The transformation of CK and the influence of beliefs, make it clear that the knowledge of students, of the gaps and difficulties they might have brought into the classroom and teacher's beliefs of what needed to be done can play a role in the success of teaching a particular topic.

The Davidowitz and Rollnick model (2011) shows the beliefs and domains of teacher knowledge as inter-related with one another, as indicated by the double-headed arrows in Figure 2.2 above. The teacher's knowledge of subject matter together with his/her beliefs gives an idea of what could help students to confront the difficulty of the topic and what could possibly work to enable them to learn a particular topic. Knowledge of the previous cohorts of students entering the same class plays a role as a teacher can draw from that previous experience in assisting the current students with what could be lacking in their learning. The beliefs which are inter-linked to knowledge of students, knowledge of subject matter, knowledge of general pedagogy and knowledge of context were revealed in experts and can be regarded as a compass which can show the teacher a direction desirable for students to follow.

While the researchers above have developed models showing that CK and PCK are integrated, others have developed hierarchies of the components of PCK. Some of these are discussed below.

#### **2.4.5. Hierarchy of the components of PCK**

Veal and MaKinster (1999) took a slightly different approach to PCK from other researchers and developed two taxonomies of PCK, namely general PCK and attributes of PCK. In the former, which provides a hierarchy in the relationship between the components, these researchers appear to shift the focus on PCK from that contributed by models discussed previously to providing an illustrative model in a form of taxonomy showing the hierarchy between the components of PCK. The components recurring most frequently for the PCK taxonomies provide clues about which components are to be considered the most important. The hierarchy of their PCK taxonomy is shown below in Figure 2.3, which demonstrates that the starting level in the hierarchy is General PCK.

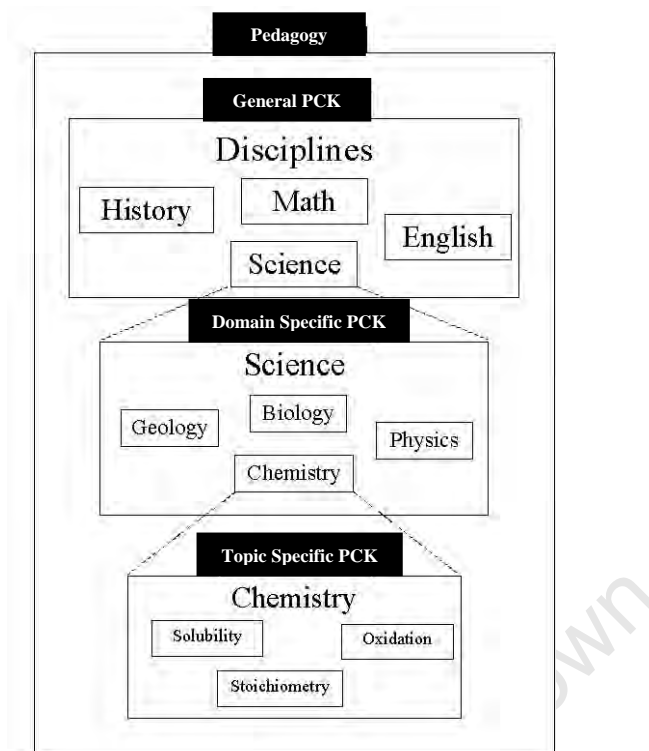


Figure 2.3 A model of general taxonomy of PCK, Veal & MaKinster (1999).

The model elaborates the hierarchy of PCK components from the most general component, which is General PCK as knowledge of pedagogical skills across all disciplines, to the most specific level in the PCK components which is Topic Specific PCK. This component was found to be the most relevant construct to my study, which is directly framed from the components of Topic Specific PCK described by Mahvunga (2012).

Within a particular domain such as science there are different topics, and these might need specific subject representations with specific instructional strategies which might be different from a case of another topic within the same domain. According to Veal and MaKinster's (1999) taxonomy, PCK is topic specific. It is thus reasonable that one takes into consideration the manner in which teachers deal with each topic. It is for this reason that my study will focus specifically on the lower part of the general taxonomy which is Topic Specific PCK. Mavhunga (2012) also considers the transformation of Content Knowledge to be topic specific, which corresponds to the level of Topic Specific PCK in the taxonomy in Figure 2.3 above, Veal and MaKinster (1999) argued that before a teacher reaches the stage of Topic Specific PCK, they

should have a solid base in pedagogy, namely general PCK and domain specific PCK.

### 2.4.6 The topic specific nature of PCK

The topic specific nature of PCK is described in a wide range of literature, (Geddis & Wood, 1997; Magnusson et al, 1999; Mavhunga, 2012; Veal & MaKinster, 1999). The transformation of subject matter with respect to a specific topic is premised with the construct of Topic Specific PCK. According to the Magnusson et al. (1999) model, Figure 2.4, PCK is reflected as an understanding of teachers in helping learners to comprehend a specific subject matter. Among the various knowledge components which are included in PCK and which are also shaped by orientations to teaching a specific topic is knowledge of instructional strategies which lead to science specific strategies and strategies for specific science topics. This kind of knowledge helps teachers in understanding topic specific strategies, which are seen through conceptual representations and activities which teachers articulate in a classroom environment.

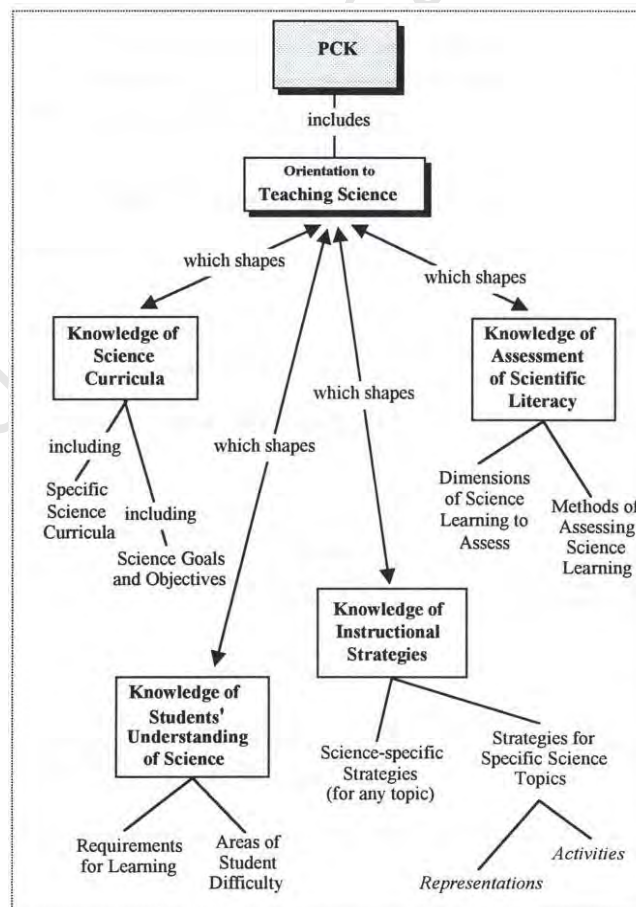


Figure 2.4 Magnusson et al's. (1999) model of PCK

Among the domains and the interrelatedness depicted in the Magnusson et al. (1999) model is the very interesting concept of the topic specific nature of PCK aligned with knowledge of instructional strategies. This implies that, for any specific topic, the representations, which sometimes involve specific teaching strategies, are very important for that particular topic. Mavhunga (2012) argued that the transformation of a specific topic is reasoned through the five components of her model to produce not only general PCK but also Topic Specific PCK. The model proposed by Magnusson et al. (1999) shows representations and activities as being important for a specific topic while at the same time being derived from an orientation of teaching science, thereby constructing better PCK as a whole.

The Magnusson et al. (1999) model explains the links between the domains of teacher knowledge and how they connect to PCK, see Figure 2.4. They describe PCK as comprising of several components, showing the interconnection of these components with respect to science teaching. Magnusson et al. (1999) argued that the components of PCK are subject-specific rather than general and therefore the processes involved in the components of PCK for science teaching might differ from the ones involved in biology teaching. Their model, Figure 2.4, shows that PCK is developed from the knowledge domains which are informed by orientations to teaching science, which in turn depends on the domains of knowledge of students' understanding of science, knowledge of science curriculum, knowledge of assessment of scientific literacy and knowledge of instructional strategies. The interconnection between the orientation for science teaching and the domains for science teaching shows that the development of each is informed by the knowledge of the other.

#### **2.4.7 Topic Specific Model of PCK**

Based on the work of previous researchers described above, Mavhunga (2012) developed the construct of Topic Specific Pedagogical Content Knowledge (TSPCK) which is described as the capacity to transform the subject matter of a given topic for the purpose of teaching. TSPCK is also related to Ball et al.'s (2008) concept of specialised content knowledge for teaching in mathematics. The Mavhunga (2012) model of PCK is informed by, among others, the views of Geddis and Wood (1997,

that consider subject matter transformation being reasoned through a variety of knowledge components and these are:

#### *Learners' Prior Knowledge*

This knowledge component concerns the learners' preconceptions and misconceptions which they might already have before learning a specific subject matter.

#### *Curriculum Saliency (deciding what is important for teaching and sequencing)*

The term, Curricular Saliency (Geddis & Wood, 1997) refers to the teacher's understanding of the place of a topic in the curriculum as a whole and the purpose(s) in teaching it, for example which topics are fundamental and which are peripheral. This understanding would influence planning of lessons with respect to the amount of time spent on a particular aspect of a topic and the depth to which it should be covered.

#### *What makes a topic easy or difficult to understand and teach*

This knowledge helps teachers to recognise gate-keeping concepts within a particular topic as well as concepts which might be difficult for students to comprehend. This understanding will then help teachers in developing conceptual representations and instructional strategies which might be useful in confronting the difficulty of the concepts.

#### *Representations including powerful examples and analogies*

This is a knowledge component which includes a variety of conceptual representations in a specific topic such as models, analogies, illustrations and examples, which help teachers in re-enforcing particular concepts. The topic of organic chemistry depends on explanation of concepts mainly at symbolic level and understanding of this component would help teachers to determine which representations should be used to represent these concepts, as visualisation of the structure of molecules is one of the common problems in the topic of organic chemistry (Bucat, 2004).

#### *Conceptual Teaching Strategies*

It is the knowledge component which informs teachers about teaching strategies which could be used for instruction in confronting learner misconceptions and difficult

concepts in a particular topic. The Mavhunga (2012) model is shown in Figure 2.5 below.

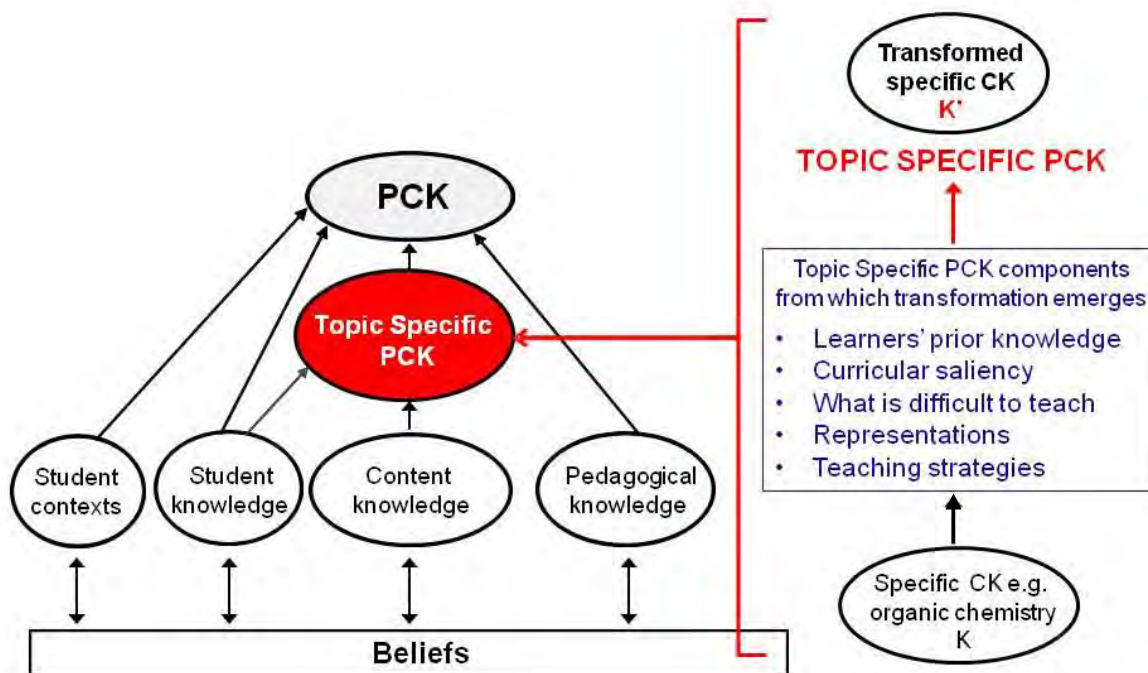


Figure 2.5 A model of TSPCK developed by Mavhunga (2012)

The model emphasises the way in which Content Knowledge is transformed. Content Knowledge forms part of a teacher's internal knowledge domains which all feed into PCK. The model expands the manner in which CK (K) is specifically transformed into Content Knowledge for teaching (K') a form which students can understand. Specific Content Knowledge (K), one of the domains of teacher knowledge, is expressed through the five components of Topic Specific PCK shown in the model and results in transformed specific Content Knowledge (K'). When K is transformed to K' it creates material which can be understood by students.

An example of the transformation of CK to TSPCK was reported by Davidowitz and Rollnick (2011) who carried out a case study of a lecturer of organic chemistry. During one of the lectures which they observed, the lecturer stressed that students would have to learn the skill of depicting three dimensional structures in two dimensions. He is aware that this is a fundamental concept in the discipline of organic chemistry. The lecturer emphasises this concept by drawing the structure of propane on the blackboard and annotating it to illustrate key features of the drawing thus demonstrating his TSPCK.

The model above implies that for any specific topic transformed through the five knowledge components, the results of that transformation will differ from topic to topic. There are processes which might be applicable when transforming a topic such as organic chemistry that are different from those which will be applicable in teaching chemical equilibrium, hence the concept of Topic Specific PCK (Mavhunga, 2012). Since the focus of Mavhunga's study was to capture the transformation of CK via instruments and recorded interviews, the manifestations in the classroom noted by Rollnick et.al. (2008) as well as by Davidowitz and Rollnick (2011) are not included in the Mavhunga (2012) model.

In my view, a teacher with good PCK is not the one with the most knowledge but the one who is able to transform his/her Content Knowledge into a teachable form. PCK has been defined from the perspective of teachers' knowledge but effective teaching is what is important for students' understanding to ensure meaningful lessons. It is for this reason that most of the work on PCK described above, for example, Cochran et al. (1993), includes knowledge of students as one of the most important domains of teacher knowledge blended with other teacher domains. In their work on mathematics education, Hill, Ball and Schilling (2008) argued that there is little evidence showing the relationship of teachers' PCK and learner gains specifically in mathematical thinking and learning, and therefore these researchers attempted to measure teachers' knowledge of content and students (KCS) in order to improve teachers' PCK. In defining the knowledge needed for mathematics they came up with a model of mathematical knowledge for teaching. The main domain in the model developed by Hill et al. (2008) that relates strongly to Topic Specific PCK in science education was Specialized Content Knowledge (SCK) in mathematics education. SCK is also concerned with the knowledge a teacher needs for a particular topic, which will include representations and explanations directed to the learning of particular tasks in mathematics. This is no different from Topic Specific PCK which proposes that a teacher needs to transform content through knowledge of the five components described by the Mavhunga model (2012).

## **2.5. Working with rubrics in the field of PCK**

Since the current research aimed to design and evaluate instruments to capture TSPCK of teachers of organic chemistry in Grade 12, it is necessary to describe

some of the literature related to the use of these in this field. Tepner and Dollny (2011) used paper and pencil tests consisting of multiple-choice items to evaluate teachers' Content Knowledge and PCK in topics such as the structure of atoms and the periodic table, chemical bonding and chemical reactions using acids and bases. This allowed them to survey a sample of 166 teachers. Their study reveals that developing and effectively using the methodology of a large-scale test instrument for measuring chemistry teachers' CK and PCK is feasible.

Open-ended instruments such as the one designed in this study for PCK cannot be scored as if they were conventional tests since there is the expectation of a wide range of responses which cannot be scored as correct or incorrect. The use of a rubric (Goodrich, 1996) allows the researcher to measure a particular objective such as behaviour, performance or quality. In the case of this study, a rubric was used to measure the quality of teacher's PCK in a specific topic. The degree of fairness and accuracy in the assessment provided by rubrics is important and rubrics allow the achievement of this objective by using a range to rate performance to portray consistent criteria for grading. Rubrics articulate certain characteristics of performance and these are divided into levels which give an idea of an extent to which a particular standard has been met. The rubric for this study used a four-point scale to rate teachers' responses from a range of 1, representing a limited response to 4 for an exemplary response. The responses of teachers were rated according to this scale to see whether a particular teacher met the standard at a particular performance level and for the determination of a holistic score.

Park, Yang, Chen and Yung (2011) used an instrument to evaluate the topic specific nature of PCK for two specific biology topics. TSPCK is a concept which argues that for any given topic within one subject, (for example organic chemistry or chemical equilibrium), the transformation of subject matter that emerges is specifically valid for the topic at hand. The transformation for each of these topics will differ from topic to topic even though they might all be conceptualised through the five components of transformation as elaborated by the Mavhunga (2012) model. These researchers designed a rubric which specifically evaluated learner knowledge for a specific topic, which they named KSU, and knowledge of instructional strategies and representations of the subject matter, KSIR. The study which was conducted by Park et al. (2011) looked at the way in which classrooms were informed by standard

based, inquiry based and learner centred approaches in teachers within a specific topic. The study by Park et al. (2011) revealed that there is, however, a high correlation between teachers' PCK in a specific topic, and the way in which teacher's instruction is reform oriented.

Mavhunga (2012) also constructed a rubric specifically for the topic of chemical equilibrium which she used to analyse the responses from the group of teachers since her study had intentions of exploring links between CK and TSPCK.

## **2.6. Exploring links between CK and PCK**

As noted above, the more developed the teachers' PCK for a specific topic, the more are the chances that the teacher will have better ways of implementing "reform principles of science teaching", (Park et.al., 2011, p. 252). According to these authors an instrument, Reformed Teaching Observation Protocol, which aims to explore links between classroom and reform principles of science teaching, consisted of five sections, namely background information, contextual background and activities, lesson design and implementation, content and classroom. The content (which in the case of reformed science teaching is divided into procedural and propositional knowledge) revealed more relevance to the teachers' level of PCK. According to Shulman (1986) PCK is the transformation of subject matter which entails deeper exploration of subject matter into different forms which students can comprehend. In the paper by Rollnick et al. (2008), a feature of the research reviewed is particularly noteworthy,

.....whether seen as a component of PCK or as a distinct area, SMK is crucial to the development of PCK." (Rollnick et al., 2008, p. 1368).

The foundation of PCK is sound knowledge of content together with pedagogical skills. This implies that the higher the levels of a teacher' understanding of learner knowledge with respect to a specific topic, the higher is his/her ability to identify students' difficulties in understanding a certain topic and the better are the teaching strategies which might help to address the learners' prior knowledge, including misconceptions.

Park et al. (2011) reported a link between the teachers' propositional knowledge and PCK which means the better the teacher's understanding of subject matter for a

specific topic the better her/his PCK will be, but the understanding of subject matter alone does not guarantee better PCK. One of the interesting results reported by Park et al. (2011) was the correlation between the lesson design and implementation with PCK, specifically knowledge of instructional strategies and representations. These results are not surprising considering that the lesson plan and application should incorporate the students' prior knowledge and deal with the concepts which students find difficult to learn. It is when a teacher has a better understanding of learners' misconceptions that he/she can design a lesson plan which aims at implementing representation and instructional strategies which address these students' issues with respect to a specific topic.

Tepner and Dollny (2011) conducted a research study in which amongst other lines of enquiry was a question to find out whether the quality of PCK has a correlation with teachers' Content Knowledge. Questionnaires were constructed for both CK and PCK as probing tools and administered to a large cohort of teachers. The findings of this study showed that the correlation between CK and PCK observed was evidence for a link between the two dimensions. The study also confirmed that, even though CK can be considered a prerequisite for the development of PCK, high levels of CK do not automatically guarantee developed PCK, meaning that CK alone is not all that is needed for the development of PCK.

## **2.7. Conclusion**

The discussion of the literature in this chapter shows that PCK plays a very important role in teacher knowledge as it integrates both pedagogy and content knowledge simultaneously for students to grasp the ideas and concepts being presented to them. It has been made clear that this type of knowledge comes with experience and its acquisition is a continuous process. The literature agrees that this knowledge is likely to be limited in novice teachers and develops with teaching experience (Gess-Newsome and Lederman, 1993; Feiman-Nemser & Parker, 1990; Geddis *et.al.*, 1993). The aim of this project was to evaluate the transformation of Content Knowledge for teaching organic chemistry at Grade 12 level. Thus an instrument based on the Mavhunga (2012) model was designed for evaluation of PCK in teaching organic chemistry as there has not been much research done in this area. The research questions to be answered are:

1. Is it possible to design a valid and reliable instrument for determining Topic Specific PCK of organic chemistry teachers at Grade 12 level?
2. Is there a correlation between CK and TSPCK?
3. Is there a relationship between teachers' TSPCK and level of education or years of experience?

The process of design and implementation of the TSPCK instrument in organic chemistry is described in the chapters which follow.

University of Cape Town

## CHAPTER 3

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### 3. Research Methodology

*In this chapter I discuss the methodology which was followed to construct instruments to gather data as well as the manner in which the research was conducted. The mixed methods approach was used to transform data collected into numerical clusters as well as to carry out a qualitative analysis. I will briefly discuss the different stages of development of the instruments and at the end of this chapter I provide a flow chart showing the development of the instruments, which will be described in detail in the next chapter. The instruments were developed to probe Content Knowledge and Topic Specific PCK and used for data collection purposes. The first version consisted of a single instrument probing both CK and TSPCK which was administered in a pilot study. This was followed by consultation with experts which led to refinement of the instrument to produce the two separate instruments which were administered to 44 teachers from various schools in South Africa. The Rasch model was used to obtain evidence of the construct reliability and validity of the instruments. The ethical procedure required by the University of Cape Town was followed before sampling and data collection.*

#### 3.1. The Mixed Methods paradigm

The overall aim of this study was to design and evaluate instruments which could assess Topic Specific PCK of Grade 12 teachers who are teaching organic chemistry. It was decided that the mixed methods paradigm would be a suitable research methodology for this study. Mixed methods is a recently evolved paradigm compared to using separate qualitative and quantitative methods and it adds to these widely used methodologies to form a third methodological movement (Teddlie & Tashakkori, 2003). This research method is defined by a number of researchers (Maxwell & Loomis, 2003; Onwuegbuzie & Teddlie, 2003; Sandelowski, 2003) as a method which transforms data using both quantitative and qualitative techniques to answer the research questions which a particular study is trying to address. A

quantitative technique includes data which is transformed into numerical codes and subjected to statistical analysis while a qualitative study would mean data are transformed into narratives which are analysed, for example identifying recurring themes. Amongst a variety of other factors which make mixed methods methodology preferable to other methodologies is that it can address research questions which the qualitative or quantitative methodology cannot address as stand-alone. In an editorial in the first issue of the Journal of Mixed Methods Research, Tashakkori and Creswell (2007) define mixed methods as:

.... research in which the investigator collects and analyzes data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or a program of inquiry. (Tashakkori & Creswell, 2007, p. 4.)

Mixed methods thus allow one an opportunity to apply both quantitative and qualitative methodologies simultaneously which means exploring and confirming the underlying assumptions of the study at the same time.

The reason that mixed methods were found to be the preferred approach in answering research questions posed in this study was that it allowed the application of both narrative and numerical clusters to analyse the data collected from teachers. Other studies which probed the transformation of CK to produce PCK, for example Davidowitz and Rollnick (2011) and Rollnick et al. (2008), used a case study approach to portray the level of PCK of the teachers. The case study approach was not suitable for my study because the aim was to capture the level of TSPCK of a larger group of teachers.

The study reported planned to investigate the extent to which Grade 12 teachers transform their Content Knowledge in organic chemistry. The hypothesis for this study was that teachers with high levels of CK would score well on the TSPCK instrument and those with low CK would reveal low levels of TSPCK. Another assumption was that there would be cases where teachers with good CK perform at a low level with respect to TSPCK. The quantitative method would allow confirmation of these underlying assumptions. The study was also interested in focusing the lens on aspects of the transformation of CK to produce TSPCK. Qualitative methods such as the interviews conducted with expert teachers as well as instruments were used to gain some insight into how teachers transformed their CK into TSPCK.

### 3.2. The Research Instruments

The study used a survey method to conduct the investigation. Many researchers have used questionnaires to conduct their research, for example Mavhunga (2012); Park et al. (2011) and Tepner & Dollny (2011). According to Cohen, Mannion and Morrison (2011), surveys are useful for gathering factual information, data on attitudes and preferences, beliefs and predictions, opinions, behaviours and experiences. In particular, the aim of this study was to collect data on the ability of teachers of organic chemistry to transform their CK for a specific topic into a form which makes it suitable for teaching. Even though it is a challenge to ensure that participants would understand all questions and scenarios posed to them in the same way, instruments such as the one developed to evaluate teachers' Topic Specific PCK in organic chemistry are useful in that they can be administered to large groups of teachers. The design of the questions tried as far as possible to take into consideration the disadvantages posed by using instruments to gather data.

The rationale in designing the CK instrument is the guiding assumption of the study that CK is a prerequisite for the development of PCK (Tepner & Dollny 2011). The first instrument, designed to evaluate teachers' CK, is based on the Big Ideas which were distilled from the grade 12 chemistry curriculum by a group of expert teachers. The Big Ideas for a particular content area such as organic chemistry highlight a number of key concepts commonly viewed by practitioners as important for students to learn in order to understand the topic (Loughran et al. 2004). The IUPAC system, isomers, chemical reactions, functional groups and physical and chemical properties were found to be the Big Ideas which comprise the organic chemistry topic at Grade 12. Therefore it was assumed that teachers who are teaching this topic should be able to master the concepts which they are teaching. The PCK instrument was based on the knowledge components of TSPCK in the Mavhunga (2012) model, namely students' prior knowledge, curricular saliency, what makes a topic difficult to teach, representations and conceptual instructional strategies.

Teachers' experiences on how they transform their CK were collected using open-ended instruments and interviews. The nature of the topic, organic chemistry, lends itself to questions which require respondents to draw chemical structures. Thus all items in the instrument were of the open response type to probe teachers' ability to

generate the correct response rather than being able to recognise a structure from those provided in a multiple choice format. During the development phase of the project, interviews were conducted based on the instruments designed. In addition to teachers giving written responses, the discussions about the instruments were recorded. For the CK instrument; teacher responses were scored as if they were conventional test items while for the TSPCK instrument it was decided to score responses using a rubric since there are a wide variety of responses possible for the TSPCK instrument. The development and refinement of the instruments will be discussed in chapter 4, while chapter 5 will discuss the manner in which the instruments were scored and analysed.

### **3.3. Validity**

There are several validity issues both internal and external which should be taken into account as they have a potential of posing a threat to the validity of the results, analysis and findings in a research study should those concerns not be taken into consideration (Onwuegbuzie, 2003). Internal validity refers to concerns arising from internal replication and the extent to which the results presented by the study would re-occur if the same study was repeated using the same sample (Onwuegbuzie, 2003). External replication on the other hand concerns the extent to which the findings of the study would re-occur if the study was repeated across different populations of persons (Onwuegbuzie, 2003). Internal validity concerns such as pretesting would not be significant in the current study as the tests were piloted with a group of teachers who were attending a conference in Mafikeng in the North West Province. The results from the pilot study were used to refine the instrument which was then administered to a group of expert teachers from schools in Cape Town. The final instruments were completed by a large group of practising teachers who were not involved in the development phase, which means the scores which the teachers achieved were not influenced by prior administration or by being familiar with the test. The internal validity threat to the instrument was also minimised as the tests were administered to experts to ensure that the instrument had an adequate level of consistency in terms of validity concerns such as inadequate content or construct related validity. For example, expert teachers were used to ensure that the content within the CK instrument was valid to probe understanding of the topics in the grade

12 syllabus as well as the content incorporated in the questions of the TSPCK instrument.

Other internal validity threats which were avoided in this study were threats such as reactive arrangements or reactivity effects. According to Onwuegbuzie (2003), participants can feel threatened by the presence of an observer, which could influence the manner in which they respond, thus posing a threat in the internal validity of the study. There had to be close relationship and trust with teachers involved in the study to ensure that there were minimal rival explanations in the prevailing findings. The teachers approached for this project were teachers with whom I had a close relationship, for example, one of the teachers who participated was my teacher for grade 12. A colleague who had formerly taught at a local high school was helpful in recruiting teachers who were part of a group with whom she had been conducting a workshop. These teachers were comfortable enough to participate without any reservations.

External validity threats such as population validity were considered and would ideally be minimised by targeting a large sample from across the country. Population validity refers to the degree to which the findings can be generalised from the participants of the study to a larger population across different subpopulations within the larger population targeted (Onwuegbuzie, 2003). The larger and more random the sample, the better the population validity will be. It is for this reason that the study targeted a minimum of 40 teachers as a realistic sample size for final data collection. Ecological validity ensures that the findings of the study can be generalised across different realities of social backgrounds such as ethnicity, socioeconomic status and academic achievements. In an effort to deal with this issue, the sample included teachers from rural, township and urban schools across the country.

#### **3.4. Scoring the instruments**

The CK instrument was scored as if it was a conventional test according to a memorandum. An expert teacher of organic chemistry was approached to ensure that the memorandum was fair and correct. The expert is a lecturer in the chemistry department at the University of Cape Town and was involved in my research. The

PCK instrument was scored using a rubric which was originally developed for the topic of chemical equilibrium (Mavhunga, 2012) and adapted to suit the organic chemistry instrument that was designed for my study. The rubric went through a series of iterations and was used to analyse teachers' responses to the TSPCK instrument. Rubrics have been used by other researchers to score the participant's responses, for example the work reported by Mavhunga, (2012) and Park et al., (2011).

Scores corresponding to the five categories, with each being rated on a five point scale, from 0 (No response), 1 (Limited), 2 (Basic), 3 (Proficient) and 4 (Exemplary), were used to interpret each response that teachers gave on their open-ended written instruments. Table 3.1 shows an example of a section of the rubric used to interpret the extent to which a particular teacher was able to transform his or her CK through knowledge of representations. The rubric will therefore indicate whether the teacher's understanding of a knowledge category is limited, basic, proficient or exemplary. The disadvantage of using a rubric as designed for this study is that there are instances where it is difficult to judge whether the responses given by participants should be classified as limited because the teacher had limited knowledge, did not pay sufficient attention when responding to the question or was given a representation with which he or she is not familiar. A teacher might have given a different response if he/she was responding verbally to questions posed by a researcher which could be recorded for later transcription.

<b>TSPCK</b>	<b>Section D1 Representations</b>	<b>Section D2 Representations</b>
<b>Level 1</b>	<ul style="list-style-type: none"> <li>• Describes use of 1/2 of the reps provided (use may not be appropriate)</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to use of symbolic representation of scientific notation i.e. formulae/equations</li> <li>• No enforcing of specific concept</li> <li>• Poor link between the choice of representation in part (a) and the use of it emphasizing a specific concept part (c)</li> </ul>
<b>Level 2</b>	<ul style="list-style-type: none"> <li>• Describes appropriate use of 3 of the reps provided</li> </ul>	<ul style="list-style-type: none"> <li>• Provides standardized knowledge to define reps</li> <li>• Use of symbolic representation to enforce a specific aspect of a concept</li> <li>• Gives textbook definition to explain the use of a certain representation in emphasizing a specific concept.</li> </ul>

TSPCK	Section D1 Representations	Section D2 Representations
Level 3	<ul style="list-style-type: none"> <li>• Describes an appropriate use of 4 of the reps provided</li> <li>• Describes an appropriate use of 4 of the reps provided</li> </ul>	<ul style="list-style-type: none"> <li>• Use of representation of a molecule to enforce a specific concept i.e. may link representation to intermolecular forces.(lines drawing more than equations)</li> <li>• Makes link between C chain length and/or surface area to bpt and/or IMF with explanation</li> <li>• States facts but does not mention energy or bpt. explicitly</li> </ul>
Level 4	<ul style="list-style-type: none"> <li>• Describes an appropriate use for 5 representations provided</li> </ul>	<ul style="list-style-type: none"> <li>• Use of macroscopic representation (analogies, models, etc.) / <u>or</u></li> <li>• Use of scientific symbolic representation: Includes conceptual explanation of factors such as chain length, surface area and links them to explain differences in IMF, energy and bpt.</li> </ul>

Table 3.1 An example of the section of the rubric; scoring representations.

### 3.5 Using the Rasch Model to determine reliability and validity

A quantitative technique was used in this study to confirm whether the data collected measured a single construct. The numerical data generated by scoring the two instruments were subjected to Rasch analysis to obtain estimates of reliability and validity. The Rasch measurement theory (Andrich, 1988; Bond & Fox, 2007; Wright & Stone, 1999) is applied in the social sciences based on the assumption that measurement of human performance and attributes should aspire to achieving the rigour that is typically associated with physical measurement. In this project Rasch analysis was used to obtain evidence for the construct validity of both CK and PCK instruments, to provide a trustworthy estimate of its internal consistency and to convert raw score performance data to interval measures for comparison with PCK proficiencies. The Rasch model is built on the assumption of unidimensionality, which means that all items must work together to measure the same variable or latent trait, in this case mastery of basic organic chemistry. Empirical evidence for unidimensionality is therefore also evidence for the construct validity of the instrument. Another assumption of the Rasch model is that of local independence, which requires that every item contributes related, but independent information regarding the variable being measured. When violations of local independence occur,

the reliability of the test instrument is inflated giving a more favourable indication of internal consistency than is justified (Tennant & Conaghan, 2007).

The Rasch model can yield measures of both validity and reliability of the instrument, (Boone & Rogan, 2005). The model examines the manner in which the instrument functions, focusing its lens exactly on how the responses of participants perform on a given set of test items. Most importantly the model of Rasch basically reveals two constructs of reliability of the data subjected in the model namely, a person separation reliability index as well as an item separation reliability index. It provides internal consistency coefficients like Cronbach's alpha (Tavakol & Dennick, 2011) to indicate reliability of an instrument. The person reliability index estimates the observed variance, which was in CK and TSPCK in the case of this study. The advantage of Rasch reliability estimates is that they estimate the accuracy of any person's capability whose response pattern can be predicted from their score on the test and this is independent of the sample to which that person belongs. According to Boone & Rogan (2005), the item separation reliability indicates:

.. the ability to define a distinct hierarchy of items along the measured variable and the replicability of item placement within the hierarchy across other samples.  
(Boone & Rogan, 2005, p. 36).

Therefore, the estimates of the item reliability index derived from the model are concerned with the outcome of an encounter between a person and an item which in turn is governed by the product of the ability of the person and the difficulty of the item.

The Rasch analysis yields person-item maps which are a visual representation of alignment and spread of person proficiencies and item difficulties and therefore give in-depth insights which will determine whether the replicability as well as reliability measures of the instrument have been compromised should the spread of items be narrow with large standard errors.

### **3.6. Ethics**

An ethics clearance application was submitted to the Science Faculty Ethics Committee for approval. Permission was granted to conduct a research study with science teachers across the country. In the field of educational research, ethical

issues need to be taken seriously to protect participants against violation of their rights to freedom, their self-determination to consider all possible options in participating and to make voluntarily decisions regarding whether they would like to participate or not (Cohen et al., 2011). Ethics also involves informing the participants about the rationale of the study and the procedures which the research would follow, for example protection of data.

The participants in a research project should be granted a right to remain anonymous, especially for school-based projects. In the case of this project, while teachers form part of schools, they were approached to complete the instruments in their personal time. Therefore it was crucial to ensure that their rights were not violated, e.g. teachers were invited to use a pseudonym or code to identify their instruments to cover all ethical concerns of the research project and to ensure that all the data gathered from the participants was treated as confidential. Participants were granted the right to withdraw from the study at any given point if they chose to do so. The pages designed to capture demographic details and background information were detached from all instruments and stored separately. A copy of the Science Faculty Ethics Clearance Letter and the first page used for both the CK and TSPCK instruments are provided in Appendices 1 and 2 respectively.

It should be noted that the original title chosen for the thesis and for which ethics approval was obtained was “Investigating the transformation of subject matter knowledge for teaching in organic chemistry.” While the planned research methodology as outlined in the ethics proposal was used in the project, it became clear during the analysis of the data that title above no longer reflected the way that the project developed. Thus the title of the thesis is “Development and validation of instruments to assess Content Knowledge and Topic Specific Pedagogical Content Knowledge of teachers of organic chemistry.”

### **3.7. The sample for this study**

The larger the data set the easier it is to make comparisons and generalisations of research findings, especially when statistical data analysis is involved. Ideally a large sample would be required for the study but recruiting of teachers who were prepared

to complete two instruments was likely to be difficult. Linacre (1994) noted that “You can certainly perform useful exploratory work using Rasch analysis with a small sample”, a view echoed by Andrich (2013) in a response via email to a question posed to the The Matilda Bay Club<sup>4</sup>. It was decided to target a group of 40 or more teachers as this sample size, while small, is still large enough to be able to identify macro problems with the instrument, such as poor alignment with the sample, multidimensionality and misfitting items.

The teachers who participated in this study were those who have been teaching for a number of years. The number of years in which they had taught varied but all had some experience in teaching. The sample was drawn from across South Africa, from schools in urban areas, townships and rural areas. The schools also varied from well-resourced schools to disadvantaged schools for example there were schools, which used laboratories, molecular models and Chem-Sketch software to draw structures of molecules while other schools relied only on the use of textbooks.

The first version of the instrument was piloted with a group of 16 science teachers who attended a South African Association of Science and Technology Educators conference in Mafikeng in 2011. The second sample comprised a small group of experts from local schools in Cape Town. These teachers were consulted to ensure that the content in the instruments was in accordance with the current grade 12 syllabus.

The sample size for the final data collection comprised of 44 participants across the country and falls into the category of non-probability sampling which can be described as convenience sampling. According to Cohen et al. (2011), the term non-probability sample applies when the researcher is focusing on a particular group while aware that the group chosen does not necessarily represent the wider population, but only represents that group in the study. There are different types of non-probability sample and the type used in this study was convenience sampling. The convenience sampling, also called opportunity sampling, means that the

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<sup>4</sup> **The Matilda Bay Club (MBC)** aims at contributing to the diffusion of Rasch Measurement Theory and Models in the social sciences. See <http://www2.wu-wien.ac.at/marketing/mbc/index.html>

researcher targets individuals who are easily accessible to him/her and requests these individuals to serve as participants. The researcher continues doing so to a point where the target sample size is achieved. As the purpose of the research was to assess TSPCK of science teachers teaching organic chemistry at Grade 12 level, and focusing on the association of this construct with experience, the teachers chosen were teachers who were already teaching (practising teachers). They were approached and invited to participate; small tokens of appreciation, e.g. pens and periodic tables, were given to teachers on completion of the instruments.

### **3.8. Data collection**

The data collection involved teachers in South Africa, where teachers sometimes find themselves under high pressure due to poor performance, especially in physical sciences and mathematics (CDE, 2011). Thus it was important throughout the sample collection to first build a relationship with teachers so that they would feel free to respond, knowing that their responses would be used for the stated purposes and not for anything else which would violate their rights and privacy.

As mentioned in section 3.7 the first version of the instrument was administered in a pilot study with a group of science teachers who were attending the local conference in Mafikeng. Most of these teachers had more than 10 years of experience in teaching and came from the North West province. The programme of the conference was such that teachers and all other attendees chose for themselves which workshops they would attend. Teachers attending our workshops were attracted by the strategically chosen title "Do you have a problem with Organic Chemistry?" A short presentation to give them a sense of where the instrument came from as well as the background of the topic encouraged them to stay at the workshops as it also gave them an opportunity to voice both teachers' and students' difficulty with respect to the topic of organic chemistry. The workshops gave me my first opportunity to engage with teachers, to listen to their complaints and struggles and to show that I am not only interested in using them as participants to my pilot study. After teachers completed the tasks in the instrument, my colleague ran a workshop on intermolecular forces, a key concept in organic chemistry, using models and demonstrations which teachers could use in their own classrooms.

Valuable feedback on the second version of the instrument was obtained from a small group of expert teachers at local high schools in Cape Town. The expert teachers all had a bachelor's degree in science with a one-year postgraduate teachers' certificate. These teachers also had a working relationship with a colleague who was involved in my project from the beginning. She was also doing her Master's degree at UCT; thus when I needed to consult with experts she was able to refer me to them. The expert teachers completed the instruments after which they participated in interviews where they had the opportunity to elaborate on their responses to the questions as well as to provide feedback on the design of the instrument. This process helped in further refining the instrument. The final version of the instrument was ready to be administered with a larger group of teachers after incorporation of the suggestions from the expert teachers.

Part of the group who completed the final version of the instrument was teachers who were attending a workshop in a science school in Khayelitsha, a township close to Cape Town. The workshop on organic chemistry was aimed at empowering teachers to conduct experiments which might motivate students to grasp the concepts, as well as improving the teachers' pedagogical skills. At that stage I was working closely with the organisers, who were themselves researchers pursuing their Masters degrees in science education. They were experts in the topic of organic chemistry and were involved in the construction of the first phase of the development of the instrument. The workshop they were conducting provided an opportunity for me to be involved and build a relationship with these teachers before asking them to complete my instrument. At the end of the workshop, I asked the teachers to complete the instrument and those who were willing to participate did so. Some could not complete the instruments at that time as the workshop was conducted during the school holidays, thus we made appointments to administer the instrument at their schools. A second group of teachers was recruited via a colleague whom I knew on a personal level who was also working with different districts for the TRAC, (Technology Research Activities Centre) laboratory. TRAC is a centre initiated by Stellenbosch University together with Crocodile and Data Harvesting Sensors from Khanya with the purpose of helping teachers and learners to cover concepts of science using a more hands-on approach. My colleague gave me contact details of the teachers participating in TRAC and allowed me to use her as a reference when approaching

these teachers. This group had a good relationship with her and had no reasons for not trusting her, which made it easier for them to be comfortable with me as well. I made a few telephone calls to them and visited them at their schools to administer the instruments and to explain to them the aim of the project before they could engage in the research project as respondents.

Another group of teachers was based in the Eastern Cape Province. Sasol, a chemical and energy company based in South Africa created the Inzalo Scholarship Programme (Sasol Inzalo Foundation, 2013) which funds those interested in pursuing Masters' and doctoral degrees in education. As indicated in chapter 1, I am a member of this scholarship programme and am a Sasol Inzalo fellow. These teachers in the Eastern Cape had a good relationship with one of the Sasol Inzalo fellows, who was assisting the science teachers in improving learning and teaching of science in schools in the rural region of Mthatha in the Eastern Cape. He was willing to assist me with my data collection. I used this as another opportunity to gather data as these teachers trusted him. I used a courier to send the instruments to the Eastern Cape together with an accompanying letter which had all the details of the research with instructions on how the instruments should be administered, together with the small gifts which were awarded to teachers who completed the instruments, as a token of appreciation for their time.

Another group of teachers were from the Gauteng province, I know them on a personal level and they were also willing to participate in the project. The instruments were sent to them electronically, but it was very important that I had a conversation with them, taking them through the instrument before they could start completing them. This interaction allowed me to answer all their questions and to give clarity about any uncertainties as well as issues related to the confidentiality of their responses. Some of these teachers had attended the same university as I did and had decided to go into the teaching profession after graduation. The process of selection was continued until the targeted sample size of 40 or more teachers had been reached. This sample could yield in-depth results when supported by statistical analysis and it could provide a chance to make comparisons among the type of responses given by teachers.

### 3.9. Flow chart of the stages of development of the instruments

The development of the instruments comprised a large part of this study and therefore it is necessary that the manner in which the instruments were developed should be discussed in detail as there were several stages of development. The discussion of the development of the instruments follows the steps summarized in the flow chart shown in Figure 3.1 below.

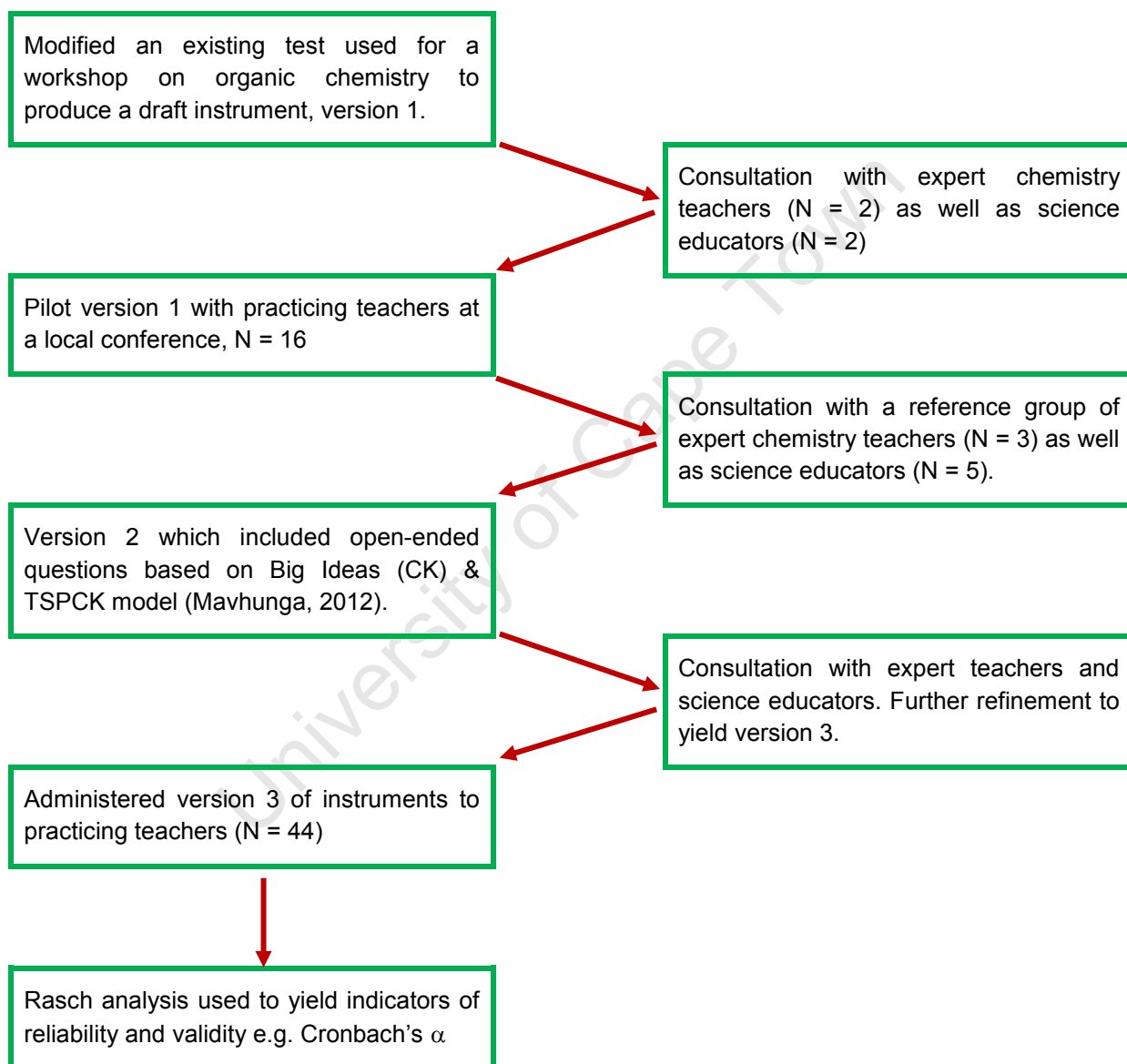


Figure 3.1. Flow chart of the stages of development of the instruments

## CHAPTER 4

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### 4. Instrument design

*In this chapter I will describe the design and evaluation of the two instruments. The first instrument, designed to evaluate teachers' Content Knowledge, CK, is based on the Big Ideas which were distilled from the grade 12 chemistry curriculum and which were validated by a group of expert teachers. The instrument to evaluate the teachers' PCK was based on the categories of Topic Specific PCK captured in the Mavhunga (2012) model described in chapter 2. Topic Specific PCK is the skill of a teacher to transform subject matter of a specific topic into a variety of formats for students to understand. The TSPCK instrument was scored using the rubric and in this chapter I will also include a discussion about the design of the rubric. The design of the instruments went through several iterations which are described below.*

#### 4.1. Introduction

The aim of this study was to design and validate instruments which would assess Content Knowledge and Topic Specific PCK of Grade 12 teachers who are teaching organic chemistry. The study used a survey as the research method. In particular, the aim of this study was to collect data on science teachers as teachers of organic chemistry and their ability to transform their CK for this specific topic into forms which make it suitable for teaching.

As outlined in chapter 3, all items in the instruments are of the open response type. Teacher experience (the number of years in teaching) and teacher education were other important issues which were considered as they may have impact on the development of PCK. The level of content knowledge which teachers could draw from based on their training at tertiary institutions as well as levels of PCK may be influenced by the number of years or experience as teachers. As noted by Shulman (1986) and other researchers such as Cochran et al. (1993); Geddis and Wood (1997); Rollnick et al. (2008) whose findings were discussed in chapter 2, PCK is a combination of content and pedagogy, skills which develop after years of teaching. It

is therefore important to document teachers' level of content knowledge while at the same time attempting to capture their level of PCK of Grade 12 organic chemistry. Teachers were also asked to provide information about their qualifications, the length of their courses and major subjects, as well as the highest level reached with respect to their science content subjects. The other aspect of importance was the number of years of teaching and the other grades which they have taught.

The study aimed at gathering data from across the country, but specifically with grade 12 teachers who are already working as practising teachers, to assess their TSPCK. According to Cohen et al. (2011, p. 256), a survey provides a platform to be used with a large group of people to capture and interpret general constructs, meaning that one can collect data using the same test items for all teachers who are participating in the study. Surveys become very convenient when the study aims to capture generalizable information; in the case of this study, the construct of TSPCK. Surveys are also useful in cases where a researcher is interested in tracing any relationships in the information gathered from the participants: for example; one of the research questions to be answered is whether it is possible to design a tool that is suitable for evaluating Topic Specific PCK of organic chemistry teachers at Grade 12 level. The benefits of surveys are that they can generate instruments which can be validated through piloting and revision. Surveys also gather information which can be processed through statistics, relying on large data samples in a wider population to be able to generalise factors or variables in a given study.

#### **4.2. Initial attempt at instrument design**

The first version of the instrument was based on a test used by a researcher at the University of Cape Town who was conducting a workshop for pre-service teachers. This test was subsequently edited to suit the aim of probing chemistry teachers' CK and TSPCK. The test was sent for comments to science educators at the University of the Witwatersrand who had experience in developing this type of instrument. Their suggestions were incorporated in the instrument before the test was used for the pilot study, (see section 4.3). This early version of the instrument probed understanding of the organic chemistry concepts being taught as part of the grade 12 syllabus. The CK section was constructed using Big Ideas distilled from various grade 12 chemistry

text books to ensure that the study focussed on the content being taught by the teachers at this level. The instrument is shown in Appendix 3. The test items assessing the CK of teachers were combined with TSPCK test items in a single instrument but were separated into 5 different tasks designated A - E. The first task focused on probing the Content Knowledge of science teachers and consisted of 11 items; 6 of these were designed to evaluate teachers' understanding of structural formulae and isomers. Four items probed teachers' knowledge of typical reactions in organic chemistry. The last item in the first task probed teachers' knowledge of functional groups and naming of organic compounds. Figure 4.1 shows some examples from task A in the instrument, see also Appendix 3.

- |    |   |
|----|---|
| 1. | Draw the structural formulae for each of the following compounds  |
|    | Butanol                      Pent-2-yne                      Ethyl-propanate  |
| 2. | Complete each of the following chemical reactions, balancing them where needed.   |
|    | Combustion of butane      Esterification reaction      Elimination reaction   |
| 3. | Draw as many structural isomers for butanoic acid ( $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ ) as you can think of and include the IUPAC name for each. |

Figure 4.1 A selection of tasks from Task A

Tasks B, C and D, while containing tasks about content, were weighted more heavily in terms of PCK. It is important that one considers the fact that at this point the instrument was at an early stage of development. Task B in this instrument consisted of items directed at evaluating teachers' curricular saliency, students' prior knowledge and concepts which are difficult to teach, three of the categories which make up the Mavhunga model (2012). Task B is shown in Figure 4.2 below.

1. What do you consider to be the main concepts to be taught in organic chemistry?
2. What makes organic chemistry concepts difficult to teach? Explain.
3. What topics (from the list provided) must have been covered in chemistry before you can teach organic chemistry? Give a reason why you think these topics are needed. If you don't think they are needed, indicate this by writing 'not needed'. You can also add topics of your own.
4. Why is it important for learners to learn about organic chemistry?
5. What ideas/concepts in organic chemistry do your learners struggle to understand. Why you think they struggle with these concepts?

Figure 4.2 Questions posed for Task B

The third task, C, focused on items aimed at evaluating the teachers' understanding of students' prior knowledge as well as instructional strategies related to molecular formulae and isomers. The fourth task, D, probed the way teachers would teach the topic of intermolecular forces using suggested instructional strategies. Task E probed the Content Knowledge of science teachers and was based on an interpretation of physical properties of organic compounds in terms of intermolecular forces.

#### 4.3. Piloting the instrument

At an early stage of the project an opportunity presented itself to participate in workshops run by a colleague and I decided to use this opportunity to pilot the instrument which was still being developed for this study. The first version of the instrument was administered to a group of 16 science teachers from diverse backgrounds who were attending the local conference of the South African Association of Science and Technology Educators (SAASTE) that was hosted by North West University from the 10-14<sup>th</sup> July 2011. The majority of teachers had taught for more than 10 years; only 4 of them had been teaching for fewer than 5 years. Most of these teachers were based in the North West province of South Africa. In this cohort of 16 science teachers, ten had qualifications from teacher training colleges where the curriculum combines aspects of content and pedagogy. Six teachers had discipline-based qualifications such as BSc degrees and later obtained pedagogy based qualifications such as Post-Graduate Certificates in Education. The

programme of the conference was such that delegates chose which workshops they would attend and therefore my colleague and I had to strategize as this was a situation where we could not tell whether teachers would attend our workshops or not. The sixteen teachers described above attended our workshops which were titled "Do you have a problem with Organic Chemistry?" The workshop began with an introduction trying to give teachers a sense of the origin of the instrument as well as the background to the topic. This encouraged them to stay in the workshops as it also provided an opportunity for them to voice both teachers' and students' difficulties with respect to the topic. One of the teachers mentioned that it is not easy to teach organic chemistry

.... because you need to use your imagination to visualize structures from different angles as well as chemical bonding to be able to understand the concepts e.g. intermolecular forces. (Teacher X, SAASTE conference, July 2011).

This was found to be especially true if a school was not well resourced and lacked any models which would be useful as a teaching tool. Some teachers mentioned that students struggle to make sense of organic chemistry from grades prior to Grade 12 since the problems start with an understanding of the periodic table, the behaviour of group 4 elements, which include carbon, their unique properties and the abundance of carbon compounds in nature. Teachers aired these views as we tried to engage them and show an interest in their fears rather than simply being interested in data collection. The workshops were arranged in such a way that, after teachers had completed the tasks in the instrument, the expert researcher who organises teacher workshops specifically in organic chemistry would then provide materials to the teachers to support them in the way in which they teach this topic and to give them the opportunity to perform some experiments which they could later use in their classrooms.

As was stated earlier the first version of the instrument had tasks probing both CK and PCK in a single instrument. I realised that this version of the instrument would be time-consuming for teachers and, since only an hour was allotted for each session, I had to develop a strategy to gather as much data as possible in the time available. The data about teachers' background information was collected on separate sheets. To avoid incomplete responses due to time constraints, teachers were first asked to

complete their background information and create codes for themselves which they would use throughout the instrument to protect their anonymity. The five tasks were not compiled together but were issued separately and therefore teachers would complete any of tasks at random. Of the sixteen teachers, six teachers completed task A, four teachers answered all sections in task B, six teachers answered task C, seven answered task D and six teachers completed task E. The conference continued for four days and we were granted the opportunity to have a workshop on three of the days. Some teachers completed all the tasks; these were teachers who came to all our sessions and we asked them to complete the tasks which they had not completed in the earlier sessions. This strategy ensured that the group of participating teachers would between them produce a number of responses to the tasks which were complete instead of having several instruments with many blank responses.

The aim of attending the conference was not only to gather data but also to meet science teachers especially those teaching organic chemistry at Grade 12. Attending the conference also contributed as a foundation to my research question or problem statement as I do not have teaching experience and hence the instrument was designed in a way that it could give an idea of how much teachers understand about the subject matter for organic chemistry and their levels of PCK.

Most of the teachers who came to the workshops at the SAASTE conference in 2011 reported difficulties in teaching the topic. For example one teacher mentioned that he had taught physical sciences at the former standard grade<sup>5</sup> level for most of his teaching career and when the new syllabus included concepts which had only been taught at the former higher grade level, he struggled and needed help. Another teacher, from Bloemfontein in the Free State Province, mentioned that she was recently placed in a post to teach grade 12 Physical Science whereas she used to teach this subject at grade 9 level. She said that she did not know where to start especially with organic chemistry as her last engagement with organic chemistry had been at tertiary level a number of years previously, thus her content knowledge was rusty.

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<sup>5</sup> One of the significant changes for the new curriculum (NCS) was the decision to discontinue the standard and higher grade delivery of subjects; instead all candidates would write the same National Senior Certificate (NSC) examinations for the subjects that they are enrolled for at the end of the Further Education and Training phase, Grades 10-12.

As this was a pilot study, the instrument was not subjected to detailed analysis. The responses to tasks A and E revealed that, with the exception of being able to draw structural formulae, this particular cohort of teachers had a poor level of understanding of the content with respect to isomers, classes of reactions and intermolecular forces. The average scores for tasks A and E are shown in Table 4.1 below.

Task number	Description	Number of items	Average score; %
A1	Drawing structural formulae	6	72.2
A2	Major classes of organic reactions	4	45.8
A3	Drawing and naming isomers	1	25.0
E1-3	Intermolecular forces and boiling points	3	40.0

Table 4.1 Average scores for the pilot study

In addition, teachers had answered tasks B, C and D as if they were testing content knowledge instead of explaining how they would teach given the scenario posed in the tasks. This latter observation led to the decision to modify the instrument extensively and to divide it into two separate instruments to probe CK and TSPCK respectively. The refinement of these instruments will be discussed in the following sections, 4.4 and 4.5.

#### 4.4 The next phase of development of the CK instrument

The Mavhunga model (2012) implies that a teacher who has an understanding of specific Content Knowledge could transform their CK to give rise to PCK for a specific subject. As noted earlier, Shulman (1986) described PCK as transformation of Content Knowledge to produce CK for effective teaching. Content Knowledge is clearly fundamental in any attempt to portray or capture this construct. It can thus be proposed that there is a correlation between the level of a teacher's CK and PCK. In the attempt to assess the PCK of teachers, it became important to consider the levels of CK in teachers before attempting to capture their PCK.

Based on the teachers' performance and feedback from other researchers participating in the project, the CK instrument was modified extensively. The second version of the CK instrument also consisted of 5 tasks (see Appendix 4). The questions from phase 1 which all teachers managed to answer were eliminated as they did not discriminate between levels of content knowledge thus leaving only 2 items on structural formulae in task 1 (see Figure 4.3).

1	Draw the structural formulae for each of the following compounds:
2-methylhex-3-ene	ethyl propanoate

Figure 4.3 An extract from the instrument to probe CK in organic chemistry

Since teachers had struggled to answer items about isomers, most of these were retained for task 2. The third task probed CK related to reactions. In addition to the items in the first instrument about combustion, esterification, elimination and substitution, an item testing knowledge of addition reactions was added since all these reactions are included in the current curriculum for organic chemistry at Grade 12 level. Functional groups, one of the Big Ideas in organic chemistry, were not probed thoroughly in the first instrument. Thus a task, based on an example from the literature (Johnstone & Ambusaidi, 2001) was used to probe teachers' ability to recognize the various functional groups. The final task on intermolecular forces in the second version of CK instrument was the same as for version 1. The requirement to draw a graph for task E in version 1 was, however, eliminated as none of the teachers participating in the pilot study had answered the question and it only increased the length of the instrument. Instruments which require a long time to complete might hinder the data collection process as teachers' time is very precious and it would not be fair to ask them to put in long hours to answer research surveys. Thus the second version of the CK instrument, which was separated from the TSPCK instrument, was formulated and can be found in Appendix 4.

When all the perceived weaknesses in the CK items were dealt with, the instrument was ready for another attempt to collect data from teachers. The internal validity

threat to the instrument was also minimised as the tests were administered to experts to ensure that the instrument had an adequate level of consistency in terms of validity concerns such as inadequate content or construct related validity. For example, expert teachers were used to ensure that the content within the CK instrument was valid to probe understanding of the topics in the grade 12 syllabus as well as the content incorporated in the TSPCK questions of the instrument.

#### **4.4.1 Expert teachers' input into the design of the instruments**

Interviews were conducted with expert teachers from three schools in Cape Town. These teachers all had a pure science bachelor's degree with a one-year postgraduate teachers' certificate. Their performance on the CK questions was exemplary and they were well versed about current changes in the curriculum. The instrument was therefore administered with this group of teachers to also check the content validity of the instrument. One of the experts, for example, noted that in one of the test items the structural formulae were not represented in the way in which the Grade 12 curriculum addresses structural formulae. Experts also highlighted areas where the wording of the questions was not clear with respect to probing a particular concept. Such feedback was important to ensure that we would be likely to obtain the type of answers we expected when the instrument was administered with a larger group of teachers. Another teacher from the group of experts came up with some interesting ideas, showing his expertise in teaching organic chemistry. In response to a question from the instrument which probed students understanding of the hydroxyl group, -OH, as a functional group he said:

.....I would tell them that we going to recap now and go back to Grade 11 and talk about acids and bases. Remind them about the definition of bases, OH group and then put sodium hydroxide and ethanol on board through images and say now you know what a base is and what is an acid is and so what is the difference? Allow them {students} to discuss that, is there any difference or not? Then drive them to an understanding that, or remind them the differences in bonding type within sodium hydroxide (ionic bonding) and bonding type within ethanol (covalent bonding). Talk about covalent bonds vs. ionic bonding, talk about ionisation in NaOH and the differences in bonding ionic vs. covalent and that these two different species behave differently. .... I think to me the key learning point to them would be that even though they (OH in both sodium hydroxide and ethanol) have same atomic make up but they behave differently....Take a very strong base and an alcohol and show them that they have different reactions . (Teacher P, interview, November 2011).

The expert teachers also demonstrated that while they taught for understanding concepts, they were very aware of the assessment criteria which would apply to the matric examination, e.g. in representations of organic compounds. For example one of the questions which were posed to them required them to choose from various representations of an organic compound the ones which they would use to teach the topic of intermolecular forces. Teacher B mentioned that he would not choose the space filling model, one of the representations offered, as it never appears in assessment tasks or in the textbooks. The feedback from these teachers was valuable as it led to the point where we could have the confidence that the instrument was ready to be administered to a larger sample of science teachers.

#### **4.5 PCK instrument phase 2**

The pilot study also revealed that the design of the PCK instrument was somewhat superficial. Strengthening this area was the main focus for the second version of the instrument. Many models have been employed to trace the transformation of pure content knowledge to PCK for teaching as manifested in the classroom; for example Cochran et al., (1993), proposed a model of PCK comprising teachers' integrated understanding of four components namely knowledge of students, contexts, content knowledge and general pedagogical knowledge. As has been mentioned in Chapter 2.4.7, Mavhunga (2012) developed the construct, Topic Specific PCK (TSPCK) which includes:

- Learners' prior knowledge
- Curriculum saliency (deciding what is important for teaching & sequencing)
- What makes a topic easy or difficult to teach
- Representations including powerful examples & analogies
- Conceptual teaching strategies

The second version of the PCK instrument was comprehensively reconstructed based on the five components of Topic Specific PCK as captured in the Mavhunga (2012) model. Valuable feedback on the second version of the instrument was once again obtained from a small group of expert teachers at local high schools. For the PCK instrument they offered different approaches for teaching based on the scenarios posed. They demonstrated the depth of their pedagogical content

knowledge through their explanations and answers given to the PCK questions. They also displayed curriculum saliency (Geddis & Wood, 1997) in the way they taught for understanding of concepts but were aware of the assessment criteria which would apply to the matric examination. The PCK instrument consisted of 5 sections corresponding to the 5 categories of TSPCK (Mavhunga, 2012) mentioned above. All items assumed correct CK, as a necessary precursor for any PCK. The questions are described below; the PCK instrument can be found in Appendix 5.

### *Section A: Students' Prior Knowledge*

The first question, designed to probe Students' Prior Knowledge via the identification of common misconceptions, consisted of two items. The first of these, exploring understanding of the alcohol group, posed the following scenario, (see Figure 4.4 below):

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:

<b>1</b>	$\text{CH}_3\text{-OH}$	<b>2</b>	$\begin{array}{c} \text{O} \\    \\ \text{CH}_3\text{-C-OH} \end{array}$	<b>3</b>	$\text{NaOH}$	<b>4</b>	$\text{CH}_3\text{-CH}_2\text{-OH}$
----------	-------------------------	----------	--	----------	---------------	----------	-------------------------------------

Sipho selects compounds 1, 2, 3 and 4. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds?

Figure 4.4 Item probing students' prior knowledge of alcohols

This item probed the misconception that any compound containing the OH group could be classified as an alcohol. In fact only compounds 1 and 4 above are alcohols. The important ability being probed here is whether the teacher is able to recognize the misconception, and design an explanation that would move the learner to the correct understanding.

The second item in this category evaluated the teachers' understanding of students' misconceptions related to naming organic compounds. The first step in naming

compounds according to the International Union of Pure and Applied Chemistry depends on identifying the longest continuous carbon chain in the compound. In many cases; this chain may not be obvious to the student which was the case in task 2 in section A of the PCK instrument. During the evaluation phase of the PCK instrument, one of the expert teachers demonstrated his TSPCK by suggesting the following strategies in response to the question of naming organic compounds. He said:

- 2 To solve the chain length error, the next step depends on the type of learner, i.e.
  - 2.1 Visual – look for a longer chain than the obvious horizontal row.
  - 2.2 Auditory – Never have an –eth (ethyl group) on a penultimate carbon.
  - 2.3 Kinesthetic – Imagine picking up two end-carbons and pulling them out into the longest possible chain. Which two carbons are these?

(Teacher W, response to a task in the instrument, November 2011).

Here the teacher manifests his knowledge of students' difficulties in mastering the naming of organic compounds, in particular identifying the carbon chain from which the name of the compound is derived.

#### *Section B: Curricular Saliency*

The second category of the PCK instrument probed issues related to Curricular Saliency which refers to teachers' understanding of the place of a topic in the curriculum and the purpose(s) in teaching it. Curricular saliency may be observed, for example, in teachers' decisions to leave out certain aspects of the topic, and in teachers' awareness of how a topic fits into the curriculum (Geddis & Wood, 1997). This component explored teachers' ability to sequence topics and select Big Ideas. For item 1, teachers were asked to select from a given list prerequisite concepts for the teaching of organic chemistry. Item 2 required teachers to select from a list three Big Ideas to be taught in organic chemistry at Grade 12, (see Figure 4.5 on the following page).

- 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.	

Figure 4.5 Question probing curricular saliency

Teachers were then asked to list the Big Ideas in the order in which they should be taught, giving reasons for their proposed order. The following item, required teachers to draw a map or a diagram of the 3 Big Ideas showing how they link to any subordinate ideas. The final item probed teachers' responses to questions related to the importance of learning organic chemistry.

*Section C: What is difficult to teach?*

Teachers were provided with different concepts in organic chemistry in tabular form. They were asked to select those which they considered difficult to teach and explain why this would be the case. The question was designed to probe whether a teacher

was able to identify which concepts students found difficult to learn so that they would be able to devise strategies which help students to understand the concepts. Topics included Molecular formulae, Structural formulae, Functional groups, IUPAC names, Isomers, Homologous series and Types of Organic Reactions namely substitution, addition, elimination, combustion and esterification.

#### *Section D: Representations, models and analogies*

One of the major challenges faced by novice learners in organic chemistry is the need to interpret multiple representations of chemical structures used by practising chemists. While the expanded structural and condensed formulae are the most commonly used representations in Grade 12 organic chemistry text books, teachers should be familiar with a range of representations and might choose to use these in their classrooms. The rationale behind the design of this question was that an expert teacher would be able to use different representations at both macroscopic level and submicroscopic level.

Teachers were presented with a range of representations for pentane (see Figure 4.6 below); the descriptions were not included in the instrument.

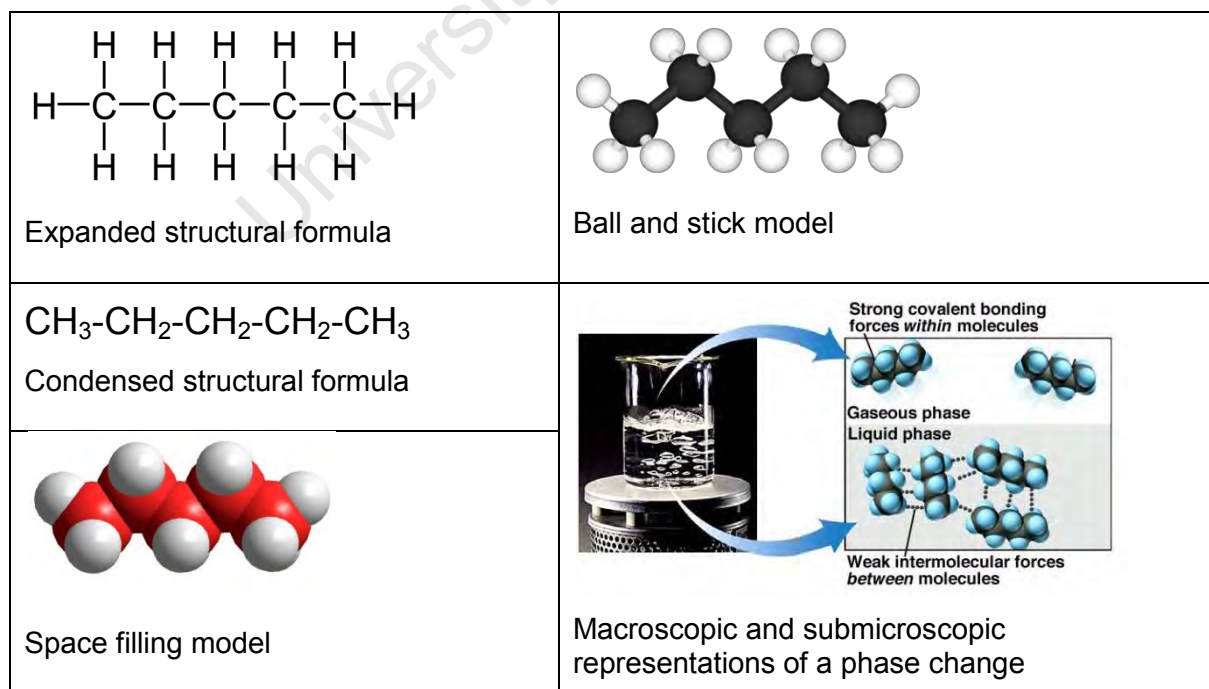


Figure 4.6 Representations of pentane

Teachers were asked which representations they found most useful and to describe when they would use the representations in the figure above in teaching organic chemistry. Lastly they were asked to describe how they would use the representation(s) chosen earlier to explain that the boiling point of butane is lower than that of pentane.

### Section E: Conceptual Teaching Strategies

This component is considered the most demanding for teachers as it requires accumulation of some or all of the above components. The strategies here are conceptual rather than procedural. One of the questions used is shown in Figure 4.7 below:

1. You draw the structure of chloromethane as shown below on the chalk board.

$\begin{array}{c} \text{H} \\   \\ \text{H} - \text{C} - \text{H} \\   \\ \text{Cl} \end{array}$	$\begin{array}{c} \text{Cl} \\   \\ \text{H} - \text{C} - \text{H} \\   \\ \text{H} \end{array}$
Teacher's Drawing	Learner's Drawing

A learner asks: "Is it okay if you swop around the chlorine and a hydrogen atom like this (the learner draws a second structure as shown above)".

**How would you teach a lesson about the different ways of representing organic molecules to this class?**

Figure 4.7 Probing instructional strategies with respect to depicting structures in organic chemistry.

An expert teacher would have to address the issue that the structure as drawn does not take into account that the molecule shown is not a planar structure but has a tetrahedral shape in three dimensions. One way to make this idea concrete for the learners would be to make use of a three-dimensional model where it would become immediately clear.

The second question addressed the issue that learners often do not draw structures depicting carbon as having four bonds. Two versions of this question are shown in Figure 4.8 below to demonstrate how feedback from the group of expert teachers shaped the development of this task in the final PCK instrument. The experts pointed out that at Grade 12 level structures were written either as condensed structural formulae or expanded structural formulae (structure B).

2. In a diagnostic test a learner drew the incorrect structure below. Given that you have taught your learners how to draw structural formulae, how would you conduct a revision lesson, to correct this student's response.

$$\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_3 - \text{CH} - \text{CH}_2 - \text{CH}_3 \\ | \\ \text{CH}_3 \end{array}$$

A. Structure: used for expert teachers' evaluation

$$\begin{array}{cccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & | & & | & & | & & | \\ \text{H} & - \text{C} & = & \text{C} & - & \text{C} & - & \text{C} & - & \text{H} \\ & | & & & & | & & | \\ & \text{H} & & & & \text{H} & & \text{H} \end{array}$$

B. Structure: used for final version of task

Figure 4.8 Probing students' understanding of structural formulae

In this way, the PCK instrument was refined and used for data collection and sampling purposes. The final instrument was used to collect data from a large sample of teachers from different provinces.

#### 4.6. Development of a rubric to score the TSPCK instrument

In this study, instruments were designed to collect data and experiences of grade 12 teachers, in teaching organic chemistry. After the data collection process was complete, the responses given by teachers were analysed using a rubric. The rubric was appropriate for this study because it took into account the information gathered in the form of written responses from participants in the instruments. A rubric also gives an in-depth understanding and speaks to the core issues underlying the way in which the participants conduct themselves around the phenomena being investigated

(Cohen et al., 2011). The construct which is being investigated, namely TSPCK, was assessed through the responses which teachers gave from the instruments probing both CK and PCK.

As noted above the instruments were going to be analysed using a rubric and therefore a rubric which would suit the type of questions constructed for the PCK instrument was required. A number of researchers have employed rubrics in their research for different purposes. Park et al. (2011) used the rubric to measure if there was any relationship between a teacher's level of PCK and the extent to which his or her classroom is reform-orientated. In the case of this study, a rubric developed by Mavhunga (2012) was adapted. She used her rubric to score the responses given by teachers for an instrument which was constructed for the topic of chemical equilibrium. As discussed in chapter 3, the rubric developed for this project focused on the transformation of CK for organic chemistry, using the five categories of the Mavhunga (2012) model. Each category was rated on a four-point scale according to the rubric, from 1 (Limited) which represented a limited response given by a particular teacher to 4 (Exemplary) which represented an excellent response. The rubric for this study went through different editions as it had to be adjusted to changes in the PCK instrument. The rubric was sent to two independent researchers for comment to ensure that it would be suitable to score the responses to the PCK instrument. As the first group of teachers completed their instruments, the rubric was used to score their responses. Teachers' responses to the tasks in the PCK instrument played a role in refining the rubric as they gave insight of what possible responses teachers would give. Table 3.1 showed the section of the rubric used to score the category of representations.

As was mentioned above, the rubric designed for the topic of chemical equilibrium was adapted for the organic chemistry instrument. It had to go through several stages to make sure that it accommodated all the questions posed in the organic chemistry instrument. As the first group of teachers completed their instruments, the rubric was used to score their responses. Teachers' responses to the tasks in the PCK instrument played a role in refining the rubric as they gave insight of what possible responses teachers would give. Since the raw scores from the rubric were going to be subjected to Rasch analysis, it was suggested during the refinement process that items from four of the categories could be divided into sub-categories

and be analysed separately. The rubric was reformatted to reflect the division of the categories according to the question in each category. For example, the curricular saliency category focused on the teachers' understanding of concepts which should have been taught prior to grade 12 for scaffolding purposes, the big ideas at grade 12 including their sequencing as well as the conceptual progression of the topic. At the beginning all the tasks were scored according to the rubric using a combined version of the description of the levels. At a later stage these were separated (as shown in Table 4.2) to make it easier to score the instruments using the rubric. Table 4.2 below shows the rubric at an early stage of development and how it was changed as it was being refined for category 1 (Limited) of question 2 in the TSPCK instrument.

1 (Limited) combined score	1 ( Limited) separate scores	
<ul style="list-style-type: none"> <li>• Identified concepts are a mix of Big Ideas and subordinate ideas</li> <li>• Identified subordinate ideas a mix with those of Big Ideas of other topics</li> <li>• Identified pre-concepts are a mix including those to be taught in current topic</li> <li>• Sequencing no value due to mixed concepts</li> <li>• Reasons given for importance of topic limited to general benefit of education</li> </ul>	B1	<ul style="list-style-type: none"> <li>• Identifies correctly 4 prior concepts with some that are generic(mole and stoichiometry) , and provides no reasons for choice; (<i>concepts/reasons may not be relevant to the topic</i> ) Q1</li> </ul>
	B2	<ul style="list-style-type: none"> <li>• Identifies 1 Big Idea from set of concepts provided, may be a mix of big ideas with subordinate ideas Q2</li> <li>• Provides sequence for teaching the Big Ideas, sequence may not be logical, with no reasons provided Q3 &amp; Q4.</li> <li>• Provides no map/illogical map of Big Ideas, Q5</li> </ul>
	B3	<ul style="list-style-type: none"> <li>• Identifies importance of organic chemistry as a topic with no reasons related to conceptual progression or application or motivation/interest. Q6</li> </ul>

Table 4.2 Probing teachers' understanding of curricular saliency, Q refers to the number of the question in the PCK instrument

The Rasch analysis (Chapter 6) later revealed that in a few categories the level descriptors were not sufficiently fine-grained. These were amended. The analysis of how the rubric was used to score responses from the PCK instrument will be presented and discussed in Chapter 5.

## CHAPTER 5

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### 5. Analysis of the findings from the instruments

*In this chapter, I discuss the manner in which the findings from the instruments were analysed. I will start with the Content Knowledge, CK, instrument which was scored as if it was a conventional test of organic chemistry. The concepts tested in this instrument were based on the ideas which were distilled from Grade 12 textbooks. I will show how the raw scores were obtained to be used later for Rasch analysis. I will therefore include the samples from the data collected and highlight some trends on the data analysis. I will then discuss the analysis of the Topic Specific PCK instrument which was coded using the rubric. The rubric was designed according to the five knowledge components of the Mavhunga (2012) model to score teachers' responses on the TSPCK instrument. Each category comprised four different levels to interpret teachers' understanding of each of the TSPCK components which were defined in chapter 4. I will also include examples of the way in which the rubric was used to analyse teachers' responses. I will include samples from the rubric and teachers' instruments to show the manner in which these were coded and how teachers' responses fitted the categories in the scale. Scoring the TSPCK instrument using the rubric was more challenging than marking the CK instrument, thus the former will be the main focus of this chapter.*

#### 5.1. Scoring the CK instrument

The design of the instrument to assess CK and how it was used to collect data from a large cohort of science teachers was discussed in the previous chapter. The CK instrument used in the study is attached as Appendix 4. For the CK instrument, responses were assessed as if they were a conventional test, meaning that teachers' responses were either correct or incorrect. For example, the first item of the CK instrument asked teachers to draw the structural formulae for both 2 methylhex-3-ene and ethyl propanoate. Teachers were awarded a mark for a correct answer for each compound. As indicated in Table 5.1, only a few teachers were not able to provide the correct answers as the question was fairly straightforward; the average mark was

92%. The second item of the instrument probed teachers' understanding of isomers (structural and geometric). While the latter are not included in the Grade 12 syllabus, a decision was made to retain the task on geometric isomers in the questionnaire as it can be assumed that teachers' content knowledge should be a level higher than their learners. Table 5.1 below shows an average score of 37.5 % which indicates that most of the teachers had difficulty in answering this question. One of the reasons might be the fact that teachers do not teach geometric isomers at Grade 12, thus the last time they had to think about geometric isomers was at college or university.

Task number	Description	Number of items	Average score; %
1	Drawing structural formulae	1	92.0
2	Drawing and naming structural and geometric isomers	2	37.5
3	Major classes of organic reactions	5	72.0
4	Functional group recognition	6	91.9
5	Intermolecular forces and boiling points	3	63.6

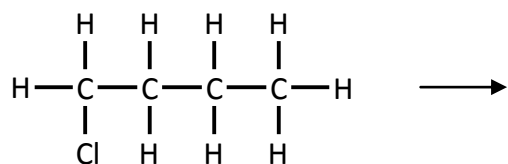
Table 5.1 Average scores for tasks in the CK instrument

The third task was based on classes of reactions and is a close match to the Grade 12 curriculum. This section carried 25.6% of the overall mark. Teachers had to give the structure of the product of the reaction, the name of that product and sometimes the specific type of reaction. For example, teachers were asked to give the product of an elimination reaction and to name it, and a mark was awarded for each correct answer (for an example see Figure 5.1). Teachers were also awarded a mark for naming this particular type of elimination reaction. In some cases, teachers gave only the product of the reaction and not the name of the product which would have led to a lower mark for the question since the correct names of the compounds comprised 12.8 % of the total for the instrument. It cannot be assumed that if a teacher gave a correct product that he/she would be able to give the name of the product even though it is unlikely that a teacher would be able to draw the product and not know how to name it. Figure 5.1 below shows a section of the task probing knowledge of

organic reactions where teachers had to draw the product, name it and also give the type of reaction.

Complete the following chemical reactions, balancing them where needed. Give the name of the organic product of each reaction.

**Q3b. ELIMINATION REACTION:**



Type of elimination reaction: .....

Figure 5.1 Sample of the question on chemical reactions

Teachers found the fourth item of the instrument fairly easy. This task, based on an example from the literature (Johnstone & Ambusaidi, 2001), was used to probe teachers' ability to recognize the various functional groups. The task, which is shown in Table 5.2 below, required teachers to apply their knowledge of functional groups to identify the correct class of compound in accordance with the question posed to them. For example, the first question asked teachers to identify all the alcohols in the molecules shown in Table 5.2 below.

1	2	3	4
$\text{CH}_3\text{-OH}$	$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-OH}$	$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-H}$	$\text{CH}_3\text{-CH}_2\text{-OH}$
5	6	7	8
$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-CH}_3$	$\text{H}\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$	$\text{CH}_3\text{-O-CH}_3$	$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$

Table 5.2 Structures used to probe understanding of functional groups

The final item in the instrument probed teachers' understanding of physical properties of organic compounds, in particular boiling points. The response to this question indicated that teachers did not perform very well as they achieved an average score of 63.4%. Unlike the previous question where teachers had to simply recognise the alcohols, aldehydes or ketones and be awarded a mark for choosing the correct answer, teachers had to apply their knowledge in interpreting the intermolecular forces acting in the compounds presented to them.

Raw scores for the CK instrument are shown in Appendix 6. The average score for the CK instrument was 68.1% with 39% of the cohort achieving over 75%. Six teachers failed to achieve 50% for the CK instrument. In summary, drawing structural and geometric isomers presented a challenge to almost all teachers while answering questions on intermolecular forces proved to be difficult for some teachers. One of the items in task 2 required teachers to draw structural isomers of a carboxylic acid each containing a different functional group. The average score for this item was 36.4% showing that there is a much greater conceptual challenge related to generating isomers of this type than recognizing and identifying them as in task 4f, where the average score was 95.5%. Task 2 tested knowledge of isomers beyond the demands of the school curriculum, which may provide an explanation for the low performance (37.5%) on this item in the CK instrument.

## **5.2. Scoring the Topic Specific PCK instrument**

There are a wide variety of responses possible for the PCK instrument and therefore it was decided to score these using a rubric. Park et al. (2011) used this quantitative method to investigate the correlation between a teacher's level of PCK as measured by a rubric and the degree to which his/her classroom is reform-oriented as measured by a Reformed Teaching Observation Protocol. Gardner and Gess-Newsome (2011) developed a rubric based on eight criteria to examine teacher knowledge and practice. Their rubric was organized into three categories: content knowledge, pedagogical knowledge and contextual knowledge. Mavhunga (2012) constructed a rubric based on her model of TSPCK and used it to score teachers' responses constructed for the topic of chemical equilibrium. Since the Mavhunga rubric (2012) was based on the topic of chemical equilibrium, it was adapted to score teachers' responses to the Topic Specific PCK instrument for organic chemistry.

Scores were assigned to the five categories with each being rated on a five point scale, from 0 (No response) to 4 (Exemplary) and were peer validated by independent raters. An agreement rate of 85% was obtained. Table 5.3 below shows the final version of the rubric which was used to score teachers' responses.

University of Cape Town

TSPCK Components	(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
Learner Prior Knowledge including misconceptions (may be implied)  Section A1 and A2	<ul style="list-style-type: none"> <li>Content-based explanation only (correct answer)</li> <li>No consideration of student prior knowledge or misconceptions</li> </ul>	<ul style="list-style-type: none"> <li>Identifies misconception or prior knowledge</li> <li>Provides standardized knowledge as definition</li> </ul>	<ul style="list-style-type: none"> <li>Identifies misconception or prior knowledge</li> <li>Provides standardized knowledge as definition</li> <li>Expands explanation</li> </ul>	<ul style="list-style-type: none"> <li>Identifies misconception or prior knowledge</li> <li>Provides standardized knowledge as definition</li> <li>Expands explanation</li> <li>Explanation demonstrates conceptual understanding</li> </ul>
	B1	<ul style="list-style-type: none"> <li>Identifies correctly 4 prior concepts with some that are generic (mole and stoichiometry), and provides no reasons for choice; (<i>concepts may not be relevant to the topic</i>) Q1</li> </ul>	<ul style="list-style-type: none"> <li>Identifies correctly 4 prior concepts that are relevant to topic but reasons for choice are generic (<i>may not be related to teaching or scaffolding of learning the topic</i>) Q1</li> </ul>	<ul style="list-style-type: none"> <li>Identifies 4 prior concepts, provides acceptable reasons related to teaching or scaffolding of learning; Q1</li> </ul>
Curricular Saliency  Section B	<ul style="list-style-type: none"> <li>Identifies 1 Big Idea from set of concepts provided, may be a mix of big ideas with subordinate ideas Q2</li> <li>Provides sequence for teaching the Big Ideas, sequence may not be logical, with no reasons provided</li> <li>Provides no map/illogical map of Big Ideas, Q5</li> </ul>	<ul style="list-style-type: none"> <li>Identifies 2 Big Ideas from set of concepts provided may include subordinate idea, Q2</li> <li>Provides sequence for teaching the three Big Ideas, sequence/reasons may not be logical, Q3 &amp; Q4</li> <li>Draws a map of Big Ideas, no subordinate concepts. Q5</li> </ul>	<ul style="list-style-type: none"> <li>Identifies 3 Big Ideas from set of concepts provided, Q2</li> <li>Provides logical sequence for teaching the three Big Ideas Q3</li> <li>With reasons that are generic Q4</li> <li>Draws a map of Big Ideas with some links to subordinate concepts Q5</li> </ul>	<ul style="list-style-type: none"> <li>Identifies 3 Big Ideas from set of concepts provided, Q2</li> <li>Provides logical sequence for teaching the three Big Ideas Q3</li> <li>Reasons for sequence related to logical progression, conceptual scaffolding of learning, Q4</li> <li>Identifies <u>subordinate concepts</u> and shows links to Big Ideas in form of a logical map, Q5</li> </ul>
B3	<ul style="list-style-type: none"> <li>Lists importance of organic chemistry as a topic related to application and/or motivation/interest.</li> <li>No reasons given Q6</li> </ul>	<ul style="list-style-type: none"> <li>Identifies Importance of organic chemistry as a topic related to two aspects, application and motivation/interest.</li> <li>Gives reason for one aspect listed (Q6)</li> </ul>	<ul style="list-style-type: none"> <li>Importance of organic chemistry as a topic with namely, application and motivation/interest</li> <li>Reasons related to <b>both</b> aspects Q6</li> </ul>	<ul style="list-style-type: none"> <li>Importance of organic chemistry as a topic related to <b>all</b> aspects namely <b>conceptual progression</b>, application and motivation/interest</li> <li>Reasons related to <b>all</b> aspects Q6</li> </ul>

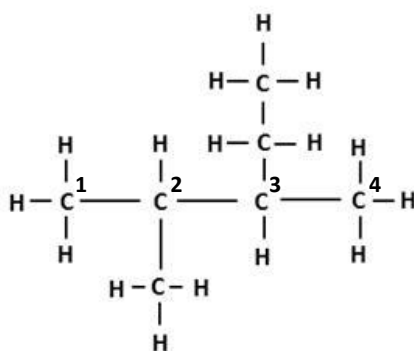
TSPCK Components	(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
What makes topic difficult to teach  Section C	<ul style="list-style-type: none"> <li>Identifies broad topics without specifying the actual sub-concepts that are problematic</li> <li>Reasons not given</li> </ul>	<ul style="list-style-type: none"> <li>Identifies specific concepts</li> <li>Provides broad /generic reasons such as 'abstract'</li> </ul>	<ul style="list-style-type: none"> <li>Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions (which may be implied)</li> </ul>	<ul style="list-style-type: none"> <li>Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions</li> <li>Provides reasons linking to specific gate keeping concept(s) that when not fully understood adds to the difficulty of a concept regarded as difficult</li> </ul>
	Section D  Representations  D1 = b  D2 = a and c	<ul style="list-style-type: none"> <li>Describes use of 1/2 of the reps provided (use may not be appropriate)</li> <li>Limited to use of symbolic representation of scientific notation i.e. formulae/equations</li> <li>No enforcing of specific concept</li> <li>Poor link between the choice of representation in part (a) and the use of it emphasizing a specific concept part (c)</li> </ul>	<ul style="list-style-type: none"> <li>Describes appropriate use of 3 of the reps provided</li> <li>Provides standardized knowledge to define reps</li> <li>Use of symbolic representation to enforce a specific aspect of a concept</li> <li>Gives textbook definition to explain the use of a certain representation in emphasizing a specific concept</li> </ul>	<ul style="list-style-type: none"> <li>Describes an appropriate use of 4 of the reps provided</li> <li>Use of representation of a molecule to enforce a specific concept i.e. may link representation to intermolecular forces.(lines drawing more than equations)</li> <li>Makes link between C chain length and/or surface area to bpt and/or IMF with explanation</li> <li>States facts but does not mention energy or bpt. explicitly</li> </ul>
Teaching Strategies  Section E E1 and E2	Chooses strategy that <ul style="list-style-type: none"> <li>Gives only the correct answer to the task</li> <li>No confirmation/confrontation of student prior knowledge and/or common misconceptions</li> </ul>	Chooses strategy that <ul style="list-style-type: none"> <li>Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>Uses only symbolic representation</li> <li>No conceptual approach</li> </ul>	Chooses strategy that <ul style="list-style-type: none"> <li>Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>Conceptual approach to topic not clear</li> <li>Uses a representation or model of a molecule to enforce an aspect of a concept.</li> </ul>	Chooses strategy that <ul style="list-style-type: none"> <li>Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>Uses a <u>model</u> or <u>symbolic</u> representation to enforce a singular aspect of a concept.</li> <li>Conceptual approach explicit</li> </ul>

Table 5.3 Rubric designed to score PCK instrument

The following discussion shows how scores were assigned to different responses which teachers gave to the TSPCK instrument and will include both the samples from completed teachers' instruments and how they fitted the categories of the rubric. For example, task A2 of the instrument focused on learner's prior knowledge and misconceptions (see Figure 5.2 below).

You have asked the learners in your Grade 12 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.



Both Mary and Charlie agree that this compound is 2-methyl-3-ethyl-butane. How would respond to these two learners?

Figure 5.2 Task A2 from the TSPCK instrument

A teacher, T1, gave the response which is in Figure 5.3 below, showing the manner in which she would apply her knowledge in confronting the misunderstanding posed in the question above.

-When you are giving IUPAC name of organic compounds with side chains, you must count the number of carbon atoms starting from the side which  $\ddagger$  is closer to the side chain. But in this case we have two side chains (ethyl and methyl) so since (eth) is before (meth) in the letters of the alphabet so we have start from the left-hand side (since e is nearer to it) to the right-hand side. Therefore the IUPAC for this compound is  
2,3-ethylmethylbutane.

Figure 5.3 Item scored as 1 (Limited) in category A2

The response above was awarded a score of 1 (Limited) as per the rubric, because the teacher's response simply provided the steps which should be followed in determining names of compounds according to the IUPAC system of nomenclature. In addition, the teacher failed to give the correct name for the compound, showing a limited understanding of the concept, which in return might hinder him/her from being able to identify the problems learners might have. According to Rollnick et al. (2008), teachers' confidence in their content knowledge does boost their PCK to an extent, as discussed in chapter 2. On the other hand, in the very same category another teacher, T42, was awarded a score of 2 (Basic) when the teacher gave the response below, see Figure 5.4.

$\ddagger$  the Name is incorrect because of the wrong numbering of the longest chain  
 $\Rightarrow$  the longest chain has 5 Carbon atoms with branches at C-2 and C-3 and the branches are methyl groups  
 $\therefore$  the Name should be 2,3-dimethylpentane.

Figure 5.4 Example of a score of 2 (Basic) for T42 for category A2

The response above shows that the teacher is aware of the fact that sometimes learners fail to identify the correct longest continuous carbon chain, which is one of

the most common misconceptions which students have with respect to the use of IUPAC nomenclature. Learners tend to think that the longest straight chain numbered from left to right should be the parent name of a particular compound; this was highlighted by one of the expert teachers who were used in this study to verify content validity. In his response he said that:

.....and I will also tell them that they will be tempted to start from left to right when numbering the longest chain simple because they are South African English students and if it were Chinese student they will be tempted to start from right to left but there is no method of numbering this molecule. You can start anywhere.

(Expert Teacher P, interview, November 2011).

The explanation that T42 gave in confronting this misconception is a correct answer without going beyond what a textbook would have presented in making sure that learners understand how to apply skills needed when dealing with IUPAC naming of organic compounds and hence the response given by this teacher fitted category 2 of the rubric.

The rubric for section B which probed teachers' knowledge of curricular saliency was divided into three sub-sections. According to the rubric, teachers should have an understanding of the prior concepts which should have been taught to grade 12 learners. The second sub-section of the task probing curricular saliency included teachers' knowledge of Big Ideas in Grade 12, as well as the sequence in which these should be taught, and the last sub-section focused on teachers' knowledge of the importance of organic chemistry as a topic. As before, the teachers' responses for section B2 were scored on a scale from 1 (Limited) to 4 (Exemplary) as shown by the rubric in Table 5.3 above and a zero was given for a blank score. It is also important to note that while the items for B2 were probing teachers' understanding of curricular saliency with respect to the Grade 12 syllabus, the sequencing of these ideas carried more weight than simply making a tick next to the concepts in the list provided. Since this aspect distinguished between teachers who have high levels of PCK and those who had little PCK, the map which teachers were asked to draw was considered to be the main focus as it elaborated clearly how the Big Ideas are linked (section B2, part 4). This section had four tasks which were scored according to section B2 of the rubric. Table 5.4 below shows the questions abstracted from the PCK instrument about the item discussed above.

1. 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.	

2. In the table below **list these main concepts you have chosen in the order in which they should be taught.**
3. Explain briefly your reasons for the order you chose.
4. Make a map or a diagram of these three ideas showing how they link to subordinate ideas.

Table 5.4 Tasks for question B2 of the PCK instrument

T3 was awarded a score of 2 because she managed to choose the Big Ideas for Grade 12 from the list of concepts from the list given and gave the order of teaching these concepts. In the map which this teacher constructed she simply expanded on each of the Big Ideas rather than including any subordinate ideas. The teacher was therefore awarded a 2 for her response as it matched that category in the rubric. The Figure below shows the response given by T3. As mentioned above, in answering task B2, teachers could demonstrate their ability to rearrange the concepts in a reasonable sequence and be able to link the corresponding sub-concepts to the Big

Ideas which would allow evaluation of their PCK. The map which T3 drew in Figure 5.5 below has the Big Ideas as requested in the task but the map has no links to subordinate ideas and hence T3 earned a score of 2 according to the rubric.

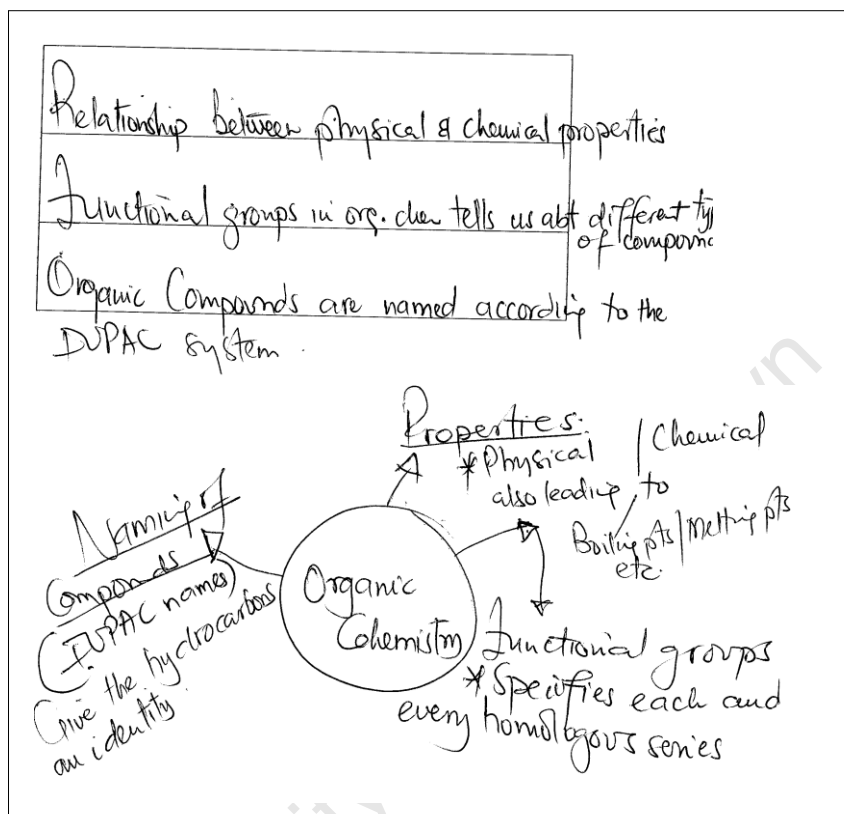


Figure 5.5 T3's response for section B2

T1 was scored at level 4 for task B2; see response in Figure 5.6 below. The teacher chose the concepts which he considered three Big Ideas and gave the order as well as his reasons. The most significant aspect of his response was the map which this teacher drew which showed clearly with arrows why it was important to first understand the unique nature of carbon. The map also included the sub-concepts which would inform learners about the uniqueness of carbon. The teacher gave the periodic table as the source which elaborates this unique nature of carbon and includes concepts such as electronegativity and chemical bonding, as shown in Figure 5.6. The ability of this teacher to map out his Big Ideas linking them with the subordinate ideas led to the awarding of a score of 4 (Exemplary).

*Carbon has a unique nature*

*There are different ways of representing organic substances.*

*There are several major types of reactions for organic materials.*

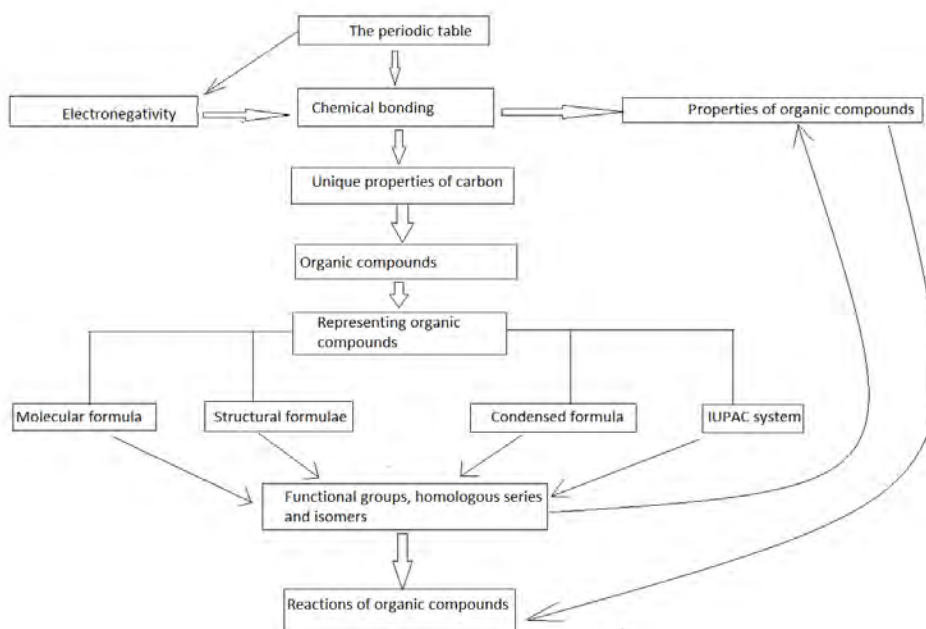


Figure 5.6 T1's response to section B2

The third item of the instrument probed for teachers' knowledge of topics which are most difficult to teach at grade 12 levels as well as the reasons why a particular topic was difficult to teach. Teacher 37 was awarded a 2 because the reasons which he gave are generic without specifying what exactly made these concepts difficult. The concepts chosen are shown in Table 5.5 below; the reasons given by the teacher are in column 2 of the table. The first concept that the teacher chose was IUPAC nomenclature, but it is not clear why learners take time to know and use IUPAC rules. With respect to esterification, the link between the good foundation for homologous series and ester formation is not clear. Thus the reasons this teacher provided were found to be generic and broad. The category in the rubric which accounts for generic reasons is category 2 (Basic) which was the score awarded to T37.

Concepts	Reason
IUPAC	Learners take time to know how to use the IUPAC rules of naming organic compounds.
Isomers	Learners find it difficult to differentiate between molecular formulae of compounds but they can differentiate between structural formulae with easy.
Esterification	Learners would understand this provided a good foundation has been laid with regard to homologous series of organic compounds

Table 5.5 T37's response for section C of the instrument

Teacher 6 on the other hand was awarded a score of 3. In responding to the scenario posed by the instrument, he chose the concepts shown in Table 5.6 below and the reasons this teacher gave were linked to misconceptions which students have in dealing with the concepts the teacher chose. For example the reason that the teacher gave for confusion over functional groups is similar to the misconception which was posed by the instrument in probing learners' prior knowledge where learners thought any compound containing an OH group is an alcohol. This teacher gave specific reasons related to each of the concepts he found difficult to teach and that earned him a score of 3 according to the rubric

Concept	Reason
Structural formulae	It is difficult for learners to picture out (imagine) the 3-D structure of organic compounds
Functional groups	Some functional groups are confusing to learners e.g. $-C-O-H$ and $-COOH$ .
Combustion	Learners struggle to balance equations

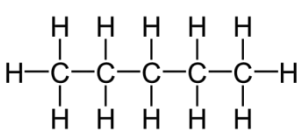
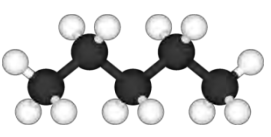

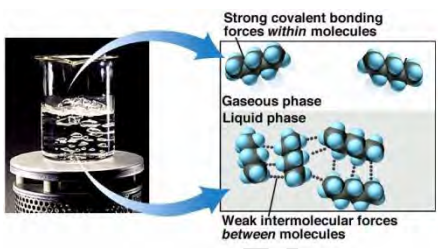
Table 5.6 T6 response for section C of the instrument

Two examples of the use of the rubric to score teacher's knowledge of conceptual representations are described below. As shown in Figure 5.7, Task D required teachers to select which representations they found useful, to say how they would use them in their teaching and to provide a specific example related to the difference in the boiling point of selected alkanes.

**Section D: REPRESENTATIONS/ANALOGIES/MODELS**

1. There are many ways of representing a molecule with molecular formulae  $C_5H_{12}$ , (pentane). Representations for  $C_5H_{12}$  are shown below.

- Which representations do you find the most useful?
- 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 	

- How would you use the representation(s) that you chose in (a) to explain the differences in the boiling points of butane ( $-0.5^\circ C$ ) and pentane ( $36^\circ C$ )?

Figure 5.7 Task D from the PCK instrument

T7's response was scored as 1 (limited) for two reasons: Firstly, the teacher could not describe the use of any of the representations shown in Figure 5.7 above. Secondly, the explanation to the question posed reveals a misconception related to the intermolecular forces in that hydrogen bonding is present in butane and pentane (see Figure 5.8 below). This misconception which depicts hydrogen bonding

occurring between carbon and hydrogen atoms has been noted at secondary level by one of the expert teachers who participated in this project.

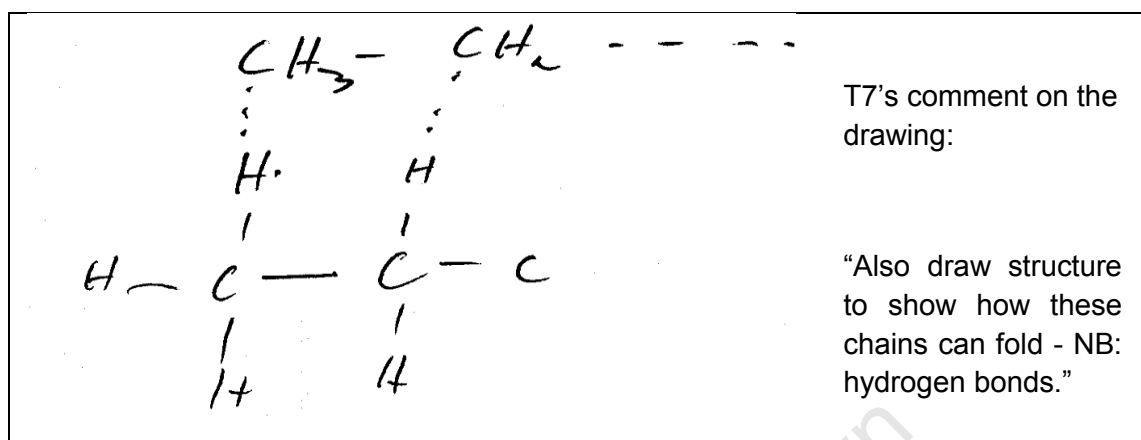


Figure 5.8 Teacher 7's responses to the question on representations. (Dotted lines are commonly used to represent hydrogen bonds.)

At the other end of the spectrum, teacher 1's response was coded as exemplary. Having chosen the expanded structural formula in Figure 5.7, the teacher said

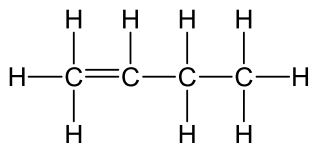
Representation 1 (structural formula), which clearly show how atoms are present in each of the compounds. This will give a clear comparison and link this to the strength of the intermolecular forces of the compounds leading to the conclusion on the amount of energy needed to break the bonds.

Eg: Pentane has a longer chain than butane and therefore in pentane, there is a larger surface area for weak van-der Waals forces to act on. This results in the intermolecular forces in pentane being stronger than those in butane, and therefore more energy need to break these stronger forces, resulting in a higher boiling point in pentane than in butane. (T1, TSPCK instrument).

The final section of the rubric was probing for teacher's knowledge of teaching strategies. In designing this part of the rubric, the ideas which framed this part were based on an understanding that teaching strategies incorporate the understanding of all other components of Topic Specific PCK (Mavhunga, 2012). When teachers consider their teaching strategies, they need to first identify learners' prior knowledge or misconceptions, to understand the curricular saliency they are dealing with at Grade 12, and also be able to identify concepts in the curriculum which are difficult for students and which are also difficult for teachers to teach. It is then that teachers will be able to choose representations which are best suitable for confronting the

learners' misconceptions, as well as teaching strategies to deal with all the problems that the learners are faced with (see example in Figure 5.9).

E2 In a diagnostic test a learner drew the incorrect structure below.



Given that you have taught your learners how to draw structural formulae, how would you conduct a revision lesson, to correct this learner's response?

Figure 5.9 Question for task E2

In scoring task E2 for example, teacher T10 was awarded a score of 1 in this section because the teacher gave a correct answer but did not present a strategy to deal with the learners' misconception. Hence the teacher's response, shown in Figure 5.10 below matched the first category of the rubric for section E2.

Each C atom must have 4 bonds in a molecule, not more or less, because it has 4 valence e<sup>s</sup>.

Figure 5.10 T10's response in section E2 of the instrument

On the other hand T3, who was awarded a score of 4, showed the way in which she would teach her learners in confronting the problem and her teaching shows the examples which would help learners to understand the concept around the tetra-valent nature of carbon. The strategy she chose includes the learners, i.e. it is a learner-orientated approach. The teacher also uses representations to show that the carbon must always have four bonds. Figure 5.11 below shows the response by T3.

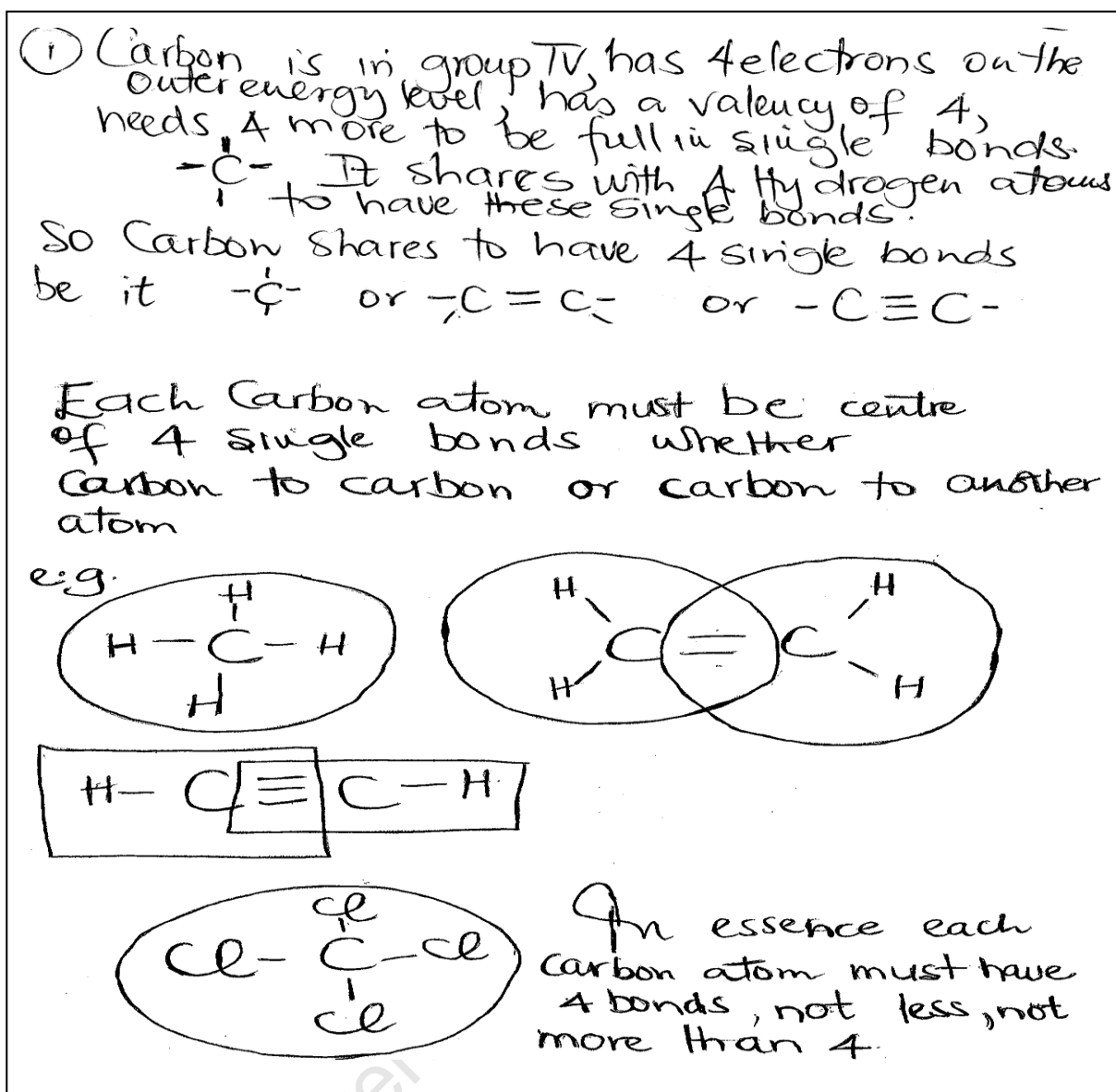


Figure 5.11 T3's response to the task in section E2

T3 gave the response above and went on to give further examples, thus engaging her students in the task. The figure above shows some examples of what she mentioned in trying to convey a message to her students that whether you have single-bonded atoms, double- or triple-bonded atoms, the important fact that learners need to consider is that carbon must always have four bonds.

The purpose of the discussion above was to highlight a few examples which will help others in understanding how the raw scores were assigned using the rubric. In the cases where teachers left blank spaces without any responses, a score of zero was awarded. All other responses were awarded according to the categories of the

rubric. A full copy of the instruments and the raw scores will be attached as Appendices 5 and 7 respectively.

The foundation of this study was the assumption that all the five knowledge components of TSPCK together inform the teacher's level of PCK with respect to that particular topic, which in this case was organic chemistry. Since there are issues of validity with respect to drawing conclusions about teacher's PCK based on the raw scores only, the next step therefore was to subject these raw scores to Rasch analysis to further analyse these results and ensure that they were valid to make claims about the findings. In the next chapter the focus is determining the validity and reliability of these instruments by measuring whether all these five components are indeed measuring TSPCK of science teachers teaching organic chemistry at Grade 12. The Rasch analyses are discussed in detail in chapter 6.

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### 6. Rasch Analysis of the CK and PCK instruments

*Validity and reliability are important issues in the analysis of quantitative data. A Rasch statistical model was used in this study to validate the instrument designed and also to obtain estimates of reliability. In addition, the Rasch model was used to convert raw scores from the two instruments, namely CK and TSPCK into interval measures of teacher competence. In this chapter I will discuss how the Rasch model was used to evaluate the two instruments developed to capture the extent to which grade 12 teachers transformed their content knowledge in organic chemistry. I will provide a brief description of the Rasch measurement model and the manner in which it works to produce reliability and validity estimates. I will thereafter provide a discussion of how the model provided evidence of the reliability and validity of the two instruments which were developed for this study and how it helped in improving the rubric designed to score the TSPCK instrument.*

#### 6.1. Introduction

The rationale of this study has been discussed in previous chapters, which included development of two instruments to assess the transformation of content knowledge of teachers teaching organic chemistry at Grade 12 level. These instruments were administered to a group of teachers after they had been piloted and their content validated with a group of expert teachers. One of the research questions which this study sought to answer was whether there is any correlation between CK and TSPCK based on an assumption that teachers with high levels of CK are most likely to reveal high levels of TSPCK and vice versa. To answer this question, instruments are required which are valid and reliable as well as being unidimensional with respect to measurement of scores for CK and PCK. Boone, Townsend and Staver (2011) advise that the Rasch statistical model can be used to convert raw score data to obtain interval data to increase the rigour of instrument development and analysis. The Rasch model is based on the assumption of unidimensionality of data, i.e. that the instrument is designed to capture data that varies on a scale of less than or more

than along a single dimension. If the data fit the model then unidimensionality is empirically confirmed (Bond & Fox, 2007).

The Rasch model (Bond & Fox, 2007; Boone & Rogan, 2005) was used firstly to confirm whether the data collected with the instrument for the two constructs, CK and TSPCK, respectively, was unidimensional. The model would achieve this by highlighting items from the instruments which were misfitting with respect to the Rasch model. These items could then be refined or excluded and the analysis repeated. In this way the model can assist in improving the quality of both the items and the instruments.

There are important aspects which play a role in evaluating the instrument using the Rasch model. Firstly it grants the researchers an opportunity to obtain information about underlying traits such as abilities or proficiencies as well as the features of test items which were involved in evaluating or measuring those traits. These traits can be narrow or broad, depending on what the test is intended to measure, but the important issue is that test scores should be meaningful and the test items should function in unison or in harmony. As noted earlier, the Rasch model is built on the assumption of unidimensionality, which means that all items must work together to measure the same variable. In the case of the CK instrument this would be mastery of basic organic chemistry while for the TSPCK instrument it would be the teachers' ability to transform their content knowledge for teaching. Empirical evidence for unidimensionality is therefore also evidence for the construct validity of the instrument.

The Rasch model also produces estimates of local independence, which indicates whether the response that a person gives to any of the test items is affected by his/her response to another item. The Rasch model is also based on the theory of presumption of maximum effort which estimates the probability of a person's ability to provide the correct response to an item. This implies that Rasch analysis makes it possible to estimate characteristics such as item difficulty, item discrimination and guessing of test items (Glynn, 2012).

The Rasch model is a probability based model, which transforms raw score data into linear measures which can be used for parametric tests (Bond & Fox, 2007). The model provides an analysis for reliability and validity for both persons and items. The

advantage of using this model is that the scores can be assigned on a linear scale allowing one to generate informative visuals such as person-item maps produced on this metric. The Rasch model used in this study was the one-parameter model because the aim of this study was to measure a single construct for each instrument, namely CK or TSPCK of teachers of organic chemistry at Grade 12 level. The Rasch model helps in producing results and conclusions which are not based solely on the raw scores but on linear measures, and, in addition, it has the capability of generating estimates of the validity and reliability of an instrument or any test data.

Data from both instruments was subjected to Rasch analysis (Andrich, 1988; Bond & Fox, 2007; Wright & Stone, 1999) to obtain evidence for the construct validity of the instruments and to provide a trustworthy estimate of their internal consistency. This statistical model was also used to convert raw score performance data to interval measures in order to determine any correlation between proficiencies in CK and TSPCK. The RUMM2030 suite of software programmes (Andrich, Sheridan & Luo, 2011) was used to analyse the data. The assistance of an expert, Professor Marietjie Potgieter, University of Pretoria, was solicited due to my unfamiliarity with the technique.

## 6.2. Analysis of the CK instrument

The data gathered from 44 respondents was subjected to Rasch analysis. The data set consisted of 17 test items to evaluate person proficiency with respect to CK. The cohort of teachers was grouped according to two categories, teaching experience in organic chemistry and the level of training in chemistry. The respondents were coded as U for University, C for College and T for Technikon (which are now called Universities of Technology). Table 6.1 below shows the relationship between years of teaching experience and the codes assigned. The groupings in Table 6.1 were based on Huberman (1992).

Years teaching Grade 12	Code	Comment
1-4	A	Teachers trained in the new curriculum
5-9	B	Teachers familiar with new curriculum
10-18	C	Teachers who had to adjust their conceptualisation of organic chemistry to fit the demands of the new curriculum
>18	D	Teachers who have stabilised in their teaching

Table 6.1 Codes for years of teaching Grade 12 organic chemistry

### 6.2.1 Person and Item statistics for the CK instrument

Using the Rasch model to analyse data is an iterative process. The data set is refined to obtain the best possible fit to the model. In the first cycle, item 4a (identification of alcohols) was found to be too easy as there was evidence of a high probability that both weak and strong teachers would give the correct answer. Thus item 4a was removed as it added no value in discriminating the proficiencies of persons.

The next step in the analysis dealt with disordered threshold maps. Ideally the Rasch model would give threshold maps which follow a particular pattern. The ideal pattern is an indication that all the test items are functioning according to the expectations of the Rasch model, i.e. each scoring category should represent the next step in proficiency along a continuum of *less than* or *more than* the category preceding it. Since the first analysis of the CK instrument produced disordered thresholds for items 1, 2a, 2b, 4d, 4e and 5b, these items were rescored as shown in Table 6.2 below.

Item rescored	How items were rescored	Possible scores for items					Disordered thresholds
		0	1	2	3	4	
1 Structural formulae	Original score, 0, 1 or 2 marks; rescore as follows: 0 = incorrect or 1 correct response 1 = correct responses to both tasks	0	0	1			2a, 2b, 4d, 4e
2a Drawing isomers	Original score 0, 1, 2, 3, 4 marks, rescores as follows: Combine levels 3 and 4 removing requirement to name both compounds.	0	1	2	3	3	2b, 4d, 4e, 5b
2b Drawing isomers; different functional groups	Original score 0, 1, 2, 3, 4 marks, rescores as follows: Combine levels 1 & 2 and 3 & 4 i.e. remove ability to name compounds, test ability to draw structures.	0	1	1	2	2	4d, 4e
4e Choose alcohol + acid	Original score, 0, 1 or 2 marks; rescore as follows: Combine 0 and 1, test ability to draw structure of product	0	0	1			4d

Table 6.2. Items rescored to remove disordered thresholds

Rescoring of items was based on the notion that the instrument had been designed to measure the level of CK of teachers and was carried out to focus on the core

concept being tested in a particular task. For example, the original scores for item 1 were 0, 1 or 2; that is teachers would either be awarded a score of 0 for a blank response or an incorrect response, 1 mark for a partially correct response or a total of 2 for the correct response. The item was rescored such that 0 indicated an incorrect or incomplete response while a score of 1 was awarded to a teacher giving the correct response to both concepts tested in item 1. The rescoring removed the disordered threshold for item 1.

For item 2a, the original scores were 0, 1, 2, 3 and 4. The item was designed to test teacher's ability to draw structural and geometric isomers. Levels 3 and 4 were combined to accommodate empirical evidence from the Rasch analysis that proficiency on this task is better reflected by four levels (or categories) than five. In item 2b the item originally tested the teacher's ability to draw and name structural isomers of a carboxylic acid with different functional groups. When the item was rescored the teacher's ability to draw the compound was the central issue to be tested and the ability to name the compound was removed from the item. The original scores for item 2b ranged over 0, 1, 2, 3, 4. Once the items had been rescored, levels 1 and 2 and levels 3 and 4 were combined, meaning that teachers who were originally awarded 1 or 2 out of 4 were scored as 1 and teachers who were awarded 3 and 4 marks out of 4, were assigned a score of 2. This resulted in simultaneously resolving the disordered thresholds for both items 2b and 5b, meaning that rescoring item 2b provided a solution to the disordered threshold for item 5b as well.

Finally, for item 4e, which was originally scored as either 0, 1 or 2, levels 0 and 1 were combined, meaning that teachers who were able to identify the two compounds required to synthesise an ester were scored as 1; any other responses were scored as zero. The Rasch analysis indicated that after the items were rescored the disordered thresholds disappeared except for item 4d (identifying structural isomers). This item was carefully analysed but it could not be rescored in a manner that could be justified in terms of its design and subject content.

After dealing with the disordered categories, the records for teachers 1 and 16 were removed from the analysis, because they did not contribute constructively to the analysis. It should be remembered that the Rasch model is based on the idea that

the response of a person to an item depends on both the item difficulty and the person proficiency. According to the Rasch model T16 was a misfitting person, who returned erratic responses; for example correct responses to difficult items such as questions 2b and 5b, but incorrect responses to easy items such as questions 4b and 4f. Teacher T1 returned a perfect score which, in terms of the model, is considered an extreme case in that the error of measurement associated with estimating the proficiencies in these cases is large.

The final cycle of the Rasch analysis was carried out after question 4c was deleted as being redundant. Items 4b and 4c probed a teacher's ability to recognise aldehydes or ketones respectively. The same responses were noted for both items, meaning that either a teacher knew that these were both carbonyl compounds or could not recognise either compound; hence 4c was deleted as it was considered to be a redundant item. After removal of misfitting person, T16 and redundant item 4c, the category disorder for item 4d was also resolved. The Rasch analysis indicated no disordered thresholds, which meant all the test items were now functioning according to the expectations of the model and the power of fit was considered to be good.

### **6.2.2 Person-item map for CK**

The person-item map, a visual representation of alignment and spread of person proficiencies and item difficulties for the CK instrument, is shown in Figure 6.1 below. The Rasch model had earlier revealed that the performance of two teachers were either misfitting or extreme cases, thus the person measures for these teachers have been excluded from the person-item map below.

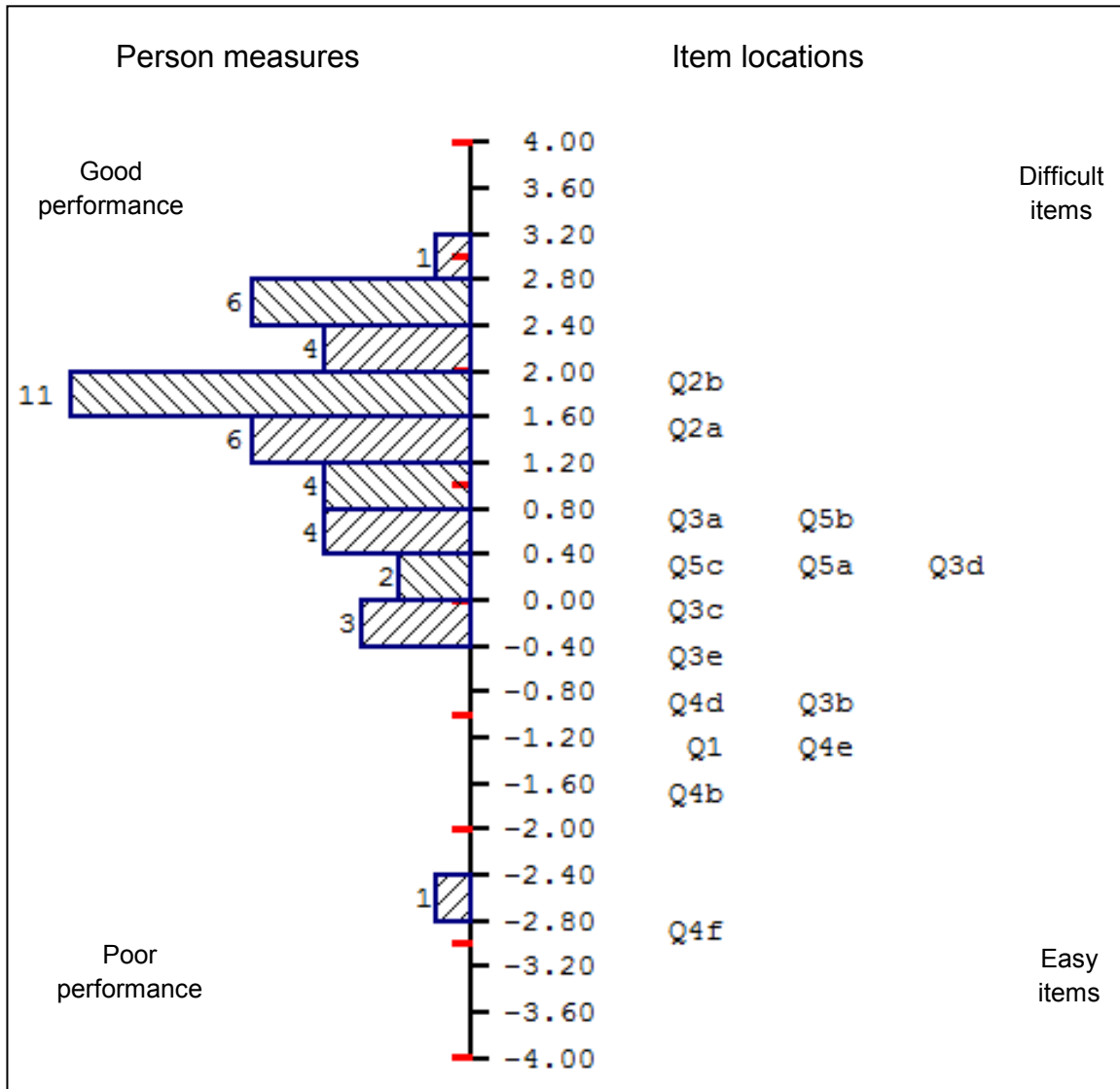


Figure 6.1 Person-item map indicating person proficiency and item difficulty for the CK instrument

The distribution on the left shows the spread of performance of the teachers according to Rasch measures based on a mean of zero for the item measure. Person proficiencies and item difficulties are located on the same vertical scale with poor proficiency and low item difficulty at the bottom of the map and high proficiency and high difficulty at the top. According to the Rasch model the specific location of a person on the map indicates that for this person the probability of correctly answering items of matching difficulty on the same vertical scale is 50%. It is higher than 50% for items of lower difficulty and lower for items of higher difficulty. Thus the bar on the left labelled “11” indicates that these 11 teachers had a ca. 50%

probability of giving the correct answer for Q2a and 2b and a more than 50% probability of giving the correct answers to items below Q2 on the scale.

The mean person performance of 1.43 (standard deviation, 1.07) reflects the fact that most teachers in this sample experienced the test as being easy. As noted above, items 4a and 4c which failed to discriminate were removed. The data did not fit the Rasch model well, as indicated by the item-trait interaction chi-square ( $\chi^2$  67.96, df 30, prob 0.0001). This means that the null hypothesis that there is no difference between the model and the data is rejected. However, the origin of misfit was not evident. All items showed good fit statistics, all response categories functioned as expected and no empirical evidence for multidimensionality was found, thereby confirming the construct validity of the instrument. The estimated value for Cronbach's alpha was 0.81 which is a trustworthy reflection of the internal consistency of the instrument. The reliability of the instrument is considered to be fairly high for a performance test consisting of only 15 items. We concluded that the instrument met the requirements for fundamental measurement and the person proficiencies estimated were suitable for comparison with TSPCK proficiencies.

The data show that the most difficult item was question 2, which assessed structural and geometric isomerism. Question 5b (interpretation of physical properties) and question 3 (completing chemical equations) were easier. Q3a, combustion of hydrocarbons, was the exception in this section. The easiest items were question 4 (recognition of functional groups); and question 1 (interpreting systematic names). It should be noted that questions 1 and 4 assess procedural competence, while questions 2, 3 and 5 assess interpretation and application of knowledge. The fact that a question 4f, matching isomers from a set of compounds provided, was the easiest item came as a surprise given teachers' difficulties in answering question 2b where they are asked to generate isomers of a given compound. The discrepancy may be due to the use in question 4f of a common example of structural isomerism featured in textbooks of organic chemistry (Atkins & Carey, 2002, p 13; Kelder, Govender & Govender, 2007, p 219,) with teachers' answers thus based on familiarity with this example.

### 6.2.3 Person Frequency Distributions for CK

Rasch analysis is able to estimate person abilities and depict the frequency distributions on a linear interval scale. The estimates for the different subsets of teachers according to experience and training are shown in Figures 6.2 and 6.3 below. In these figures, negative values on the scale indicate poor proficiency and positive values better performance. These figures are one half of the person-item map (Figure 6.1) rotated clockwise. ANOVA tests were carried out to test whether there was any statistically meaningful difference between teachers' CK and experience or level of education. The results are interpreted as shown by the two diagrams below. Figure 6.2 shows that the mean person measure increases with the level of experience as would be expected. The standard deviations of the mean person measures overlap, thus the difference is not significant at the 5% confidence level.

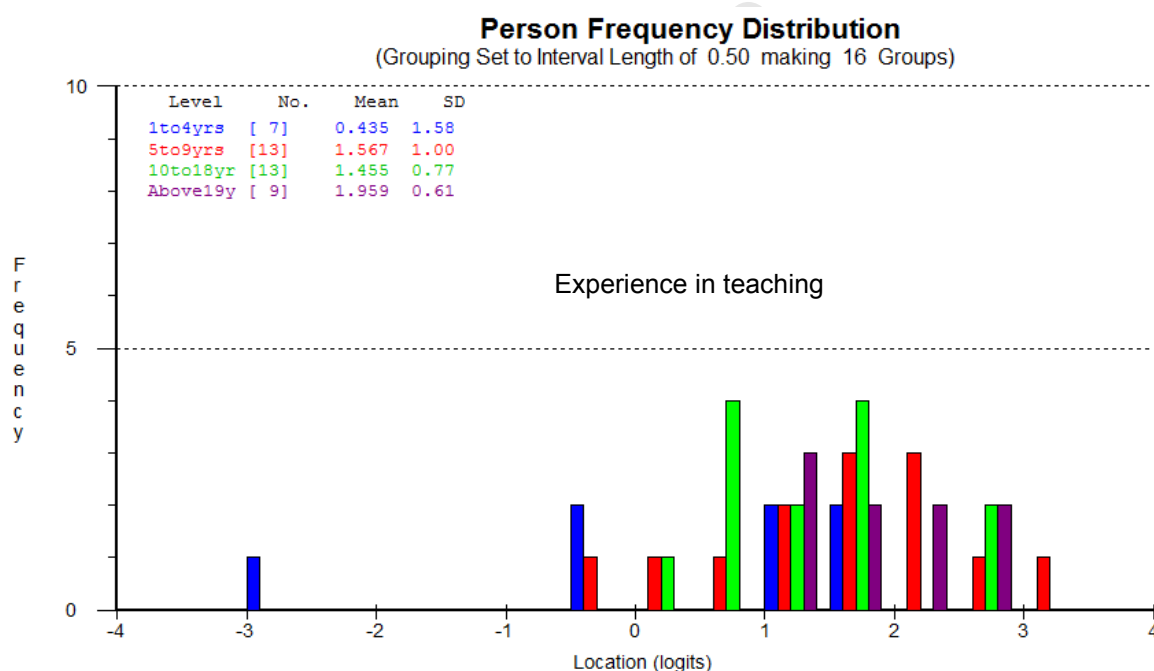


Figure 6.2. Person frequencies with respect to years of experience in teaching Grade 12 organic chemistry

Figure 6.3 below indicates that teachers with university education in chemistry have higher levels of CK than those who trained at either technikons or colleges as the mean values for teachers trained at these institutions are lower than the mean value

for those educated at universities. The standard deviations of the means overlap, thus the differences are not statistically significant.

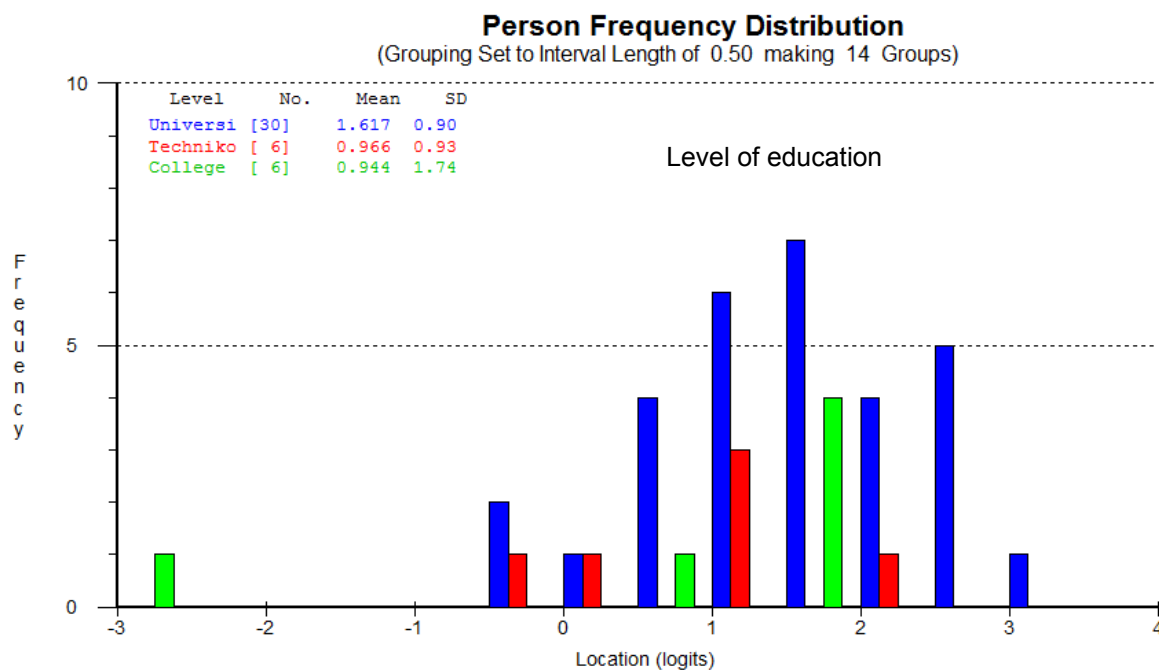


Figure 6.3. Person frequencies with respect to levels of education of Grade 12 organic chemistry

It should be noted that while the sample sizes in the groups shown in Figures 6.2 and 6.3 are small, the trends indicate that levels of CK are generally higher for teachers with extensive teaching experience and university education in chemistry.

### 6.3 Analysis of the TSPCK instrument

The TSPCK instrument was scored using the rubric, see Table 5.3. According to the rubric, a zero was assigned when a teacher failed to give a response to a particular task. The zeroes are removed from the data set before the Rasch analysis as this score was assigned to a missing response rather than an incorrect answer as for the CK instrument. If there is missing data then a value for Cronbach's alpha cannot be estimated; however, the Rasch model can be used to estimate the Person Separation Index which provides an analogous measure of the internal consistency of the instrument.

As described above, the Rasch model was used to validate the TSPCK instrument in Organic Chemistry and to obtain reliability estimates for the instrument. Data from 44 respondents consisting of 10 items was subjected to Rasch analysis. The results in the first cycle of analysis showed that Teacher 25 had very weak TSPCK (only one response) and two teachers (T1 and T20) obtained perfect scores. The analysis showed reversed thresholds for 4 items which is an indication that the scoring categories in the rubric for these items, A2, B3, E1 and E2, were not working as expected; a problem which might have been due to the design of the rubric.

Since there were reversed thresholds with the first cycle, it was decided to refine the rubric description for items A2, B3, E1 and E2 since two categories for each item in the rubric were not working well according to the results provided by Rasch analysis. The category definitions in the rubric were then clarified: the teacher responses were rescored and Rasch analysis was repeated. The inter-rater reliability was 88%. Tables 6.3 and 6.4 show the original and amended rubrics for section E, Conceptual Teaching Strategies.

Categories of TSPCK	Teaching Strategies: E1 and E2
<b>Limited (1)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Meets none of the objectives of the lesson</li> <li>• No confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Conceptual approach to topic not clear</li> <li>• No use of representation</li> </ul>
<b>Basic (2)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Meets some of the objectives of the lesson</li> <li>• Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Conceptual approach to topic not clear</li> <li>• Representation limited to symbolic equation</li> </ul>
<b>Developing (3)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Overall meets the objectives of the lesson</li> <li>• Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Considers important conceptual aspects of the task, etc.</li> <li>• Uses a representation of a molecule to enforce an aspect of a concept (Task 1)</li> </ul>
<b>Exemplary (4)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Meets all the objectives of the lesson</li> <li>• Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Considers important conceptual aspects of the task, etc.</li> <li>• Uses a <u>model</u> or <u>symbolic</u> representation to enforce a singular aspect of a concept.</li> </ul>

Table 6.3 Part of the rubric showing the original descriptions for category E, teaching strategies

Categories of TSPCK	Teaching Strategies: E1 and E2
<b>Limited (1)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Gives only the correct answer to the task</li> <li>• No confirmation/confrontation of student prior knowledge and/or common misconceptions</li> </ul>
<b>Basic (2)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Uses only symbolic representation</li> <li>• No conceptual approach</li> </ul>
<b>Developing (3)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Conceptual approach to topic not clear</li> <li>• Uses a representation or model of a molecule to enforce an aspect of a concept</li> </ul>
<b>Exemplary (4)</b>	Chooses strategy that <ul style="list-style-type: none"> <li>• Considers confirmation/confrontation of student prior knowledge and/or common misconceptions</li> <li>• Uses a <u>model</u> or <u>symbolic</u> representation to enforce a singular aspect of a concept.</li> <li>• Conceptual approach explicit</li> </ul>

Table 6.4 Part of the rubric showing the revised descriptions for category E, teaching strategies.

When the Rasch analysis was repeated, using the scores derived from the amended rubric, 3 of the items still presented with disordered thresholds as before, namely A2, E1 and E2. In each case the third scoring category (developing) did not function as expected i.e. it did not represent a stepwise gain in proficiency between basic and exemplary. It was concluded that proficiency in these items should be scored according to 3 categories rather than 4, as the data indicated that proficiency in these items naturally fall into 3 distinct categories only. The decision on the rescoring of these items was based on empirical evidence provided by Rasch analysis, because the characteristics of the categories as described in the rubric did not provide clear guidance in this regard. Items A2 and E1 were rescored 0, 1, 2, 2, which means that for these items the categories "Developing" and "Exemplary" were assigned the same score. Item E2 was rescored 0, 1, 1, 2, which means that the categories "Basic" and "Developing" were assigned the same score.

### 6.3.1 Person item map for TSPCK

The person item map generated by Rasch analysis of the TSPCK instrument data is shown in Figure 6.4 below. In addition to T1 and T16, which were removed for the CK instrument, T12 and T20 were also removed as they represent extreme cases having achieved a perfect score.

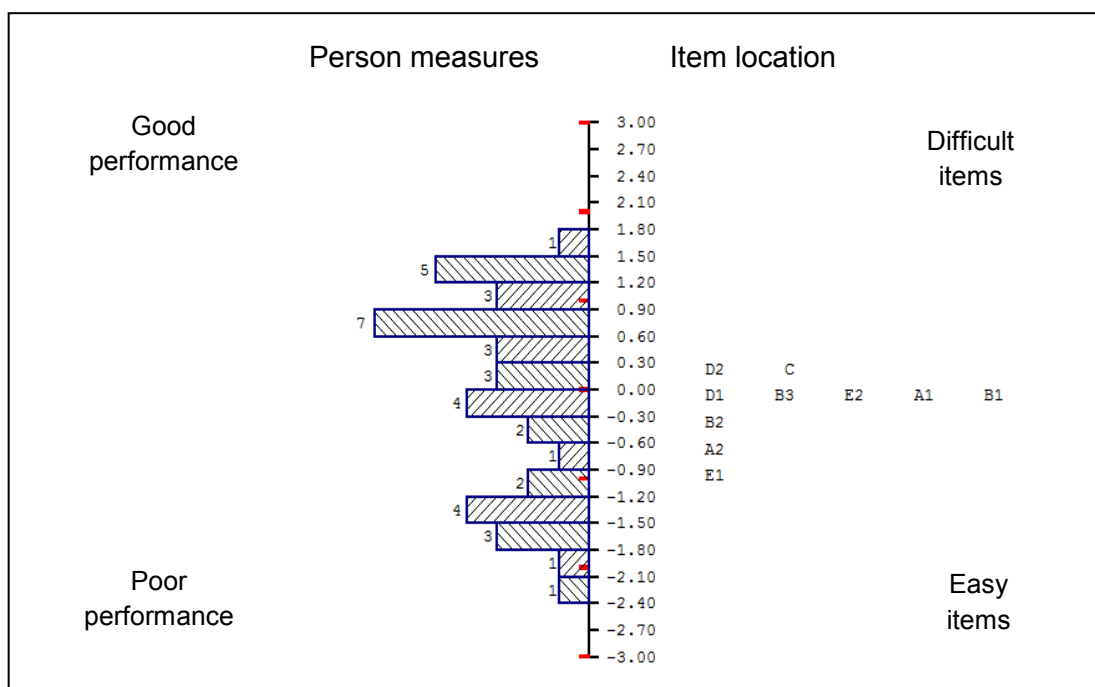


Figure 6.4 Person-item map indicating person proficiency and item difficulty for the TSPCK instrument

The Rasch analysis revealed a good overall fit of the data to the model as indicated by the item-trait interaction chi-square ( $\chi^2$  20.09, df 20, prob 0.452). This means that the null hypothesis that there is no difference between the model and the data is not rejected. The mean person performance was -0.01 (standard deviation 1.09) while the estimated value for the Person Separation Index (similar to Cronbach's alpha) was 0.83. The person-item map indicates that, in general, there is fairly good alignment between the means of item difficulties and person performance, but the items do not have a wide spread in terms of difficulty. Items A2, B2 and E1 are the easiest and Items C and D2 are the most difficult. Since there was no evidence of local dependence in the data it can be concluded that all items are contributing in a unique way to measuring the construct of TSPCK in organic chemistry.

### 6.3.2 Person Frequency Distributions for TSPCK

Teacher performance on the TSPCK instrument was compared for sample subgroups according to their teaching experience, see Figure 6.5 below. According to Geddis and Lederman (1993), teaching experience has an effect in increasing teacher's pedagogical content knowledge. In the findings of the study by Feiman-Nemser and Parker (1990) experienced teachers have a way of transforming their content into appropriate explanations and tasks for learners. These authors also argue that experienced teachers could therefore help beginning teachers by sharing with them ideas which have worked for them. As observed for the CK instrument, the mean values for the person measures for TSPCK were higher for more experienced teachers; while there is evidence that teachers with 1-4 years of teaching experience have a lower level of TSPCK than teachers with more experience. These differences were, however, not statistically significant and may be a reflection of the relatively small size of our sample.

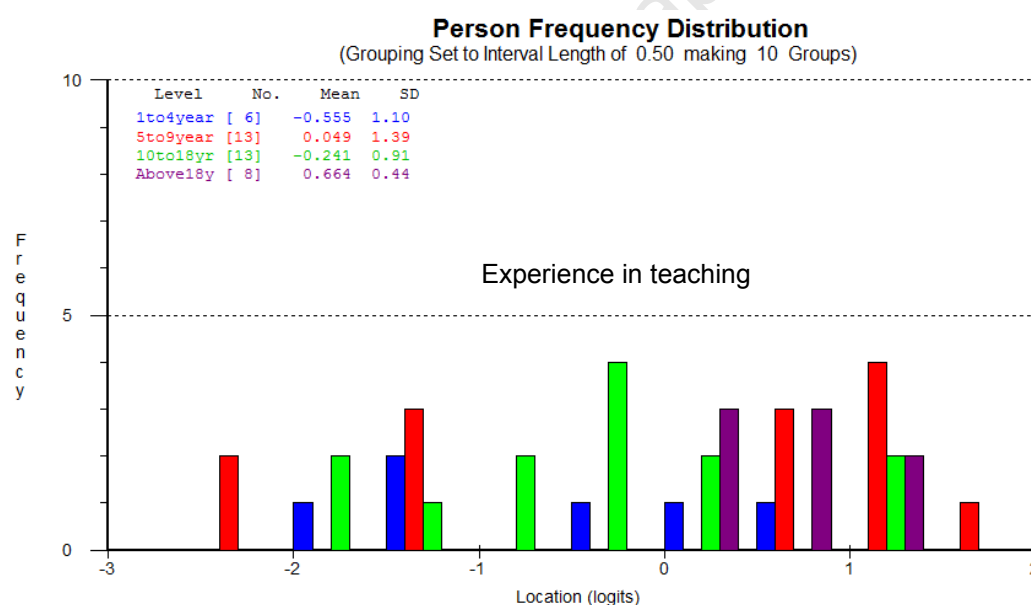


Figure 6.5 Person frequencies with respect to years of teaching Grade 12 organic chemistry

A person frequency distribution with respect to level of education is shown in Figure 6.6 below; the figure includes values of the means and standard deviations. The Rasch analysis also revealed that teachers with college and technikon training have

lower TSPCK than teachers with university education, but once again the standard deviations of the means overlap, thus the differences are not statistically significant.

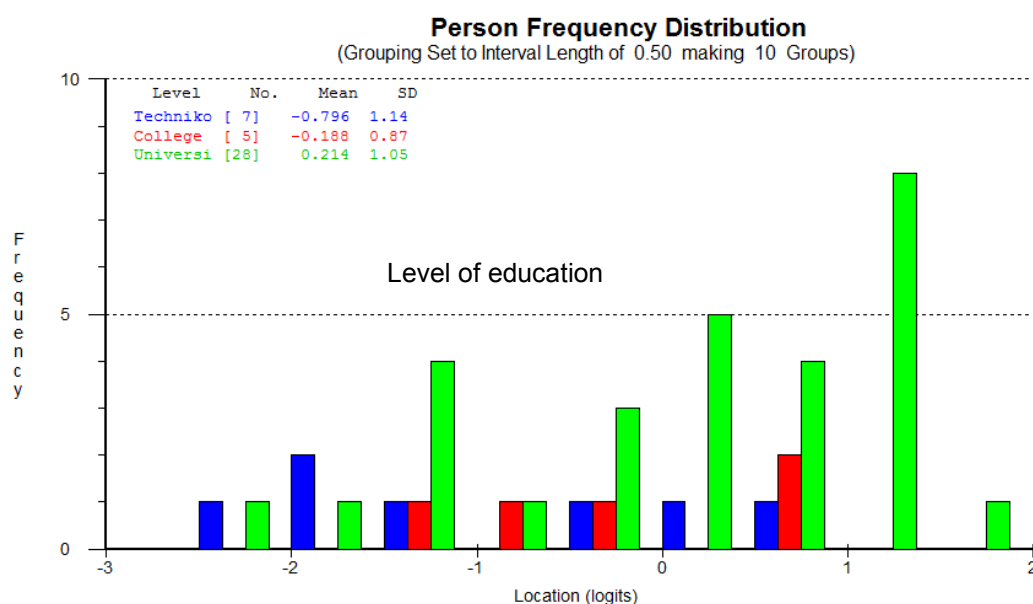


Figure 6.6 Person frequencies with respect to years of level of education in organic chemistry

#### 6.4 Correlation between CK and TSPCK

According to the Mavhunga (2012) model of TSPCK, teachers with good CK are likely to develop high levels of TSPCK while low levels of CK translate into low levels of TSPCK. Such a relationship is expected, as logic tends to dictate that with low CK there can be little TSPCK. The person measures for both the CK and TSPCK instruments (see Appendix 8) for this cohort of teachers are represented as a scatter plot; see Figure 6.7 below. The values for five teachers were omitted from the correlation analysis. The record for Teacher 16 had earlier been deleted from the data set for the Rasch analysis for the CK instrument because of misfit. Three teachers achieved perfect scores for either the CK or TSPCK instrument which means that they present extreme cases in the Rasch model. The fifth teacher provided a response to only one item in the TSPCK instrument. Four quadrants in Figure 6.7 below are indicated in different colours; the lines bounding the quadrants are broad to indicate that there is a standard error associated with the values for person measures for both CK and TSPCK. The boundary lines intersect on the mean values for TSPCK and CK that were determined empirically by Rasch analysis.

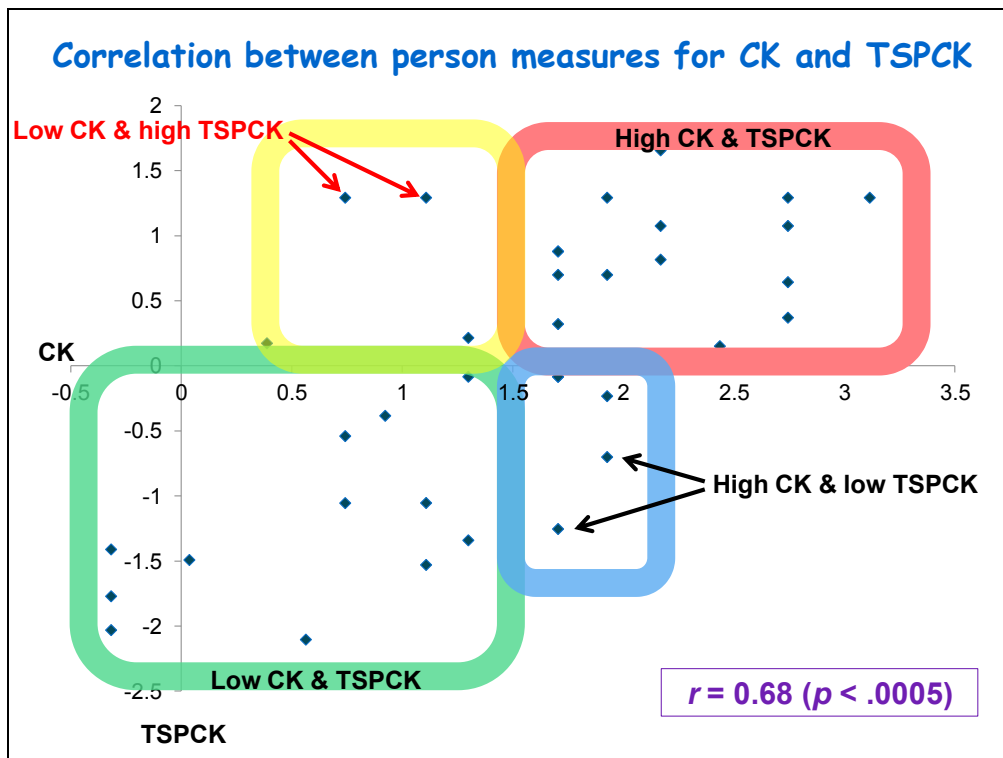


Figure 6.7 Scatter plot of person measures for CK and TSPCK

Despite the scatter, there is a reasonable correlation between levels of CK and TSPCK as predicted by the model;  $r = 0.68 (p < .0005)$ . As predicted from the Mavhunga (2012) model, low levels of CK translate to low levels of TSPCK (green quadrant) while high levels of CK translate into high levels of TSPCK (pink quadrant). Two interesting cases were noted in our findings (see Figure 6.7).

In the case of the teachers in the blue quadrant it can be seen that a high level of competency in CK does not necessarily translate into the development of good TSPCK, especially for the teachers indicated by the black arrows. The most interesting case is that of the teachers, T32 and T43, the yellow quadrant, who reflect a finding which is not predicated by the model of TSPCK. The two teachers performed very well on the TSPCK instrument, yet their CK was below the mean value (1.48) for the sample of teachers in represented in Figure 6.7. An interview with T32 revealed that she was mainly engaged in running workshops for in-service training of teachers at local high schools. This particular teacher stated that she would present the part of the workshop focusing on pedagogy while another teacher would present the content knowledge. Thus a lower than average performance on

the CK instrument may be a manifestation of the major focus of the current job of a teacher presenting effective teaching methodologies as part of the training in their workshops rather than a low level of CK per se. The CK instrument for T43, the other teacher who manifested high TSPCK and low CK, revealed that this particular teacher had a poor understanding of the concept of isomers. In addition while T43 was able to draw the products of the reactions in Task 3, he/she failed to name the products of the reactions. Since drawing isomers and naming compounds comprised 33% of the final mark for the instrument, this would account for this teacher's poor performance on the CK instrument. These cases suggest possibilities for strong TSPCK to develop even in the context of weaknesses in CK. Further probing of this issue will be required in order to understand whether this contradictory finding is more widely prevalent among South African teachers.

The correlation between CK and TSPCK shown above is broadly in line with those reported by Tepner and Dollny (2011), who developed a questionnaire to determine the extent to which the quality of teachers' TSPCK correlates with their CK in the topics of structure of atoms and the periodic table, chemical bonding and chemical reactions using acids and bases. These researchers found that teachers who performed well on the CK questionnaire regarding a specific topic know much more about students' misconceptions in the same topic than those with poor quality CK, who performed poorly in this aspect of the questionnaire. They conclude that:

The moderate but significant correlation,  $r = .36$  ( $p < .001$ ), corroborates the increasingly accepted belief that possession of good CK is a pre-condition for developing high quality PCK." (Tepner & Dollny, 2011, p. 5).

### 7. Discussion

*Chapter 1 concluded with three research questions which were primarily what this study was designed to answer. In this chapter, which is the final chapter of the thesis, I will discuss the findings to the research questions. In addition, I will discuss limitations to the work carried out. I will conclude the chapter by giving recommendations for future work to be carried out.*

#### 7.1 Findings from the study

It should be noted that this study forms a part of a larger project which is intended to investigate transformation of CK into PCK in a specific topic. Researchers working at the University of Witwatersrand have developed and validated instruments for other topics such as chemical equilibrium (Mavhunga, 2012) and the particle nature of matter (Pitjeng, 2013). While the structures of the instruments vary, they are all based on the Mavhunga's model of TSPCK. Two instruments were designed in an attempt to answer the research questions which this study posed. The overall aim of this study was to design and validate an instrument which would assess Topic Specific PCK of Grade 12 teachers who are teaching organic chemistry. The first version of the instrument, which contained both CK and TSPCK items, was piloted with a group of teachers who attended a local conference in July 2011 at North-West University. The pilot study served as a foundation to my research questions or problem statement. Since I do not have teaching experience, the instrument was designed to give an indication of how much teachers understand about the subject matter for organic chemistry and their levels of PCK.

Based on the teachers' performance, and feedback from other researchers participating in the project, the Content Knowledge instrument was modified extensively. When all the perceived weaknesses in the CK items were dealt with, the instrument was ready for another attempt to collect data from teachers. The internal

validity threat to the instrument was minimised as the tests were administered to experts to ensure that it had adequate level of consistency and construct validity. For example, expert teachers were consulted to ensure that the content of the CK instrument was valid to probe understanding of the topics in the grade 12 syllabus as well as the subject matter incorporated in the TSPCK questions of the instrument.

The pilot study also revealed that the design of the PCK instrument was somewhat superficial. Strengthening this area was the main focus for the second version of the instrument. The second version of the PCK instrument was comprehensively reconstructed based on the five components of Topic Specific PCK in the Mavhunga (2012) model. Valuable feedback on the second version of the instrument was once again obtained from a small group of expert teachers at local high schools. For the PCK instrument they offered different approaches for teaching based on the scenarios posed. They demonstrated the depth of their pedagogical content knowledge through their explanations and answers given to the PCK questions. For example, one of the expert teachers demonstrated his TSPCK by suggesting a novel strategy in response to the question of naming organic compounds (see Chapter 4.5). Expert teachers also displayed curriculum saliency (Geddis & Wood, 1997), in that they taught for understanding of concepts yet were aware of the assessment criteria which would apply to the matric examination, e.g. representations of organic compounds.

The rubric designed for the topic of chemical equilibrium was adapted for the organic chemistry instrument. It went through several stages of revision to make sure that it accommodated all the questions posed in the organic chemistry instrument. For each revision, a sample of instruments was scored by an expert teacher and the inter-rater reliability ranged from 83 to 88 %. As the first group of teachers completed their instruments, the rubric was used to score their responses. Teachers' responses to the tasks in the PCK instrument also played a role in refining the rubric as they gave insight into what possible responses teachers would give.

When the instruments and rubric reached a point where I, in consultation with the expert teachers, believed that the research instruments and rubric were ready to serve their purpose, these were administered to a larger cohort of teachers. The data collection was the first step in the process of answering the three research

questions. The second step involved scoring the data to generate numerical clusters which are called raw scores. The raw scores were subjected to analysis using the Rasch Measurement Model (Bond & Fox, 2007; Boone & Rogan, 2005) which is a statistical model based on the assumption of unidimensionality of data, i.e. that the instrument is designed to capture data that varies on a scale of less than or more than along a single dimension. The Rasch analysis was used to obtain interval data and to confirm whether the data collected with the instrument for the two constructs, CK and TSPCK, respectively, was unidimensional. If the data fit the model then unidimensionality is empirically confirmed. The following discussion shows the manner in which each of the research questions was answered.

### 7.1.1 Research question 1

**Is it possible to design a valid and reliable instrument for determining Topic Specific PCK of organic chemistry teachers at Grade 12 level?**

In attempting to answer the first question, Two instruments were designed, one for CK and one for TSPCK. The instruments were administered to a cohort of teachers of Grade 12 organic chemistry, N = 44. The main findings are summarised below. The CK instrument was assessed as if it was a conventional test in organic chemistry while the data for the TSPCK instrument was scored using a rubric to yield the raw scores which were subjected to Rasch analysis. This analysis showed that the instrument was valid and reliable; the estimated value for Cronbach's alpha for the CK instrument was 0.81 which is a trustworthy reflection of its internal consistency. The reliability of the instrument is considered to be fairly high for a performance test consisting of only 15 items. The person-item map showed a reasonable alignment and spread of person proficiencies and item difficulties for this instrument, see Figure 6.1.

The mean person performance of 1.43 (standard deviation 1.07) reflects the fact that most teachers in this particular sample found the test to be easy. The data did not fit the Rasch model well, as indicated by the item-trait interaction chi-square ( $\chi^2$  67.96, df 20, prob. 0.0001); however, it was not possible to determine the origin of misfit. All items showed good fit statistics, there were no disordered response categories and

no empirical evidence for multidimensionality, thereby confirming the construct validity of the instrument.

It should be noted that the teachers who participated in this study represent an opportunistic sample. The finding of mean of 1.43 from the Rasch analysis of the CK instrument is unlikely to reflect the performance of Grade 12 teachers across South Africa since it has been reported that in general teachers lack content knowledge (CDE, 2011). Large scale testing would be required to obtain a more complete picture of CK for organic chemistry for the teaching profession as a whole.

Analysis of the data for the CK instrument showed that the most difficult item was question 2, assessing structural and geometric isomerism. Question 5b (interpretation of physical properties) and question 3 (completing chemical equations) were easier. Q3a, combustion of hydrocarbons, was the exception in this section. The easiest items were question 4 (recognition of functional groups), and question 1 (interpreting systematic names).

The Rasch analysis for the TSPCK instrument indicated that there was a good overall fit of the data to the model as indicated by the item-trait interaction chi-square ( $\chi^2$  20.09, df 20, prob 0.452). This means that the null hypothesis that there is no difference between the model and the data is not rejected. The mean value for person performance was -0.01 (standard deviation 1.09) while the estimated value for the Person Separation Index (similar to Cronbach's alpha) was 0.83. The person-item map indicated that there is fairly good alignment between the means of item difficulties and person performance, but the items do not have a wide spread in terms of difficulty. Items A2 (learner prior knowledge), B2 (identification of Big Ideas) and E1 (conceptual teaching strategies) are the easiest and items C (what is difficult to teach) and D2 (using representations in teaching) are the most difficult. The finding that item D2 presented the greatest challenge to teachers appears to be specific to the topic of organic chemistry and is in contrast to findings reported by Rollnick (2013). Her postgraduate students found that Conceptual Teaching Strategies, category E, was the most demanding for the topics chemical equilibrium, particle nature of matter and electrochemistry while Category C, What is Difficult to Teach, was also found to be a challenge for the particle nature of matter. For organic chemistry item D2 required teachers to be familiar with a wide range of

representations of pentane as well as to articulate why they would use a particular representation in their teaching. Further investigation is required to explore teachers' understanding of representations and the links to macroscopic properties such as boiling point. The conceptual demand of the grade 12 organic chemistry syllabus is not as high as that for chemical equilibrium and electrochemistry, which may account for the fact that the category of Conceptual Teaching Strategies was found to be an easy item in the TSPCK instrument.

The findings above indicated that it was possible to design a tool that is suitable for evaluating Topic Specific PCK of organic chemistry teachers at Grade 12 level, as the Rasch analysis revealed that the instruments met the criteria of validity and reliability. The instrument designed is specific to the Grade 12 syllabus in South Africa, which makes a useful addition to the small but growing number of these types of instruments being developed in South Africa (for example Mavhunga, 2013; Pitjeng, 2013). These are useful for researchers or interested bodies who want to construct a bigger picture of what is happening in the teaching of a particular subject. There were, however, limitations encountered in the process which will be discussed in the sub-sections which follow.

### **7.1.2 Research question 2**

#### **Is there a correlation between CK and TSPCK?**

The second research question focused on determining whether there was any correlation between CK and TSPCK. The question was based on the hypothesis of CK being a prerequisite for TSPCK since PCK is the act of transforming content knowledge from teachers' personal understanding into various forms that could help students to comprehend specific topics. Rollnick et al. (2008) have referred to CK as an important construct in the development of PCK

The current study focused particularly on the transformation of CK to produce PCK. The Mavhunga (2012) model of TSPCK was used to conceptualise the study because this model focuses in particular in the components of TSPCK which bring about the transformation of content knowledge. Mavhunga's (2012) model views the transformation of specific topics of CK through five knowledge components namely:

- learner prior knowledge,
- curricular saliency,
- what is difficult to teach,
- representations and
- conceptual teaching strategies.

According to the Mavhunga (2012) model of TSPCK, teachers with good CK are likely to develop high levels of TSPCK while low levels of CK translate into low levels of TSPCK. This relationship is to be expected as logic tends to dictate that with low CK there can be little TSPCK. Since these two constructs are both involved in the process of developing general PCK, it was of interest to find out whether they were correlated as described below.

Tepner and Dollny (2011) developed a questionnaire to determine the extent to which the quality of teachers' TSPCK correlates with their CK in the topics of structure of atoms and the periodic table, chemical bonding and chemical reactions using acids and bases. These researchers found that teachers who performed well on the CK questionnaire regarding a specific topic know much more about students' misconceptions in the same topic than those with poor quality CK, who performed poorly in this aspect of the questionnaire. In a study of physics teachers, Kirshner (2013) also found that CK was the most important predictor for the development of PCK.

The findings on the determination of a correlation were discussed in detail in the previous chapter. The overall findings in this aspect revealed that there is a reasonable correlation between levels of CK and TSPCK as predicted by the model;  $r = 0.68$  ( $p < .0005$ ). This implies that an estimated 46% of the variance in PCK is accounted for by the variance in CK. The correlation coefficient compares favourably with the correlation of  $r = .36$  ( $p < .001$ ), reported by Tepner and Dollny, (2011) and provides evidence that CK is a pre-condition for the development of PCK. These findings are further supported by the scatter plot of person measures for CK and TSPCK (see Figure 6.7 in Chapter 6). The correlation analysis revealed, however, that there are exceptions to the hypothesis. It was noted that for some teachers, e.g. T2 and T10, high levels of CK did not translate into high levels of TSPCK. Two

teachers, T32 and T43, revealed high levels of TSPCK and lower than average levels of CK for this particular sample, a finding which is not predicated by the model of TSPCK. An interview with T32 revealed that she was mainly engaged in running workshops for in-service training of teachers at local high schools where she would present the part of the workshop focusing on pedagogy while another teacher would present the content knowledge. Scrutiny of the responses from the CK instrument for T43 revealed that this teacher had a poor understanding of the concept of isomers and failed to name some of the products of the reactions.

In conclusion, the results are in broad agreement with the literature (Kirschner, 2013; Mavhunga, 2012; Rollnick *et al.*, 2008; Tepner & Dolly, 2011) that CK is indeed a crucial construct in developing TSPCK and therefore these constructs are correlated. In their general taxonomy of PCK, Veal and Makinster (1999) describe TSPCK as the most specific and novel level, see Figure 2.3. They note that a teacher who has knowledge at this level could be well-versed in the skills of the preceding three levels namely, pedagogy, general PCK and domain-specific PCK. They cite the example of the concept of thermodynamics which is common to both chemistry and physics and point out that the examples and laboratory activities would be taught differently to suit the context; hence the PCK would be topic specific.

### **7.1.3 Research question 3**

#### **Is there a relationship between teachers' TSPCK and level of education or years of experience?**

In exploring the third research question which concerned teacher experience and education, data from the Rasch analysis of the CK instrument revealed that there was no statistically significant difference in the levels of teacher experience in this study. Data from the person frequency distribution graphs (see Figures 6.2 and 6.3) indicated an overlap in the standard deviation of mean person measures for each group. In terms of level of education, the main finding was that teachers with university education in chemistry have higher levels of CK than those who trained at either technikons or colleges. Despite the small sample sizes for groups of teachers the trends indicate that levels of CK are higher for teachers with extensive teaching experience. This finding is in line with Gess-Newsome and Lederman (1993) who

reported that teachers' Content Knowledge increases through the process of teaching.

The findings from the TSPCK instrument also revealed that the mean values for the person measures were higher for more experienced teachers; the difference was, however, not statistically significant (see Figure 6.5). There was evidence that teachers with little teaching experience have less complete levels of PCK than teachers with more experience, a finding also reported by Cochran and Jones, (1993). The Rasch analysis also revealed that teachers with college and technikon training have lower TSPCK than teachers with university education but once again the standard deviations of the means overlap, thus the differences are not statistically significant (see Figure 6.6). The study suggests that to obtain a more nuanced picture of the impact of the teacher experience and level of education in teacher's expertise, one would have to administer the instruments to a larger cohort of teachers.

## **7.2 Limitations of the study**

While this study did lead to the development of a valid and reliable instrument to evaluate the transformation of CK to TSPCK for Grade 12 teachers of organic chemistry, I encountered a few challenges. Firstly, it was suggested that a larger data set would make it easier to make comparisons and generalisations from research findings, especially when statistical data analysis is involved. There are, however, many dynamics associated with teaching mathematics and physical science in South Africa due to underperformance of the learners in these subject areas (CDE, 2011). Sometimes teachers sometimes find themselves under a strong pressure from the public and therefore teachers do not always feel comfortable in talking about their teaching to strangers. Due to these constraints it was a challenge to find teachers to complete the instruments and it prolonged the data collection process for the study.

Another challenge was that the instrument designed required teachers to give written responses to the tasks. While this was not an issue for the CK instrument because it

was designed as if it was a conventional test in organic chemistry this was not the case for the PCK instrument. To complete the PCK instrument teachers had to respond by describing aspects of their teaching and lesson plans. They felt, however, that they would have given more detailed responses and been able to articulate their responses more clearly but were constrained by having to give written responses to the tasks posed to them in the instrument. Teachers felt that it would have been preferable to have another party to record their responses instead of trying to capture them in writing.

As described in chapter 3, all items in the instrument were of the open response type, which meant that the instrument took a number of teachers a long time to complete; in most cases it took them almost 60 minutes and in other cases even longer.

### **7.3. Future work**

The results and findings of this study revealed interesting trends and has contributed to the hypothesis that CK and PCK are correlated. Due to the small sample size, the study could not make strong claims about the findings, especially in the case of the impact of teacher experience and level of education of teachers. In future it is recommended that in conducting research of this nature the data collection is expanded so that it can give a more nuanced picture of the South African situation.

In the design of the instrument, the Rasch Analysis indicated ways in which the design of the CK instrument could be improved. Easy items such as 4a should be deleted as there was evidence of a high probability that both weak and strong teachers would give the correct answer. Thus item 4a adds no value in discriminating the proficiencies of persons.

The first analysis of the CK instrument produced disordered thresholds for items 1, 2a, 2b, 4d, 4e and 5b, and these items were rescored. Disordered thresholds mean that these items were not functioning according to the expectations of the Rasch model and therefore these items could be refined for future use of the instrument. For example, some items such as 2b originally tested the ability of teachers to draw

and name structural isomers of a carboxylic acid with different functional groups. When the item was rescored the teacher's ability to draw the compound was the central issue to be tested and the ability to name the compound was removed from the item. Any future administration of this instrument would require modification of this item such that it only requires teachers to draw these structures. The rescoring exercise for the Rasch analysis of the CK instrument is useful in providing guidelines on how questions can be modified to streamline the instrument design.

The Rasch model highlighted issues in the TSPCK instrument as well. Reversed thresholds were observed for 4 items which is an indication that the scoring categories in the rubric for these items, A2, B3, E1 and E2, were not working as expected. Since it was suspected that this issue arose due to the design of the rubric, it was modified and these items were rescored using the new rubric. Repetition of the Rasch analysis showed that 3 of the items still presented with disordered thresholds as before, namely A2, E1 and E2. In each case the third scoring category (developing) did not function as expected, i.e. it did not represent a stepwise gain in proficiency between basic and exemplary. In future, the rubric might have to be modified with reference to the way in which it is used to score items A1, E1 and E2, which should be scored on a three-point scale instead of four or the items should be completely modified to fit the designed rubric. In summary, the Rasch model was very useful as it gave insights into both the design of the items and the rubric and these could be the areas of focus for future work. The modifications suggested above would allow the researchers to include the instruments completed by the current cohort of teachers to be included as part of any expanded data set which may be acquired at a later date. All that would be required would be to assess the CK and PCK instruments according to the revised marking memorandum and rubric respectively.

#### **7.4 Concluding remarks**

My research project has come to an end and in closing, all that has been said and done throughout this study takes me back to the first article with which I started this journey namely the one by Shulman (1986), entitled "Those who understand: Knowledge growth in teaching". The first time I read the article, I felt as if I was lost in

a world which I had never visited previously. What completely puzzled me in this article the first time I read it was the statement “He who can does, he who cannot teaches”. As my research journey progressed, it became clearer to me what Shulman was trying to say and I agree with what he said in closing his groundbreaking article addressed to those who are interested in knowledge growth in teaching:

With Aristotle we declare that the ultimate test of understanding rests on the ability to transform one's knowledge into teaching. Those who can, do. Those who understand, teach. (Shulman, 1986, p14).

This study has taught me that, indeed, knowledge growth in teaching is manifested in your ability to transform the knowledge you have.

University of Cape Town

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Appendix 1

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21 February 2012

Ms Nonkayiso Vokwana  
Department of Chemistry  
University of Cape Town  
[nonkanyiso.vokwana@uct.ac.za](mailto:nonkanyiso.vokwana@uct.ac.za)

Dear Ms Vokwana

**INVESTIGATING THE TRANSFORMATION OF SUBJECT MATTER  
KNOWLEDGE FOR TEACHING IN ORGANIC CHEMISTRY**

I am pleased to inform you that, having scrutinized the details of your above-named application for research ethics clearance, the Faculty of Science Research Ethics Committee has approved it in terms of its attention to ethical principles.

Your approval code is: SFREC 004\_2012

I wish you every success in the work involved.

Yours sincerely

Michael E Meadows  
Professor and Head of Department  
Chair: Science Faculty Ethics in Research Committee

## Appendix 2

### ORGANIC CHEMISTRY RESEARCH PROJECT

*This info is for research purposes only: your responses will be treated confidentially. Pseudonyms will be used if a need to refer arises. This page will be detached and stored separately.*

#### SECTION A: BACKGROUND INFORMATION

SURNAME: \_\_\_\_\_

NAME \_\_\_\_\_ Gender (tick✓):

Female	Male
--------	------

HOME province and town: \_\_\_\_\_

Please fill in details about all post school qualifications. (since you left school.)

Qualification and length of course (e.g. STD - 3yrs)	From (year)	To (year)	Main Subjects

Please provide the highest level reached in your science content subjects studied - i.e. science and maths courses (not education or methodology/didactics courses) and the highest level at which you have taught (e.g. grade 11).

Subject	Highest level reached (e.g. 2nd yr univ)	Highest level taught (e.g. G 11)
Chemistry		
Physics		
Physical Science		
(Others)		

Please provide the following information about your teaching.

Number of years	School and province	Subjects taught	Classes taught

**Personal Code:** .....

## INSTRUMENT FOR PILOT STUDY

## Organic Chemistry Discussion Document

Personal code: 

## BACKGROUND INFORMATION

PROVINCE: \_\_\_\_\_ DISTRICT: \_\_\_\_\_

TYPE OF SCHOOL (Please circle): Urban / Township / Rural

LIST ALL QUALIFICATION: \_\_\_\_\_

MAJOR TEACHING SUBJECTS: \_\_\_\_\_

GENDER: \_\_\_\_\_

**TEACHING EXPERIENCE:** Which grades do you teach? For how long have you taught each grade? Please tick.

- |   |                                    |                                    |                                     |                                    |
|---|------------------------------------|------------------------------------|-------------------------------------|------------------------------------|
| <input type="checkbox"/> Grade 1-7 Natural Sciences | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| <input type="checkbox"/> Grade 8 Natural Sciences   | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| <input type="checkbox"/> Grade 9 Natural Sciences   | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| <input type="checkbox"/> Grade 10 Physical Sciences | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| <input type="checkbox"/> Grade 11 Physical Sciences | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| <input type="checkbox"/> Grade 12 Physical Sciences | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |

Have you taught organic chemistry at FET level before? Yes/ No  
If yes, for how many years? \_\_\_\_\_

## OTHER SUBJECTS YOU TEACH:

## Subject &amp; Grade

## Teaching experience

- |       |                                    |                                    |                                     |                                    |
|-------|------------------------------------|------------------------------------|-------------------------------------|------------------------------------|
| _____ | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| _____ | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |
| _____ | <input type="checkbox"/> 1-2 years | <input type="checkbox"/> 3-5 years | <input type="checkbox"/> 6-10 years | <input type="checkbox"/> >10 years |

Consent: All studies of this nature require that you formally give consent. If you have any further questions regarding this study or the way in which any information you give will be used please contact René Toerien and Nonkanyiso Vokwana. Please take note of the paragraph below.

By filling in the questionnaires and handing it in I hereby give permission for my responses to be used in a study which is intended for publication either in a thesis or a peer-reviewed journal. I understand that I will not be identified by name and that reasonable measures will be taken to anonymise the responses of all participants.

**TASK A**

1. Draw the structural formulae for each of the following compounds:

butan-1-ol

butan-1-ol – but a different representation to the one you used on the left

pent-2-yne

2-methylhex-3-ene

ethyl propanoate

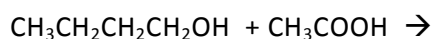
An example of a compound with the general formula  $C_nH_{2n}$

2. Complete each of the following chemical reactions, balancing them where needed:

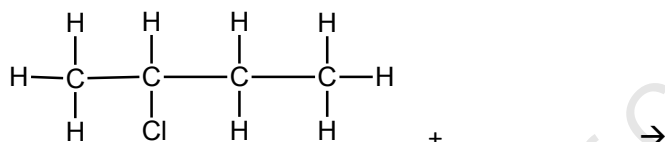
a. Complete combustion of butane:



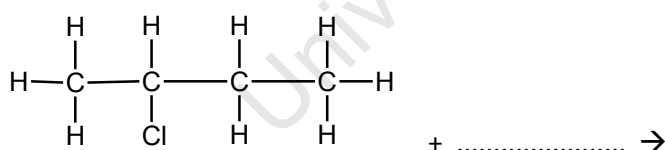
b. Esterification reaction:



c. Elimination reaction:



d. Substitution reaction:



3. Draw as many structural isomers for butanoic acid ( $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ ) as you can think of and include the IUPAC name for each.

**TASK B**

1. What do you consider to be the main concepts to be taught in organic chemistry?

2. What makes organic chemistry difficult to teach? Explain.

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3. What topics must have been covered in chemistry before you can teach organic chemistry? Some topics have been listed below. Give a reason why you think these topics are needed. If you don't think they are needed, indicate this by writing 'not needed'. You can also add topics of your own.

Topic	Reason
The atom	
Periodic Table	
Chemical bonding	
Mole & stoichiometry	
Intermolecular forces	
Gas laws	
Acids and bases	
Electrochemistry	
Redox reactions	
Chemical equilibrium	

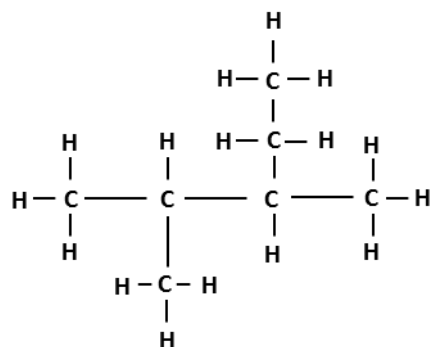
4. Why is it important for learners to learn about organic chemistry?

5. What ideas/concepts in organic chemistry do your learners struggle to understand. Why you think they struggle with these concepts?

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4. A learner is struggling to name the following compound.



- a. What is the correct name for this compound?

---

- b. There are a number of different ways to explain the naming of compounds. Which ones would you use to help learners name this specific compound? Which do you think will work best or is most effective and why?

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**TASK D**

A teacher uses the following analogy to explain some of the physical properties of organic molecules.  
*Organic molecules stick to each other as if they have pieces of Velcro attached to the hydrogen atoms.*

1. What physical properties can be explained using this analogy?
2. Do you think it is a good or bad analogy? Explain your answer.
3. How do you think you could use it in your class? What other concepts can you explain using this analogy?

**TASK D** (continued)

4. Do you think learners could misinterpret/misunderstand this analogy? Explain.

5. How would you change/modify/extend this analogy for use in your own classroom?

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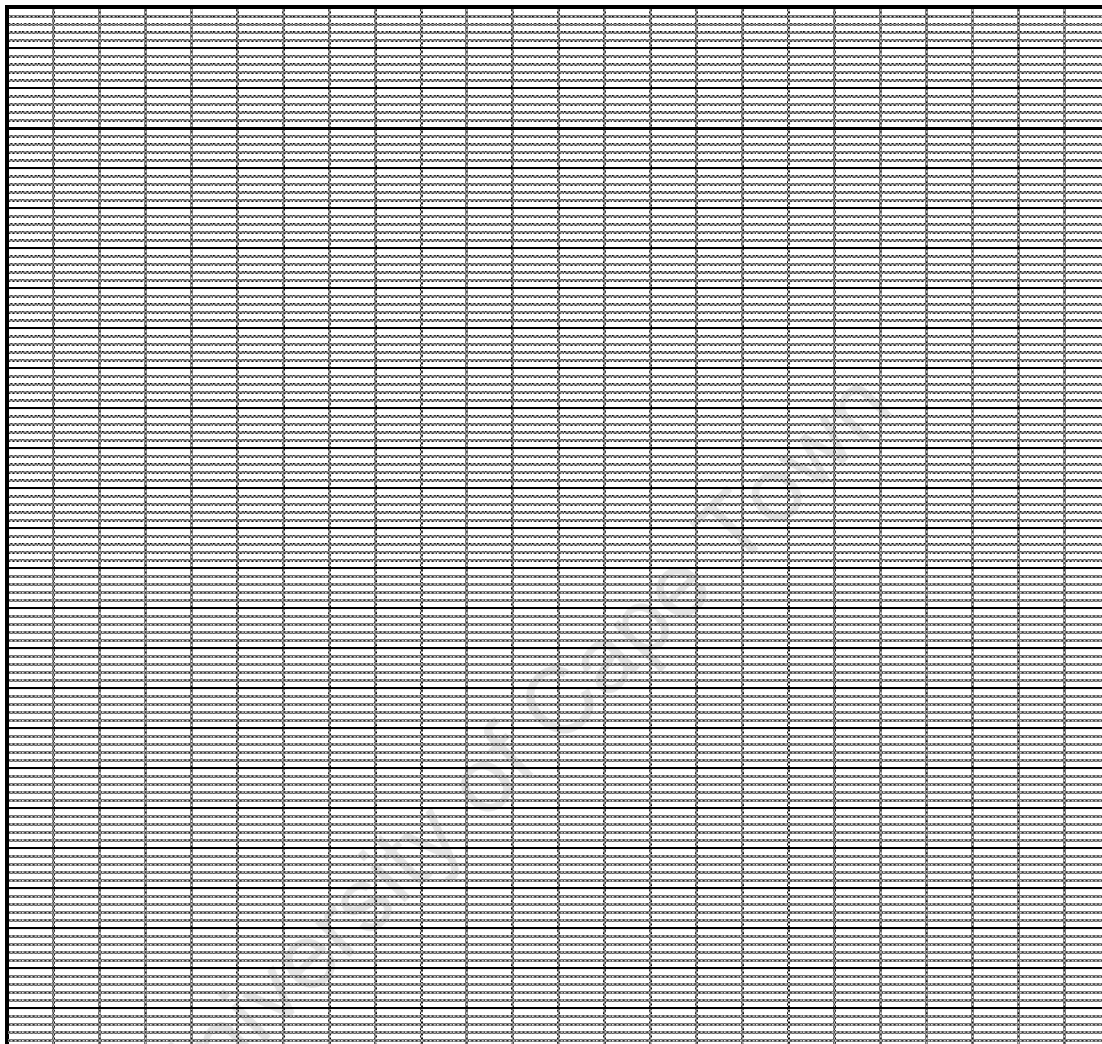
**TASK E**

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	Propanol	97	Propanoic acid	
4	Butane	-0.5	Butanol	118	Butanoic acid	
5	Pentane	36	Pentanol	138	Pentanoic acid	
6	Hexane	69	Hexanol	152	Hexanoic acid	

- a. Why is the boiling point for hexane so much lower than that of hexanol?
- b. Why is the boiling point for methanol so much lower than that of hexanol?
- 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.

- d. Draw a graph showing the boiling points for the alkanes only. Use the graph paper included on the next page for your answer



- e. Study your graph and write down any observations/comments (e.g. trends, how it can be used in your classroom, etc.)

## Appendix 4

## CONTENT KNOWLEDGE INSTRUMENT – FINAL VERSION

## ORGANIC CHEMISTRY BACKGROUND

1 Draw the structural formulae for each of the following compounds:

2-methylhex-3-ene

ethyl propanoate

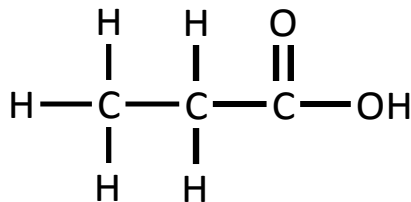
2 Molecules with the same molecular formula can have different structures, this is known as isomerism. There are several kinds of isomerism such as structural and geometric. Answer the following questions about isomers.

a) Draw the following isomers for 2-butene, name the compounds that you draw.

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 group. Draw two structural isomers with different functional groups for the compound below and include the IUPAC name for each.

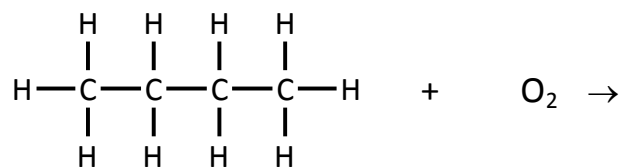


Structural isomer of propanoic acid

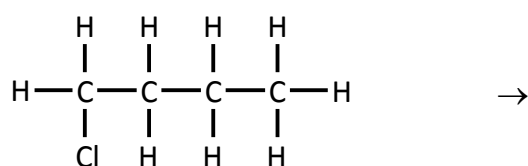
Structural isomer of propanoic acid

- 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:**

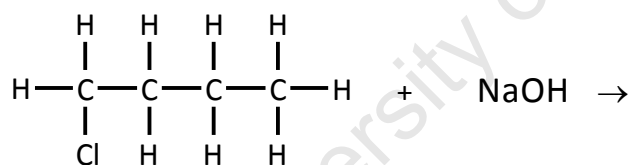


b. **ELIMINATION REACTION:**

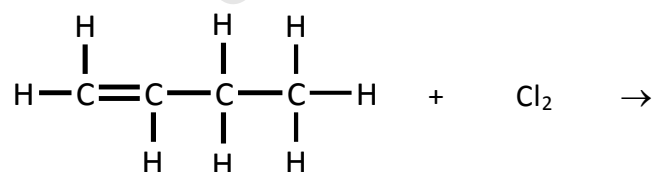


Type of elimination reaction: .....

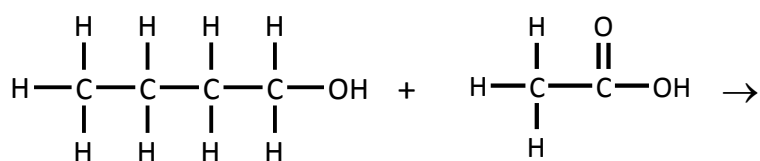
c. **SUBSTITUTION REACTION:**



d. **ADDITION REACTION**



e. **ESTERIFICATION REACTION:**



- 4 The table below contains a number of organic compounds having different functional groups. Study the compounds and answer the questions that follow.

<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
$\text{CH}_3\text{-OH}$	$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-OH}$	$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-H}$	$\text{CH}_3\text{-CH}_2\text{-OH}$
<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-CH}_3$	$\text{H}\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$	$\text{CH}_3\text{-O-CH}_3$	$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$

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?	

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	

f. Why is the boiling point for hexane so much lower than that of hexan-1-ol?

g. Why is the boiling point for methanol so much lower than that of hexan-1-ol?

h. 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.

## Appendix 5

## TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE INSTRUMENT

**Section A: LEARNER'S PRIOR KNOWLEDGE**

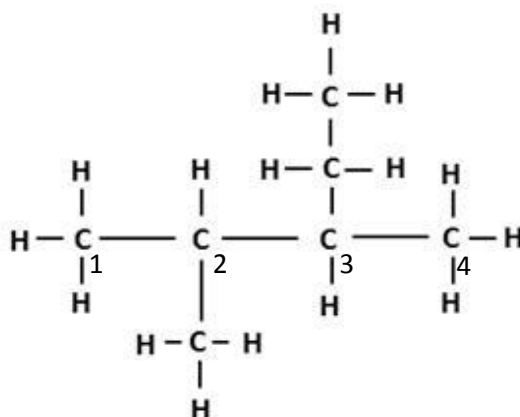
1. You hand out a worksheet to be used in a classroom activity and ask learners to select compounds that are alcohols from the table below:

1  $\text{CH}_3\text{-OH}$	2  $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-OH}$	3  $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-H}$	4  $\text{CH}_3\text{-CH}_2\text{-OH}$
5  $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-CH}_3$	6  $\text{H}\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$	7  $\text{NaOH}$	8  $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$

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

2. You have asked the learners in your Grade 12 class them 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.



Both Mary and Charlie agree that this compound is 2-methyl-3-ethyl-butane. How would respond to these two learners?

**Section B: CURRICULUM AWARENESS**

- 1 Which of the following would you consider the **four** most important chemical concepts that must have been covered in chemistry before you can teach organic chemistry? Indicate your choice with a tick [✓] next to each concept that you choose, and give a reason for your choice. You can also add any other concepts.

Concepts	✓	Reason
The atom		
Periodic Table		
Chemical bonding		
Mole and stoichiometry		
Electronegativity		
Intermolecular forces		
Gas laws		
Acids and bases		
Electrochemistry		
Chemical equilibrium		

- 2 Which of the following would you consider to be the **three main concepts (big ideas)** to be taught in organic chemistry at Grade 12? Indicate your choice with a tick [✓] next to each concept that you choose.

Concept	
Carbon has a unique nature	
Organic compounds are named according to the IUPAC system.	
Alkanes have unique properties.	
There is a relationship between physical and chemical properties	
Some acids belong to the homologous series known as carboxylic acids.	
There are different ways of representing organic substances.	
There are several major types of reactions for organic materials.	
Structural isomers have the same molecular formulae.	
Alkenes undergo combustion.	
Functional groups in organic chemistry tell us about the different types of compounds.	
Empirical formulae tell us how many atoms of each kind are present in compounds.	

- 3 In the table below **list these main concepts you have chosen in the order in which they should be taught.**


4 Explain briefly your reasons for the order you chose.

.....

.....

.....

.....

.....

.....

.....

.....

5 Make a map or a diagram of these three ideas showing how they link to subordinate ideas.

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6 Why is it important for learners to learn about organic chemistry? Identify reasons related to:

<b>i. Conceptual Progression</b>
<b>ii. Application to outside world</b>
<b>iii. Motivation or Interest</b>

**Section C: WHAT MAKES THE TOPIC DIFFICULT TO TEACH?**

Which of the following organic chemistry sections would you do you consider difficult to teach? Explain why these topics are difficult to teach.

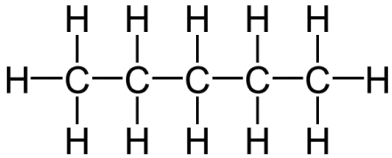
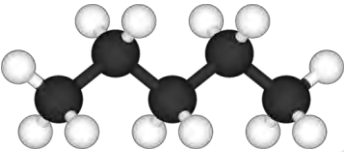
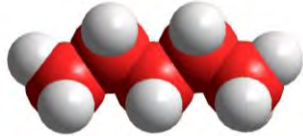
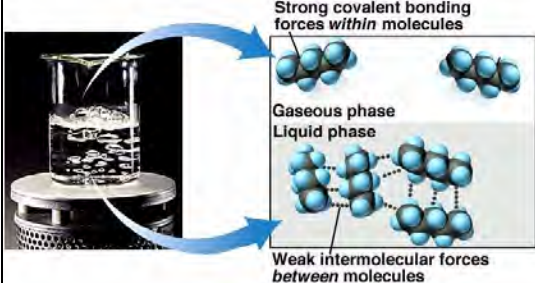
<b>Concept</b>	<b>Why is it difficult to teach the concept?</b>
Molecular formulae	
Structural formulae	
Functional groups	
IUPAC names	
Isomers	
Homologous series	
Types of organic reactions e.g. substitution, addition and elimination	
Combustion	
Esterification	

**Section D: REPRESENTATIONS/ANALOGIES/MODELS**

1. There are many ways of representing a molecule with molecular formulae  $C_5H_{12}$ , (pentane). Representations for  $C_5H_{12}$  are shown below.

a) Which representations do you find the most useful?

b) Complete the table and describe when you would use each of these representations in your teaching.

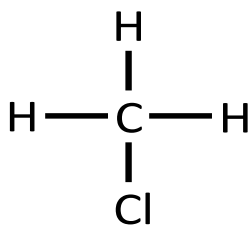
Representation	Use in teaching
1 	
2 	
3 $CH_3-CH_2-CH_2-CH_2-CH_3$	
4 	
5 	

- 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 ( $-0.5^{\circ}\text{C}$ ) and pentane ( $36^{\circ}\text{C}$ )?

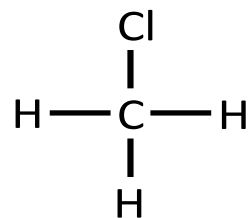
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**Category E: TEACHING STRATEGIES**

1. You draw the structure of chloromethane as shown below on the chalk board.



Teacher's Drawing

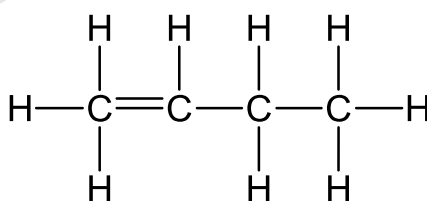


Learner's Drawing

A learner asks: "Is it okay if you swap around the chlorine and a hydrogen atom like this (the learner 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 learner drew the incorrect structure below.



Given that you have taught your learners how to draw structural formulae, how would you conduct a revision lesson, to correct this learner's response?

### Raw scores for CK instrument

Teacher ID	Highest level of chemistry	Years teaching	Q1	Q2a	Q2b	Q3a	Q3b	Q3c	Q3d	Q3e	Q4a	Q4b	Q4c	Q4d	Q4e	Q4f	Q5a	Q5b	Q5c	Total	%
			Formulae	Isomers		Reactions					Functional groups					Intermolecular forces					
T1	A-level	5	2	4	4	1	3	2	2	2	2	1	1	2	2	1	4	4	2	39	100.0
T2	3rd year coll	9	2	1	2	1	2	1	1	1	1	1	1	2	2	1	4	3	2	28	71.8
T3	3rd year coll	15	2	1	2	1	1	2	0	2	2	1	1	2	2	1	2	2	1	25	64.1
T4	1st year uni	15	2	2	2	1	3	2	2	2	2	1	1	2	2	1	3	3	2	33	84.6
T5	3rd year uni	25	2	1	1	1	3	2	2	2	2	1	1	2	2	1	3	3	2	31	79.5
T6	2nd year coll	5	2	3	3	0	3	0	2	1	2	1	1	2	2	1	2	3	1	29	74.4
T7	MSc chemistry	10	2	2	1	1	2	1	1	1	2	1	1	2	2	1	1	1	1	23	59.0
T8	3rd year uni	7	2	4	2	0	2	1	1	1	2	1	1	2	2	1	3	3	2	30	76.9
T9	2nd year uni	30	2	2	2	1	2	2	2	2	2	1	1	2	1	1	4	4	2	33	84.6
T10	3rd year coll	13	2	0	2	1	3	2	2	2	2	1	1	2	2	1	3	3	1	30	76.9
T11	3rd year tech	10	2	2	2	0	2	1	1	1	2	1	1	2	2	1	3	2	2	27	69.2
T12	3rd year uni	17.5	2	2	4	1	3	2	2	2	2	1	1	1	2	1	2	4	2	34	87.2
T13	4th year tech	10	1	1	1	1	2	1	1	1	2	1	1	2	2	1	2	3	2	25	64.1
T14	3rd year uni	18	2	1	2	0	3	2	1	2	2	1	1	0	2	1	4	4	2	30	76.9
T15	4th year tech	9	2	2	2	0	3	2	2	2	2	1	1	2	2	1	3	2	2	31	79.5
T16	School (Btech physics)	12	1	2	0	1	3	2	2	0	1	0	0	0	0	0	0	0	0	12	30.8
T17	2nd year uni	8	2	2	2	1	3	2	2	2	2	1	1	2	2	1	3	3	2	33	84.6
T18	2nd year uni	26	2	3	2	1	2	1	1	1	2	1	1	2	2	1	2	2	2	28	71.8
T19	3rd year uni	11	2	0	2	1	3	2	2	2	2	1	1	2	2	1	3	2	2	30	76.9
T20	1st year uni	20	1	2	0	1	3	2	2	2	2	1	1	1	2	1	4	3	2	30	76.9
T21	2nd year uni	45	2	2	2	0	2	0	1	2	2	1	1	2	0	1	4	2	2	26	66.7
T22	3rd year uni	7	2	2	1	1	2	2	2	2	2	1	1	2	2	1	4	4	2	31	79.5
T23	3rd year uni	29	2	2	2	1	3	2	1	2	2	1	1	2	2	1	1	2	2	27	69.2

Raw scores for CK instrument

Teacher ID	Highest level of chemistry	Years teaching	Q1	Q2a	Q2b	Q3a	Q3b	Q3c	Q3d	Q3e	Q4a	Q4b	Q4c	Q4d	Q4e	Q4f	Q5a	Q5b	Q5c	Total	%
			Formulae	Isomers		Reactions					Functional groups					Intermolecular forces					
T24	3rd year uni	1.5	2	4	2	1	3	2	2	2	2	1	1	2	2	0	3	0	1	30	76.9
T25	3rd year coll	1	0	0	0	0	0	0	0	0	2	1	1	1	0	1	0	0	0	6	15.4
T26	3rd year Tech	7	2	1	0	0	1	1	1	0	2	0	0	1	2	1	2	2	0	16	41.0
T27	1st year uni	2	2	0	0	0	1	2	2	0	2	0	0	1	2	1	2	1	0	16	41.0
T28	3rd year Uni	8	2	2	2	1	3	2	2	2	2	1	1	2	2	1	3	3	0	31	79.5
T29	2nd year Tech	4	2	0	0	1	3	2	2	2	2	1	1	2	2	1	3	2	1	27	69.2
T30	3rd year Uni	6	2	1	2	1	2	1	0	1	2	1	1	1	2	1	2	2	1	23	59.0
T31	3rd year Col	25	2	0	1	1	3	2	2	2	2	1	1	2	2	1	3	3	1	29	74.4
T32	3rd year uni	20	2	0	1	0	2	2	1	2	2	1	0	2	2	1	2	2	2	24	61.5
T33	3rd year uni	3	2	1	1	1	3	2	2	2	2	1	1	2	2	1	2	2	1	28	71.8
T34	Hons Uni	5	2	1	0	1	2	2	2	2	2	1	1	2	2	1	1	2	1	25	64.1
T35	3rd year Uni	3	2	0	0	0	2	1	1	1	2	1	1	0	2	1	1	1	1	17	43.6
T36	3rd year Tech	9	2	0	0	1	1	0	0	2	2	1	1	2	2	1	2	1	1	19	48.7
T37	2nd year Uni	17	2	2	1	0	3	2	2	2	2	1	1	2	2	1	2	2	1	28	71.8
T38	3rd year Uni	3	2	2	2	0	3	1	1	1	2	1	1	2	2	1	2	2	2	27	69.2
T39	2nd year Uni	7	2	2	2	0	3	2	2	2	2	1	1	2	0	1	3	3	2	30	76.9
T40	2nd year uni	18	2	1	1	1	3	1	1	1	2	0	1	2	2	1	2	2	0	23	59.0
T41	4th year Uni	10	0	4	2	0	1	1	1	1	2	1	1	2	2	1	1	1	1	22	56.4
T42	3rd year Uni	19	2	2	3	0	3	2	1	1	2	1	1	2	2	1	4	4	2	33	84.6
T43	3rd year Uni	13.5	2	1	0	1	1	1	0	1	2	1	1	2	2	1	3	2	2	23	59.0
T44	3rd year Uni	5	2	1	1	1	2	1	1	1	2	1	1	2	2	1	3	3	2	27	69.2
	<b>Average</b>		<b>1.8</b>	<b>1.5</b>	<b>1.5</b>	<b>0.6</b>	<b>2.3</b>	<b>1.5</b>	<b>1.4</b>	<b>1.5</b>	<b>2.0</b>	<b>0.9</b>	<b>0.9</b>	<b>1.7</b>	<b>1.8</b>	<b>1.0</b>	<b>2.5</b>	<b>2.3</b>	<b>1.4</b>	<b>26.6</b>	<b>68.1</b>
	<b>Max score</b>		<b>2</b>	<b>4</b>	<b>4</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>4</b>	<b>4</b>	<b>2</b>	<b>39</b>	

Raw scores for PCK instrument (from rubric)

Teacher ID	Highest level of chemistry	Years of teaching	A1	A2	B1	B2	B3	C	D1 (b)	D2 (a&c)	E1	E2	
			Prior Knowledge		Curricular saliency			Difficult to teach	Representations		Teaching strategies		
T1	A-level	5	4	4	2	4	2	4	4	4	2	2	3.2
T2	3rd year coll	9	3	1	1	2	2	1	2	1	1	2	1.6
T3	3rd year coll	15	3	1	2	2	1	2	2	3	2	4	2.2
T4	1st year uni	15	2	2	4	3	4	4	2	3	2	2	2.8
T5	3rd year uni	25	3	4	3	2		3	1	1	4	3	2.7
T6	2nd year coll	5	2	2	3	4	4	3	3	4	2	1	2.8
T7	MSc chemistry	10	3	2	2	2	1	3	1	1	3	3	2.1
T8	3rd year uni	7	2	4	3	3	4	3	4	3	4	1	3.1
T9	2nd year uni	30	2	3	3	3	3	3	4	4	3	4	3.2
T10	3rd year coll	13	2	2	3	3	3	1	3	2	1	1	2.1
T11	3rd year tech	10	3	2	4	3	2	2	3	2	2	1	2.4
T12	3rd year uni	17.5	4	4	4	4	4	4	4	4	4	4	4.0
T13	4th year tech	10	1	2	1	1		1	1		2	2	1.4
T14	3rd year uni	18	3	3	4	2	2	3	1	1	1	2	2.2
T15	4th year tech	9	4	4	4	4	2	3	3	1		3	3.1
T16	School (Btech physics)	12			1	2		1	2	1	1	2	1.4
T17	2nd year uni	8	4	4	3	4	3	3	3	2	3	2	3.1
T18	2nd year uni	26	4	1	3	2	4	3	4	2	4	2	2.9
T19	3rd year uni	11	4	3	3	3	3	3	4	3	3	2	3.1
T20	1st year uni	20	4	4	4	4	4	4	4	4	4	4	4.0
T21	2nd year uni	45	2	3	2	3	3	3	2	2	4	2	2.6
T22	3rd year uni	7	4	4	3	4	3	3	2	4	4	2	3.3
T23	3rd year uni	29	3	4	2	1		3	3	3	4	2	2.8
T24	3rd year uni	1.5	3	3	2	3	3	2	4	4	4	4	3.2
T25	3rd year coll	1	1										1.0
T26	3rd year Tech	7	2	1	1	1							1.3
T27	1st year uni	2	2	1	1	1					2		1.4
T28	3rd year Uni	8	3	4	4								3.7

Raw scores for PCK instrument (from rubric)

Teacher ID	Highest level of chemistry	Years of teaching	A1	A2	B1	B2	B3	C	D1 (b)	D2 (a&c)	E1	E2	
			Prior Knowledge		Curricular saliency			Difficult to teach	Representations		Teaching strategies		
T29	2nd year Tech	4	2	4	3							3	3.0
T30	3rd year Uni	6	1	2	1	1	2	2	1	1			1.4
T31	3rd year Col	25	3	3	3	4	3	3	2	3	2	2	2.8
T32	3rd year uni	20	3	4	3	4	4	3	3	2	4	4	3.4
T33	3rd year uni	3	2	1	2	4	2	2	3	3	2	2	2.3
T34	Hons Uni	5	2	1	2	3	2	1			1	2	1.8
T35	3rd year Uni	3	1	1	2	1	2	2	1	2			1.5
T36	3rd year Tech	9	1			2	1			1	2	2	1.5
T37	2nd year Uni	17	3	3	2	3	4	2	4	2	2	2	2.7
T38	3rd year Uni	3	2		1	2	3	2					2.0
T39	2nd year Uni	7	2	4	4	3	3	3	4	3	3	3	3.2
T40	2nd year uni	18	1	2	2	2	3	2	1	1	1	1	1.6
T41	4th year Uni	10	3	2	3	2	3	3	3				2.7
T42	3rd year Uni	19	4	2	3	2	4	2	3		3	3	2.9
T43	3rd year Uni	13.5	3	4	1	4	4	3	4	3	4	4	3.4
T44	3rd year Uni	5	3	3	1	4	3	2	4	4	4	4	3.2
<b>Average</b>			<b>2.6</b>	<b>2.7</b>	<b>2.5</b>	<b>2.7</b>	<b>2.9</b>	<b>2.6</b>	<b>2.8</b>	<b>2.5</b>	<b>2.7</b>	<b>2.5</b>	<b>2.5</b>
<b>Max score</b>			<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>4</b>	

## Appendix 8

Person Measures from Rasch Analysis for CK and PCK instruments

Teacher ID	SMK instrument				PCK instrument		
	Location	SE	Fit Resid		Location	SE	Fit Resid
	Logit				Logit		
T01	Record deleted during Rasch analysis						
T02	1.705	0.469	-0.495		-1.254	0.466	0.359
T03	0.923	0.432	-0.513		-0.384	0.398	0.788
T04	2.745	0.587	-1.274		0.37	0.404	1.058
T05	2.437	0.543	-0.907		0.151	0.42	0.924
T06	1.705	0.469	0.626		0.699	0.424	0.868
T07	0.742	0.427	-0.977		-0.54	0.405	0.054
T08	1.705	0.469	-0.348		0.879	0.44	0.348
T09	2.745	0.587	0.904		1.292	0.486	-0.247
T10	1.927	0.487	-0.451		-0.701	0.414	0.964
T11	1.299	0.445	-1.11		-0.084	0.394	-0.03
T12	2.745	0.587	0.56		Extreme case		
T13	1.108	0.437	0.113		-1.53	0.557	0.816
T14	1.927	0.487	1.265		-0.233	0.395	0.515
T15	2.169	0.511	-0.625		0.816	0.446	0.721
T16	Record deleted during Rasch analysis				-1.651	0.628	-0.088
T17	2.745	0.587	-1.274		1.075	0.46	-0.86
T18	1.497	0.456	-0.648		0.699	0.424	1.155
T19	1.927	0.487	-0.514		1.292	0.486	-1.379
T20	2.169	0.511	1.099				
T21	1.299	0.445	0.853		0.215	0.398	-1.615
T22	3.115	0.652	-0.267		1.292	0.486	0.088
T23	1.705	0.469	-0.514		0.321	0.426	0.237
T24	1.705	0.469	2.024		0.879	0.44	0.258
T25	-2.526	0.652	-0.27		Extreme case		
T26	-0.317	0.429	-0.172		-2.031	0.92	-0.125
T27	-0.317	0.429	0.772		-1.771	0.743	-0.341
T28	2.169	0.511	0.016		1.656	0.973	-0.489
T29	1.497	0.456	-0.219		0.401	0.671	-0.98
T30	0.564	0.424	-1.448		-2.104	0.686	-0.287
T31	1.927	0.487	-0.451		0.699	0.424	-0.914
T32	1.108	0.437	-1.009		1.292	0.486	-0.409
T33	1.705	0.469	-0.924		-0.084	0.394	-0.054

Person Measures from Rasch Analysis for CK and PCK instruments

Teacher ID	SMK instrument				PCK instrument		
	Location	SE	Fit Resid		Location	SE	Fit Resid
	Logit				Logit		
T34	1.108	0.437	-0.426		-1.054	0.498	0.145
T35	-0.317	0.429	-1.668		-1.411	0.535	-0.251
T36	0.037	0.423	-0.152		-1.492	0.65	-0.715
T37	1.705	0.469	-0.685		-0.084	0.394	-0.315
T38	1.299	0.445	-0.99		-1.341	0.643	-0.995
T39	2.169	0.511	0.755		1.075	0.46	-0.712
T40	0.742	0.427	0.44		-1.055	0.443	-0.457
T41	0.388	0.423	0.805		0.173	0.457	-1.262
T42	2.745	0.587	0.268		0.643	0.455	0.301
T43	0.742	0.427	-0.227		1.292	0.486	0.85
T44	1.497	0.456	-1.074		1.075	0.46	1.06
Mean person measure	<b>1.43</b>				<b>-0.01</b>		
Std dev of mean	<b>1.07</b>				<b>1.09</b>		

Fit residual is difference between actual and expected total scores

Should not be less than -2.5 or more than 2.5