Mapping the learning trajectories of physical sciences teachers' topic specific knowledge for teaching chemical bonding

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Abstract

Education in South Africa is a national concern and the training and professional development of teachers, especially in science and mathematics, has consequently been prioritised by the National Government. More than 60 percent of the teachers in South Africa are older than 40 years of age, which means that within the next 10-15 years many experienced teachers will exit the system, leaving a younger and less experienced cohort of teachers behind. This study aims to make explicit the learning trajectories of physical sciences teachers, specifically with respect to their knowledge for teaching chemical bonding, in order to support other teachers and thereby accelerating the route to expertise. Learning can be viewed as change, and change has a trajectory. Mapping the learning trajectories, and the significant events that influenced teachers' learning over time, can give insight into how the change had taken place.

This study used a mixed methods approach within the pragmatic research paradigm to map learning trajectories for a group of 60 South African physical sciences teachers. Pedagogical content knowledge (PCK), the unique knowledge held by teachers, was used for the theoretical framing of the study. An adapted version of the Model of Teacher Professional Knowledge and Skill, including PCK, was used as an analytical framework.

A measuring instrument for topic specific knowledge for teaching chemical bonding was designed and validated using the Rasch measurement model. Quantitative and qualitative analysis of the teachers' responses to the instrument and a grounded analysis of story-line interview data from ten purposively selected teachers were used to identify the factors that played a role in the development of the teachers' knowledge. A further qualitative analysis of PCK episodes from the interview data revealed how the above factors influenced the teachers' knowledge.

Findings revealed that teaching the same content multiple times and at multiple grade levels, embracing changes in the curriculum as opportunities for learning, and further studies at tertiary level, especially completing post-graduate studies in education, all played a role in the teachers' perceived shifts in their topic specific knowledge for teaching (TSKFT).

Three learning trajectories were identified for the teachers in this study: teachers shifted towards deeper conceptual understanding of the content and used more sophisticated explanatory frameworks; teachers shifted towards more integrated topic specific knowledge for teaching; and teachers shifted from being text book bound and teacher-focussed towards becoming more student-focussed in their approach to teaching.

The findings from this study provide guidelines for professional development programmes in terms of differentiated support to teachers according to their career stages and the inclusion of content specific training programmes which makes teaching for conceptual progression explicit. A further recommendation includes encouraging teachers to embark on post-graduate studies in education as this played a pivotal role in shifting teachers' topic specific knowledge for teaching chemical bonding.

Plagiarism declaration

This thesis has been submitted to the Turnitin module and a similarity index of 11% was obtained. I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

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List of acronyms

CAPS	Curriculum and Assessment Policy Statement
CK	Content Knowledge
CoRes	Content Representations
DBE	Department of Basic Education
DHET	Department of Higher Education and Training
DoE	Department of Education
FET	Further Education and Training (Grades 10-12)
GET	General Education and Training (Grades 7-9)
LPs	Learning Progressions
MM	Mixed methods
NATED	National Education Curriculum (in place prior to the NCS)
NCS	National Curriculum Statement
PaP-eRs	Pedagogical and Professional-experience Repertoires
PCK	Pedagogical Content Knowledge
RNCS	Revised National Curriculum Statement
SMK	Subject Matter Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge
TSKFT	Topic Specific Knowledge for Teaching

Terminology

The following are the definitions of selected terms used in this report:

BSc	Bachelor of Science: A first academic degree usually involving three to four years of tertiary education.
BEd	Bachelor of Education: A four year teacher education programme where pedagogy and subject matter are studied simultaneously.
Ex-model C	Former whites-only government schools which generally have better infrastructure and resources than township and rural schools.
Grade 10	Grade 10 is the 10^{th} year of schooling in South Africa. Students are generally 15-16 years of age, but could be older.
HDE	Higher Diploma in Education: A one-year teacher certification programme that was in place before the PGCE.
Honours degree	An additional one year course in a field of specialisation. A bachelor degree in the field of specialisation is a prerequisite. For example chemistry honours denotes four years of subject matter courses with (usually) a small research component.
Learners	The official term used for students in the South African curriculum documents. The term ‘students’ was used throughout the thesis in line with the international literature, but ‘learners’ were used in the instruments.
Master’s degree	An additional two year course in a field of specialisation. An honours degree in the field of specialisation is a prerequisite. A master’s degree includes coursework and a research component, but could also be a fully research-based degree.
PGCE	Post-graduate certificate in education: A post-graduate one year teacher education programme following a disciplinary degree. Subject matter and pedagogy are studied sequentially.
Physical Sciences	A South African school subject offered in Grades 10 to 12 consisting of both chemistry and physics.

Post-graduate	In some countries referred to as *graduate students*. Post-graduate students are students enrolled for post-graduate degrees. In South Africa this refers to any further degree programme following the first degree, and includes for example BSc Honours, MSc or MEd (Master) or PhD (Doctoral) degrees.
Private schools	Schools that are not owned by the state, which are also known as independent schools. They are usually owned and operated by a trust, church or community, or by a for-profit company. Many, but not all, private schools in South Africa charge high school fees. Certain private schools also receive a grant from the state, depending on the community served and fees charged.
Rural	An area characterized by geographic isolation and small population size. However, rural schools can also include schools in 'informal settlements in peri-urban areas where there is access to facilities and services offered in urban areas even though the education, social and cultural profiles of communities living in peri-urban informal settlements may be similar to those in rural areas as a result of the ongoing rural-urban population drift and the prevalence of high levels of impoverishment in both localities' (DoE, 2005, p. 9).
Township	An urban settlement area characterised by high unemployment and low levels of infrastructure. 'Township' has similar connotation to 'inner city' in first world settings; however townships are not situated in city centres, but rather on the outskirts of cities.
Undergraduate	The undergraduate years are those spent as an undergraduate university student, in other words completing the first degree.

Chapter 1 Introduction

This study maps the learning trajectories for a group of South African physical sciences teachers with respect to their topic specific knowledge for teaching chemical bonding. This chapter introduces the study, the rationale for the study, the context in which the research has taken place, the research problem and accompanying research questions, the background on the researcher who performed the study and an outline of the chapters to follow.

1.1 Introduction

Education in South Africa is a national concern. Continued poor student performance against international benchmarks (Reddy et al., 2016) has led National Government to focus on the quality of teaching that is taking place in South African classrooms. In physical sciences student performance is equally poor. Only 36 percent of Grade 12 students achieved 40 percent or more for the national physical sciences examination in 2015, a decrease from the 39 percent in 2012 (DBE, 2016). Poor student performance is, in part, ascribed to ‘shortcomings in the teaching strategies or methodologies applied by teachers’ and ‘the lack of content knowledge on the part of teachers themselves’ (DBE, 2016, p. 6). This situation is not unique to South Africa. Rollnick and Mavhunga (2016) reviewed the role of content knowledge in teacher education and found that teachers across the globe, but especially in developing countries, have shortcoming in their content knowledge and pedagogical reasoning about teaching the content. In addition, Kind (2014a) investigated science teachers’ content knowledge in chemistry, physics, earth sciences and biology and found that teachers, regardless of country or training, possess similar misconceptions about basic scientific ideas. Luft, Dubois, Nixon and Campbell (2015) also conducted a 30 year review of studies of beginning teachers and identified content knowledge as one of the six support areas needed. This situation provides strong impetus for a renewed focus on the training and professional development of science teachers.

South Africa has an ageing teacher population with more than 60 percent of teachers being older than 40 years (CDE, 2015). Although this indicates that there is a shortage of young teachers entering and staying in the profession, it also highlights the fact that there is a large cohort of experienced teachers in South Africa. Within the next 10-15 years the situation will change dramatically, with most of the experienced teachers exiting the system, leaving a younger and less experienced group of teachers behind.

The Centre for Development and Enterprise (CDE, 2015) found that older teachers are better qualified than younger ones, with the majority of teachers having built their qualifications over time. The projection is that by 2025 there will be a shortage of teachers in their 40s (CDE, 2015), and the less experienced teachers will have to fill the gaps in leadership roles that the older teachers would have filled. The focus should therefore be on developing skills amongst the current early career teachers so that they will be ready to provide guidance to younger colleagues in 10 years' time. If the expertise of the teachers who are currently in the system, and how they gained this expertise, can be captured it can be used to support other, less experienced colleagues. This study aims to make explicit the learning trajectories of physical sciences teachers with respect to their knowledge for teaching, to better support other teachers and accelerating the route to expertise.

1.2 Rationale

Since the 1980s the focus in science education research has shifted towards teacher knowledge, and more recently to teacher learning (Wilson & Berne, 1999). This was likely due to the advent of global curriculum reform and new requirements for student learning. If students were to learn differently, then teachers had to teach differently. As a result, the research field started focussing more on teacher knowledge and teacher professional development. Wilson and Berne (1999) asked a question which is still on the agenda of the science education research community: 'What do we know about teachers' professional knowledge?'

Shulman (1987) provided a strong motivation for viewing teachers as professionals when he proposed a professional knowledge base for teaching. One of the components of this knowledge base, pedagogical content knowledge, or PCK, he claimed, was unique to teachers, providing them with 'their own special form of professional understanding' (Shulman, 1987, p. 8). The concept of such a unique knowledge base drew the attention of education researchers, especially in science and mathematics, providing the impetus for the shift towards a research focus on teacher knowledge.

Over the past three decades PCK researchers have grown in their understanding of the construct. Although many conceptualisations of PCK still exist (Abell, 2008; Kind, 2009), progress has been made to consolidate the field and to reach consensus about the nature of PCK (Carlson, Stokes, Helms, Gess-Newsome & Gardner, 2015). This has paved the way to start investigating the development of PCK to gain understanding of the mechanism involved in the process of knowledge development.

Schneider and Plasman (2011) reviewed 30 years of PCK literature to capture possible developmental trajectories for PCK. They had limited success and could only identify a few progression sequences. They concluded that more focussed research is needed in this area to shed light on teachers' developmental trajectories. Deeper understanding of how knowledge develops is an important next step for the PCK community as it will provide specific guidelines to teacher preparation programmes and professional development initiatives about how teachers' knowledge grows. This study aims to contribute to the research field by investigating the development of PCK, and more specifically by looking at developmental trajectories for experienced teachers as they reflect on their teaching over their careers.

Pedagogical content knowledge is viewed as topic specific (Kind, 2015; Gess-Newsome, 2015; Mavhunga & Rollnick, 2013). Therefore, when PCK is studied, it is done within the boundaries of a specific topic.

Chemistry is often viewed as a conceptual and abstract subject (Taber, 2009), and perceived to be difficult for many teachers and students (Johnstone, 1991; Nakhleh, 1992). Within chemistry, chemical bonding is a central topic, fundamental for learning about further topics like acids and bases, chemical equilibrium and organic chemistry (Nicoll, 2001).

Chemical bonding is often taught as three distinct and unrelated ideas - that of covalent, ionic and metallic bonding (Levy Nahum, Mamlok-Naaman, Hofstein, & Taber, 2010). When the topic is introduced for the first time, explanations of these concepts are often limited to definitions, and their inter-relatedness is not explained. This presents chemistry as a set of isolated ideas, which, from my experience as a physical sciences teacher, students find meaningless and difficult to comprehend. Furthermore, over-arching concepts like energy, electron density and polarity are not included when teaching chemical bonding for the first time. When expansion of the concepts is needed in Grade 11, for example in dative covalent bonding or intermolecular bonding, deep conceptual understanding is hampered.

Chemical bonding is a topic for which many alternative conceptions are reported in the literature (e.g. Coll & Treagust, 2002; Nicoll, 2001; Taber, 2002). According to Taber (2010) alternative conceptions about chemical bonding appear to derive from instruction. Unlike experiential phenomena such as force or density, chemical bonding is not a topic that students are exposed to in their everyday lives. Their first encounters with the concept are in the school classroom. If student therefore encounter the concept at school for the first time, it shifts the focus to the quality of formal teaching about chemical bonding.

Teachers in South Africa find chemical bonding challenging to teach despite having teaching experience (Sibanda & Hobden, 2015). In other countries many teachers have limited knowledge of chemical bonding models (Bergqvist, Drechsler, & Chang Rundgren, 2016; Vladusic, Bucat, & Ozic, 2016) providing them with inadequate content knowledge for teaching the topic. In addition to content knowledge, teachers also need to be able to transform their content knowledge for the purpose of teaching (Shulman, 1986, 1987). This is a process that requires reflection and takes time (Loughran, 2012).

Understanding how teachers' knowledge for teaching chemical bonding developed over time, and the factors that played a role in this development, can potentially inform the design of professional development programmes to provide content specific support to in-service science teachers.

1.3 Background on the researcher

I have wanted to be a teacher since high school, but I did not enter the profession until ten years after leaving school as I was offered a bursary to study chemistry (not teaching). After completing an honours degree in chemistry at a local university, I started my career as a chemistry researcher at an industrial research laboratory. Here I realised my love for research, but I still wanted to teach. I completed my teaching certification part time while working in the laboratory. After spending about five years in industry I started teaching and after the first few weeks of teaching, I knew this is what I wanted to do. At the time education was in flux with fundamental changes in the curriculum on the horizon. There was anxiety amongst teachers about new content that was to be included in the curriculum. After seven years in the classroom I left teaching and started a university-based project developing resource materials on the new curriculum topics and distributed the material through teacher training workshops throughout South Africa. During these workshops I realised the need for content and teaching support amongst experienced qualified physical sciences teachers in South Africa.

I am a white female from a typical middle class family and I went to a typical white middle class school. While I was running workshops across the country I realised that I have very little knowledge about teaching in other settings. I therefore registered for a part time research-based master's degree, studying the teaching practice of a township teacher for three years. I gained a better understanding of the challenges most teachers in South Africa face, and realised the difficulties of improving teaching practice in constrained environments.

I have a passion for supporting science teachers and embarked on this journey to learn more about how teachers gain knowledge. I hope to transform the findings from this study into support programmes for new and practicing science teachers.

1.4 Context of the study

Physical sciences teachers from two provinces in South Africa, the Gauteng Province and the Western Cape, took part in this study. The study mainly drew teachers from the urban and peri-urban centres in each of the provinces with very few rural teachers participating. The teachers were all qualified to teach Grades 10 to 12 physical sciences, except for the pre-service teachers, who were all in a year-long post-graduate certificate in education (PGCE) programme to be qualified as Grade 10-12 physical sciences teachers.

As it is typical with teaching physical sciences in South African schools, most of the teachers in the study were also teaching natural sciences to Grade 8 or Grade 9 students, and even other subjects such as mathematics, mathematical literacy or life sciences. In South Africa, the subject 'Physical Sciences' includes both chemistry and physics. The curriculum is spread over three years (Grades 10-12), with 6 months of chemistry teaching each year. In Grades 8 and 9 one quarter of the natural sciences curriculum includes chemistry, with the rest made up of biology, physics and earth science.

In the past decade, South African teachers have experienced two rounds of curriculum change (see Figure 1.1), a process that was challenging and unsettling for many (Rogan, 2007). The National Education Curriculum (NATED)[1] was in place until 2005 in Grade 10. A staggered implementation of the National Curriculum Statement (NCS) (DBE, 2003, 2006) took place from 2006 in Grade 10, with the first Grade 12s writing the first NCS exit examination in 2008. The next round of curriculum changes took place from 2012 to 2014, when the Curriculum and Assessment Policy Statement (CAPS) (DBE, 2011a) was introduced. Most of the data collection for this study took place in 2014 and 2015.

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[1] No reference is available for NATED and obtaining a copy was extremely difficult. Teachers typically used textbooks as a proxy for the curriculum and as a result the curriculum documents were not widely available.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Grade 10												
Grade 11	NATED					NCS					CAPS	
Grade 12												

Figure 1.1 Curriculum changes in South Africa from 2004 - 2015

New content was also introduced, especially with the NCS, but chemical bonding formed part of all the above curricula and was therefore not a new topic. In all three curricula the main chemical bonding models are introduced in Grade 10 and expanded on in Grade 11. Prior knowledge for chemical bonding, such as knowledge about the development of atomic models and the periodic table, are introduced in earlier grades in all the curricula. Some concepts in chemical bonding were more prominent in some curricula, for example bond energy and bond length were more prominent in NCS, whereas specifying different types of intermolecular bonds (for example London dispersive forces) were prominent in NATED and again in CAPS, but not in the NCS.

As part of the introduction of each new curriculum numerous training workshop were held. The focus of the training workshops were to introduce the changes to the curriculum, especially the shift between NATED and NCS, as it represented a fundamental shift towards a much more progressive curriculum than what teachers had been used to. Content-related training was only provided for selected new topics, like polymers or the work-energy theorem, but not for chemical bonding.

1.5 Articulation of the research questions

The overall aim of this research study was to improve our understanding of teacher learning over time, by mapping teachers' perceptions of their learning as they reflect on their teaching of chemical bonding. The overarching research question was formulated to investigate teacher learning trajectories as follows:

What are the teachers' learning trajectories with respect to their topic specific knowledge for teaching chemical bonding?

Effective teaching has been linked to deep understanding of the content and high quality pedagogical content knowledge (PCK) (Shulman, 1987; Loughran, 2012). To identify teachers with sound content knowledge and a well-developed knowledge base for teaching chemical bonding, a method of ascertaining the quality of the teachers' knowledge was needed. A measuring tool for teachers' topic specific knowledge for teaching chemical bonding needed to be designed and validated. The first research sub-question was formulated to capture this requirement:

1. **How can a valid measure of high quality topic specific knowledge for teaching chemical bonding be obtained?**

Learning can be viewed as change, and change has a trajectory (Duschl & Hamilton, 2011). Mapping the learning trajectories and the significant events that influenced teachers' learning can give insight into how the change had taken place. Two further sub-questions were formulated to identify the factors that the teachers perceived to have played a role and how these factors have influenced the perceived shifts in the teacher's knowledge for teaching.

2. **What factors have influenced the quality of the teachers' topic specific knowledge for teaching chemical bonding?**
3. **How did the factors influence the teachers' perceptions of the shifts in their topic specific knowledge for teaching chemical bonding over time?**

1.6 General indication of research design and methodology

Teacher knowledge and teacher learning are complex phenomena, and single research methods may result in only partial understanding. To gain a more comprehensive picture of how teachers learned and the factors that they perceived to have had an influence on their learning, multiple approaches were followed.

Mixed methods research provide an approach where 'the investigator collects and analyses 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). Johnson and Onwuegbuzie (2004) proposed mixed methods research as a third research paradigm with the potential to bridge the divide between the traditional qualitative and quantitative paradigms by including elements of both. By drawing on the strengths of both methodologies, the researcher is able to not only construct a more complete understanding of the issue, but also provide stronger evidence for conclusions through the merging of findings.

Pragmatism is an epistemological view that often accompanies mixed methods approaches. It offers a practical and outcome-oriented method of inquiry that is based on action and leads, iteratively, to further action and the elimination of doubt; and it offers a method for selecting methodological mixes that can help researchers better answer many of their research questions' (Johnson & Onwuegbuzie, 2004, p. 17). The initial planning for this study involved a sequential quantitative-qualitative mixed methods approach where the quantitative findings from the first part of the study would provide insight into choosing participants for in-depth interviews in the second part of the study. A multiple case study approach was planned to identify learning trajectories for selected high achieving teachers from across the experience range.

However, the quantitative analysis of the instrument data revealed a number of factors, in addition to teaching experience, which was initially assumed, which influenced the teachers' shifts in knowledge. In a pragmatic approach to answering the research questions, the second part of the study was modified, and the quantitative data was further qualitatively analysed through an item analysis and an explanatory framework analysis, in addition to interviewing selected participants. This provided triangulation of the findings from different approaches and lead to the revision of the initial research questions. More details about the methodology and sequence of events are provided in Chapter 3.

The data collection for the first research question involved quantitative and qualitative questionnaire data which were statistically analysed to provide evidence for the validity and reliability of the instrument. A small sample of teachers (N=17) assisted in the validation of the instrument. The validated instrument was then administered to a larger sample of teachers (N=60) in the second stage of the study. Data were firstly quantitatively analysed to identify the factors which played a role, and then qualitatively analysed to investigate how the factors played a role in the shift in the teachers' knowledge.

The findings from the second stage of the study were used to identify suitable participants for interviews in the third stage. In-depth interviews were done with ten purposively selected teachers and a qualitative analysis of the interview transcripts provided evidence to answer the second and third research questions.

Each case was analysed separately, but a final qualitative cross-case analysis gave an overview and triangulated findings across the sample to answer the overarching research question.

1.7 Thesis outline

This thesis comprises eight chapters. This chapter introduces the study and provides the rationale and context, as well as the general research design and research questions which guide the study.

Chapter 2 provides an overview of the research literature on teacher knowledge and the development and measurement of topic specific knowledge for teaching. It also describes the theoretical and analytical frameworks for the study. The chapter closes with a discussion of the teaching and learning of chemical bonding, a central topic in chemistry, and its placement in the South African curriculum.

Chapter 3 motivates the choice of research methodology and research design. It describes the research instruments and data collection procedures and elaborates on the data analysis procedures that were used in the study.

Chapter 4 presents the design and validation of a measuring tool for topic specific knowledge for teaching chemical bonding to answer the first research sub-question.

Chapters 5 and 6 present the data analysis and findings for the study. The analysis of the questionnaire data is presented in Chapter 5 and the analysis of the interview data in Chapter 6. This provides the evidence for answering the second and third research questions.

Chapter 7 takes a step back and presents a cross-case analysis across the selected teachers to identify the learning trajectories for the group, in order to answer the overarching research question. Chapter 8 closes the study by summarising the answers to the research questions and discussing the limitations, implications and recommendations from the study. The thesis closes with a personal reflection on the study.

Chapter 2 Literature review

The first chapter provided the introduction and rationale for the study and stated the research questions which guided the study. This chapter reviews the literature on teacher knowledge, and specifically pedagogical content knowledge, the development of pedagogical content knowledge over the careers of teachers, as well as the capture and measurement of teacher knowledge. Since pedagogical content knowledge is viewed as topic specific, the study focusses on the teaching of one of the central topics in chemistry, namely chemical bonding. The literature on the teaching and learning of chemical bonding is also reviewed.

2.1 Introduction

Duschl and Hamilton (2011) frame learning around nine domain-general independent principles, namely, learning is change; learning is inevitable, essential, and ubiquitous; learning can be resisted; learning may be disadvantageous; learning can be tacit and incidental as well as conscious and intentional; learning is framed by our humanness; learning refers to both a process and a product; learning is different at different points in time; and learning is interactional (Duschl & Hamilton, 2011, p. 82). The authors argue that if learning is viewed as change, then learning must also have a trajectory, either positive or negative. To understand the trajectory one must consider how this change took place, the route and process, the factors influencing the change, as well as the outcome of the change.

Feiman-Nemser (2001) views learning to teach as a life-long endeavour, a learning continuum that starts at pre-service and ends when a teacher permanently leaves the profession. Teacher learning can therefore be viewed on a trajectory over an entire career, some learning being planned and intentional, for example participating in professional development activities, but more likely comprising learning that is incidental and unplanned, as a result of events that happen on a daily basis. Mapping these trajectories, by identifying the events that played a role, investigating the route and process of how the events played a role, and capturing the outcome – shifts in teacher knowledge – can provide insight into how teachers learn.

The aim of this study was to map the learning trajectories for a group of physical sciences teachers to better understand how the teachers' knowledge developed and what and how much they have learned over the span of their careers. The first step in the process of capturing this learning process was to define what is being learned. Teacher knowledge is a very broad concept and to narrow the scope of this study, science teacher knowledge, and more specifically pedagogical content knowledge, was used as the focus. A review of the literature on science teacher knowledge, and the factors influencing the development of teacher knowledge, follows.

2.2 Science teacher knowledge

Abell (2007) conducted a review of the literature on science teacher knowledge over 40 years and identified the shifts in research focus from 'knowledge about teaching produced by others to teacher knowledge residing within teachers' (p.1106). Process-product studies in the 1960s and 1970s defined effective teaching in terms of the causal relationship between treatments and their outcomes, and viewed teacher knowledge as static, often based on qualification or skill. Teachers were viewed as the 'known' (Fenstermacher, 1994) and research aimed to produce a knowledge base to summarise the formal knowledge that was needed. Since the 1980s four prominent research programmes shifted the research field on teacher knowledge from seeing the teacher as the 'known', to viewing the teacher as the 'knower'. Abell (2007) identified the four programmes as Clandinin and Connelly's (1996) reflections on teacher practical knowledge through teacher narrative; Schön's (1983, 1987) ideas around reflective practice, Cochran-Smith and Lytle's (1993, 1999) notion of teacher researcher, and Shulman's (1986, 1987) work on teacher knowledge types. In the science education community Shulman's model, and especially his introduction of pedagogical content knowledge (PCK) as one of the knowledge domains of the knowledge base for teaching, gained interest. In the 30 years since Shulman's initial work, many research studies have reported multiple conceptualisations of PCK (Abell, 2008; Kind, 2009). An International PCK Summit was held in 2012 (http://pcksummit.bscs.org/) bringing together leading science education scholars in the field of PCK with the aim of strengthening and advancing the field and 'to attend to the considerable divergences in the interpretation and understanding of PCK and clarify distinctions between different, viable models of PCK' (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015, p. 14).

2.2.1 Pedagogical content knowledge

In his 1985 Presidential Address to the American Educational Research Association, Lee Shulman (1986) introduced pedagogical content knowledge as 'the missing paradigm' in education, and one of seven categories of the knowledge base for teaching (see Figure 2.1).

The knowledge base for teaching

- Knowledge of content
- General pedagogical knowledge
- Curriculum knowledge
- Pedagogical content knowledge
- Knowledge of learners and their characteristics
- Knowledge of educational contexts
- Knowledge of educational ends, purposes, and values

Figure 2.1 Categories of the knowledge base for teaching (Shulman, 1987, p. 8)

In a follow-up paper, Shulman (1987) defined pedagogical content knowledge (PCK) as the 'special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding' (Shulman, 1987, p. 8). Since Shulman's definition, many conceptualisations of PCK have been proposed, with a large number of models published (see Fernandez (2014) or Kind (2009) for summaries). Despite the diversity in conceptualisation, scholars agree that PCK is a useful construct for studying science teacher knowledge (Abell, 2008), with the potential to 'help novices adjust to teaching, as well as aiding experienced teachers in developing more reflective practice' (Kind, 2009, p. 169).

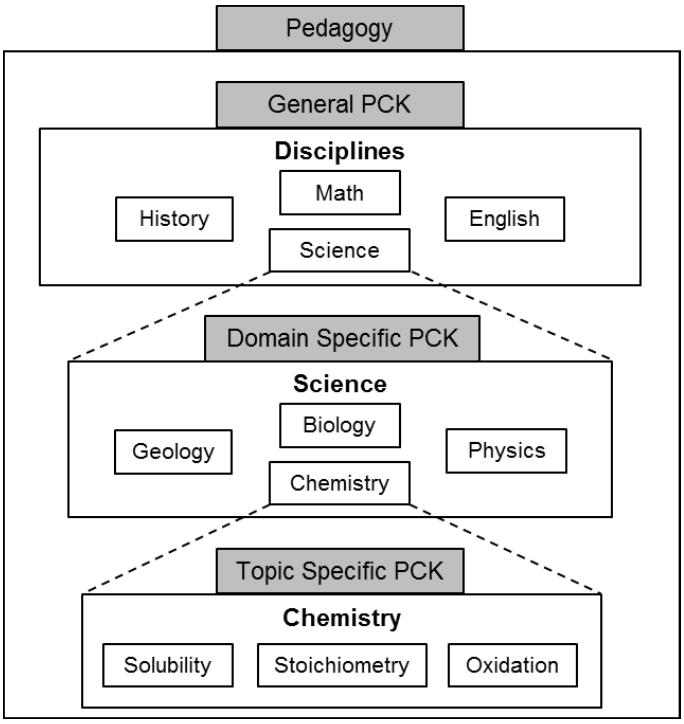


Figure 2.2 A general taxonomy of PCK (Veal & MaKinster, 1999) (redrawn)

Veal and MaKinster (1999) produced a taxonomy for PCK, suggesting that PCK exists at a general, domain specific and topic specific level (see Figure 2.2).

At a general disciplinary level, or what Magnusson, Krajcik and Borko (1999) refer to as the subject-specific level, teachers possess knowledge of concepts and strategies applicable to the specific science discipline. From there teachers have knowledge specific to chemistry, but which is not necessarily applicable to other subjects like biology or physics. Embedded in this is topic specific PCK, the 'most specific and novel level' (Veal & MaKinster, 1999, p. 10). This knowledge is specific for teaching a topic like stoichiometry or chemical bonding. Veal and MaKinster, and many other scholars, view this level as the knowledge which needs to be developed before effective teaching can take place in the classroom (see, for example, De Jong, Van Driel, & Verloop, 2005; Mavhunga & Rollnick, 2013; Park & Chen, 2012).

One of the criticisms of PCK research prior to the international summit mentioned above, was that the field lacked consensus about the nature of PCK and clarity on how PCK was linked to student outcomes. This was one of the conversations at the PCK Summit and the outcome was an agreed-upon definition of PCK and a consensus model. The Model of Teacher Professional Knowledge and Skill, including PCK (TPK&S) (Gess-Newsome, 2015), was proposed to address these concerns (see Figure 2.3) and to provide a framework for how knowledge at the general, topic specific and classroom levels interact.

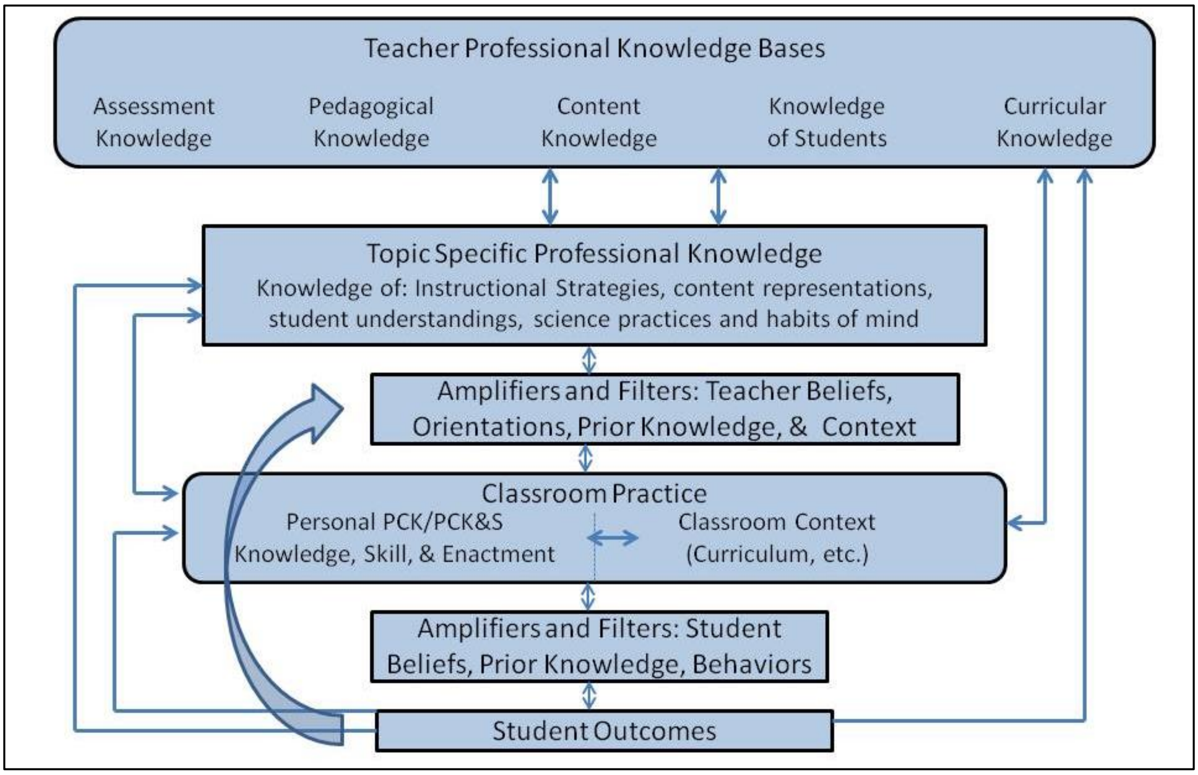


Figure 2.3 Model of Teacher Professional Knowledge and Skill, including PCK (Gess-Newsome, 2015)

The model's starting point is the Teacher Professional Knowledge Base (TPKB), with categories similar to those proposed by Shulman (1987). Knowledge at this level is general and teachers usually expand their knowledge through formal education programmes. This knowledge base underpins Topic Specific Professional Knowledge (TSPK), the knowledge about teaching a specific topic, for example chemical bonding. This includes knowledge about specific instructional strategies which will enhance understanding of the topic, effective content representations, as well as knowledge of students' understanding of the topic.

When this knowledge is enacted in classroom practice, it is filtered or enhanced by factors such as the teacher's beliefs about, and orientations to science teaching, and the context in which the teaching takes place. It should be noted that in the TPK&S model a distinction is made between what a teacher knows about teaching a topic, which Gess-Newsome refers to as Topic Specific Professional Knowledge (TSPK), and what is enacted and observed in classroom practice, which is referred to as personal Pedagogical Content Knowledge (personal PCK). TSPK is context-free and normative, and can be evaluated and measured. Knowledge at the TSPK level is drawn from best practice and research in the field, and can be referred to as canonical PCK. Personal PCK, on the other hand, is unique to the individual and refers to classroom practice only. It can be described and captured, but not evaluated and measured. Personal PCK consists of a knowledge component and an enactment component, and is defined as follows:

- Personal PCK is the knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Reflection on Action, Explicit).
- Personal PCK&S is the act of teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Reflection in Action, Tacit or Explicit) (Gess-Newsome, 2015, p. 36)

2.2.2 Topic specific PCK

What teachers know about teaching is closely linked to the topic that is taught, where this topic fits into the curriculum, the learning difficulties students may have with the topic, and what makes the topic difficult to teach (Geddis, 1993; Mavhunga & Rollnick, 2013). This knowledge is underpinned by the teachers' own understanding of the topic, their subject matter knowledge (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). The act of teaching and planning to teach involves a transformation of the subject matter to make it understandable for students (Geddis, 1993; Wilson, Shulman, & Richert, 1988). Mavhunga and Rollnick (2013) developed a framework for this transformation process, identifying the key features of the transformed form of the subject matter. Their model is shown in Figure 2.4. They identified the following knowledge components from which transformation of the subject matter emerges:

- Representations, including powerful analogies
- Curricular saliency
- What is difficult to teach
- Students' prior knowledge, including misconceptions
- Conceptual teaching strategies

The model acknowledges the influence of other knowledge domains, such as knowledge of context, students and pedagogy, but specifically focusses on the transformation of the content itself. This is important, especially in the South African context, where many science teachers have low content knowledge (CDE, 2007; Rollnick et al., 2008).

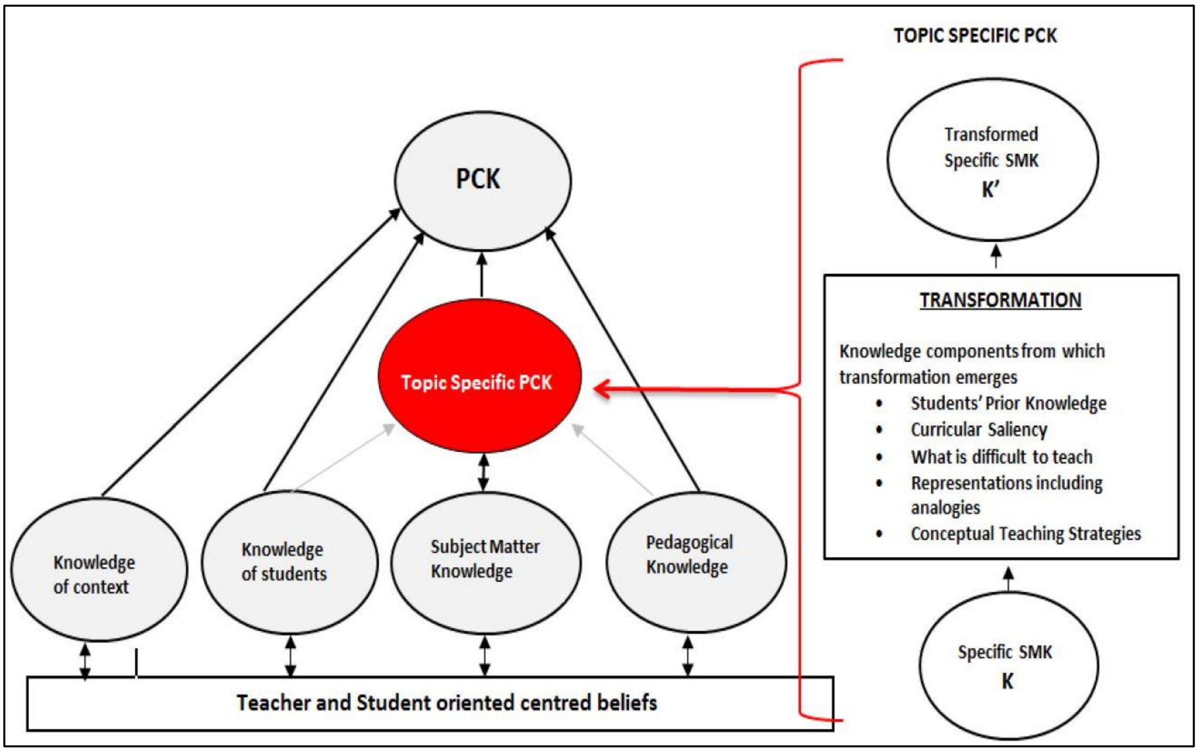


Figure 2.4 Model for Topic Specific Pedagogical Content Knowledge (Mavhunga & Rollnick, 2013)

Mathematical knowledge for teaching

Ball and co-workers (Ball, Thames, & Phelps, 2008; Hill, Ball, & Schilling, 2008), working in mathematics education, also conceptualised the knowledge needed for teaching. They proposed two knowledge domains – subject matter knowledge (SMK) and pedagogical content knowledge (PCK) – as ‘the mathematical knowledge needed to carry out the work of teaching mathematics’ (Ball et al., 2008, p. 395). Their Mathematical Knowledge for Teaching (MKT) model is depicted in Figure 2.5.

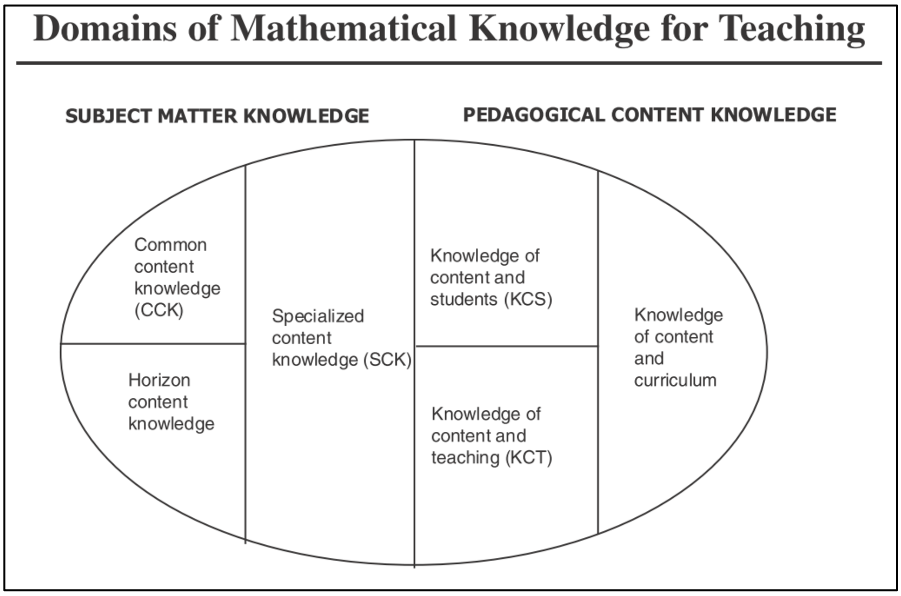


Figure 2.5 Mathematical Knowledge for Teaching (Ball et al., 2008)

In their model SMK comprises common content knowledge, the mathematical content knowledge known to both mathematicians and informed individuals alike; horizon content knowledge, which looks ahead to concepts following the current topic under discussion; and lastly specialized content knowledge, which is mathematical knowledge that is unique to teaching mathematics and generally not known to mathematicians. Pedagogical content knowledge includes knowledge of content and students, knowledge of content and teaching and knowledge of content and curriculum.

When the models for MKT and TSPCK are compared (see Table 2.1) there are many similarities, and only one notable difference. Common content knowledge, which refers to the disciplinary knowledge known to subject specialists, is seen as a component of SMK in the MKT model, whereas it is viewed as a separate knowledge domain and therefore not included in the TSPCK model. However, common content knowledge indirectly forms part of TSPCK as it is the content from which the transformation emerges.

Identifying effective content specific representations for the purpose of teaching forms part of specialized content knowledge in the MKT model as it refers to specific aspects of the content that is known to teachers, but not necessarily to content specialists. Some aspects of curricular saliency in the TSPCK model, namely knowing which big ideas follow each other, overlap with horizon content knowledge in the MKT model.

Knowledge of content and students can be compared to student prior knowledge, while knowledge of content and teaching is referred to as conceptual teaching strategies in the TSPCK model and also includes what is difficult to teach. Knowledge of content and the curriculum refers to placing the topic within the larger curriculum, which is part of curricular saliency in the TSPCK model.

Table 2.1 A comparison of the MKT and TSPCK models

MKT Model	**TSPCK Model**
Common content knowledge	Not included; viewed as separate, the content from which the transformation emerges
Specialized content knowledge	Some aspects of representations
Horizon content knowledge	Some aspects of curricular saliency
Knowledge of content and students	Students' prior knowledge
Knowledge of content and teaching	Conceptual teaching strategies What is difficult to teach
Knowledge of content and curriculum	Some aspects or curricular saliency

This study maps the shifts in science teachers' knowledge for teaching a specific topic in the chemistry curriculum, namely chemical bonding. The Model of Teacher Professional Knowledge and Skill, including PCK (TPK&S) (Gess-Newsome, 2015) provided a useful categorisation of teacher knowledge, classroom practice and student outcomes, but did not provide enough detail at the topic specific level. For the purpose of this study, the TPK&S model was modified, drawing from the MKT and TSPCK models described above, to serve as analytical framework for this study.

2.2.3 Adapted Model of Teacher Professional Knowledge and Skill

Drawing together the conceptualisations of Shulman (1986, 1987), Ball et al. (2008) and Mavhunga and Rollnick (2013), the following modification to Gess-Newsome's (2015) TPK&S model was made for this study to better define topic specific knowledge for teaching (TSKFT). The starting point was attempting to create a clearer distinction between knowledge at a more general level, and knowledge at the topic specific level. Knowledge at a general level refers to knowledge applicable to teaching any discipline or subject, with the content knowledge category referring to the specific discipline and domain. Knowledge at the next level refers only to the topic within a domain, for example chemical bonding within chemistry. More general aspects included at the TSPK level of the Gess-Newsome (2015) model, like science practices and habits of mind, are therefore classified under general content knowledge at the general

TPKB level and not at the topic level, as the original model suggests. This does not mean that teachers do not employ this knowledge when planning to teach a topic, it just more clearly indicates that knowledge of science practices and habits of mind refer to science in general rather than a specific topic. Knowledge about the nature of science would also resort at the general level, as it is viewed as an overarching principle for all topics. The adapted version of the TPK&S Model is included in Figure 2.6. The arrows between all the levels in the model are the same as in the original model, and indicate possible knowledge transfer and recontextualisation between all knowledge levels.

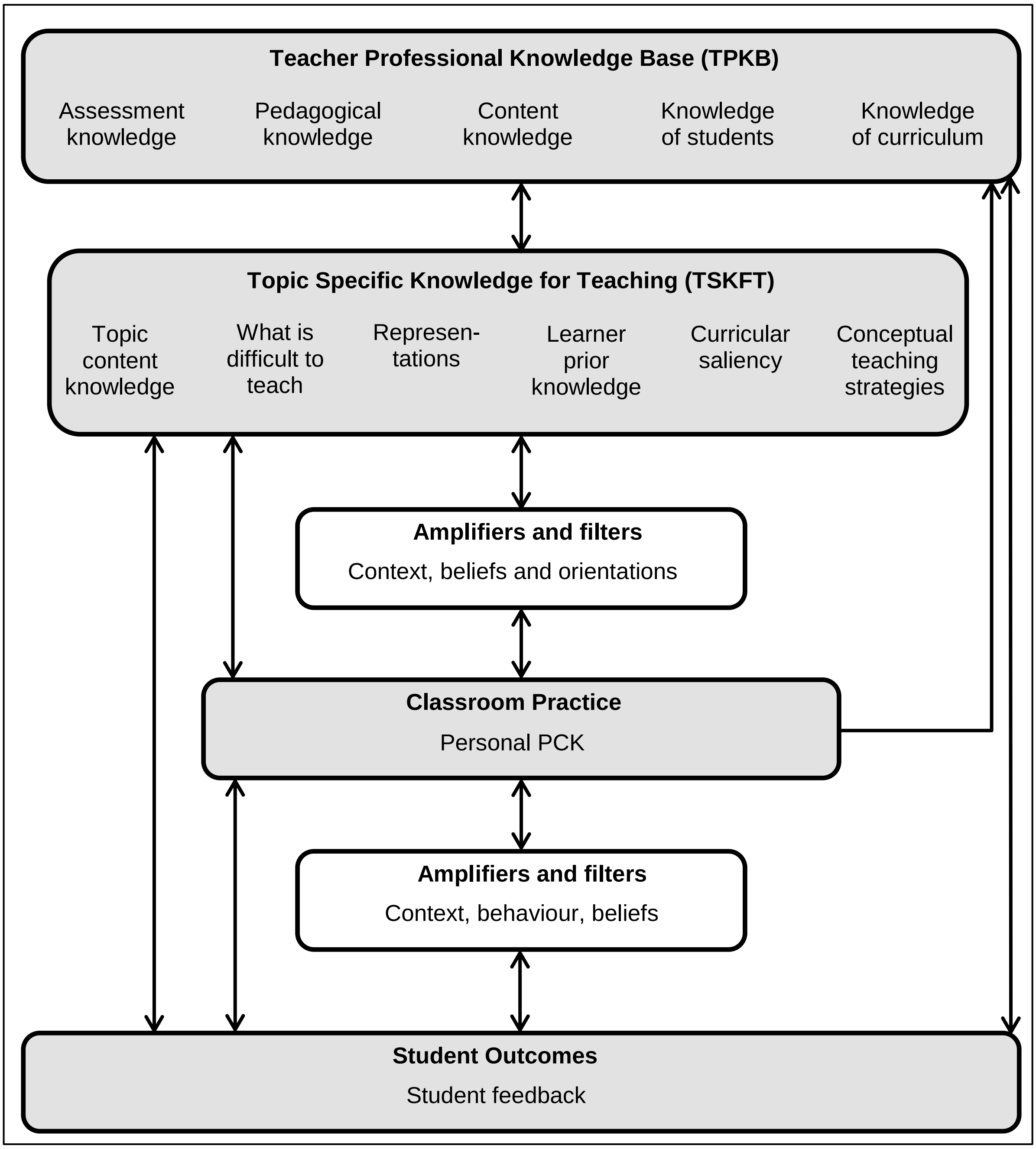


Figure 2.6 Adapted Model of Teacher Professional Knowledge and Skill

Topic Specific Knowledge for Teaching (TSKFT)

Knowledge at the topic specific level is referred to as Topic Specific Knowledge for Teaching (TSKFT) in the proposed adapted model. Effective teachers are believed to have topic content knowledge (CK) as well as knowledge of the transformed form of the content, what Mavhunga and Rollnick (2013) refer to as TSPCK. Teachers use both CK and TSPCK when teaching a topic. Here the adapted TPK&S model draws strongly from Mavhunga and Rollnick's (2013) components of the transformation process, and includes six components for TSKFT, namely:

- Topic content knowledge
- Representations
- Curricular saliency
- What is difficult to teach
- Student prior knowledge
- Conceptual teaching strategies

The general knowledge base (TPKB) supports and acts as a source for TSKFT. Teachers draw from their TSKFT when they plan for teaching and evidence, or manifestations (Davidowitz & Rollnick, 2011; Rollnick et al., 2008) of the components of TSKFT can be observed in classroom practice. It is also anticipated that the components at the topic level would interact (Park & Chen, 2012) and that teachers will integrate their knowledge when planning conceptual teaching strategies (Mavhunga & Rollnick, 2013).

The Teacher Professional Knowledge Base (TPKB)

This general knowledge base is the same as in the Gess-Newsome (2015) model, and consists of five knowledge domains, namely knowledge of assessment, pedagogy, content, students and curriculum. The Gess-Newsome model does not make a clear distinction between knowledge at the disciplinary and domain levels as Veal and MaKinster (1999) proposed, but since teachers' general professional knowledge base was not the main focus of the study, no modifications were made at this level. Each of the domains of TPKB are now briefly described.

Assessment knowledge

Knowledge of assessment includes knowing how to design and use tasks for formative and summative assessment, and how to use the results from these tasks to inform teaching, and ultimately student learning. Teachers do not start their careers with the full repertoire of assessment strategies, but develop these through formal education programmes and as they gain experience (Gearhart & Osmundson, 2009).

Pedagogical knowledge

General pedagogical knowledge refers to knowledge of theories and principles of teaching and learning, as well as the knowledge of classroom behaviour and management (Wilson et al., 1988). This category also includes knowledge of general instructional strategies, such as demonstrations, explanations, questioning, deductive-inductive approaches (for example learning cycle), scientific reasoning, representational learning (using analogies and metaphors) or cooperative learning (Treagust & Tsui, 2014). Teachers choose from the variety of instructional strategies, ranging from teacher-centred to student-centred approaches, in line with their epistemological views (Hashweh, 1996; Mavhunga & Rollnick, 2016).

Knowledge of students

Teachers' knowledge of students includes knowledge about how students learn and knowledge of their initial science ideas, for example that students may have alternative conceptions about science in general, and how they would express those ideas. It also includes personal knowledge about individual students, their backgrounds, interests, likes and dislikes.

Knowledge of curriculum

This knowledge domain includes knowledge of curricula in general, their purposes, goals, objectives and structures, as well as what science is important to teach and the sequence in which to teach it. This domain includes knowledge of what is taught in science in different grades, but also in other subjects in the same grade, as well as knowledge about curriculum resources that are available, and how to use curriculum documents to guide instruction (Shulman, 1987).

Content knowledge

Content knowledge is central to science teaching (Abell, 2007; Kind, 2014b; Shulman, 1986). The literature uses a variety of terms to refer to the teachers' disciplinary academic knowledge (Rollnick & Mavhunga, 2016). Schwab (1978) distinguishes between substantive and syntactic knowledge structures. Substantive knowledge structures include the collection of facts and concepts, and the relationships between these core ideas. Syntactic knowledge structures, on the other hand, refer to how the discipline evaluates and accepts new knowledge, and includes the principles and rules underpinning advances of knowledge in the field. In another conceptualisation, Deng (2007) distinguishes between the subject matter of a secondary school subject and the subject matter of the parent academic discipline. He claims that these two conceptualisations are different, but related, and that knowledge of school science lies at the heart of teachers' knowledge for teaching.

Science teachers' knowledge of the content that they are teaching are most often referred to as content knowledge (CK) or subject matter knowledge (SMK) (Rollnick & Mavhunga, 2016). For example, Wilson et al. (1988), as well as Magnusson et al. (1999), use 'subject matter knowledge' to refer to both substantive and syntactic knowledge structures. Gess-Newsome (2015), on the other hand, uses the term 'content knowledge' in her TPK&S model to refer to 'the academic content of the discipline' (p.32). She includes the disciplinary core ideas and cross-cutting concepts, as well as practices used to generate knowledge, thereby referring to both syntactic and substantive knowledge. For the purpose of this study, and in line with the TPK&S model, the term 'content knowledge' at the general knowledge level will be used to refer to teachers' disciplinary knowledge which includes substantive and syntactic knowledge structures, while 'content knowledge' at the topic level will be used to refer to substantive knowledge structures which includes the 'central ideas, relationships, elaborated knowledge and reasoning ability' (Abell, 2007, p. 1110) for the topic.

Topic Specific Knowledge for Teaching (TSKFT)

This study is conceptualised from the view that knowledge for teaching is topic specific and that teachers draw from a set of topic specific knowledge components when they teach or plan for teaching. Teachers' topic specific knowledge for teaching (TSKFT) comprise two domains (CK and TSPCK) and six components as listed on page 19, each of which are now elaborated on.

Topic content knowledge

Topic content knowledge refers to the facts and concepts for a specific topic, for example chemical bonding, as well as how these concepts are inter-related, as mentioned above.

It is widely agreed that knowledge of the content is essential for effective teaching (Kind, 2014b; Rollnick, 2016) and that this knowledge is transformed in the act of teaching to make it understandable for students (Shulman, 1986). Many studies have investigated the links between topic content knowledge (topic specific CK) and the transformed content (topic specific PCK). Some scholars view CK and PCK as separate domains but have shown that the two domains are closely linked and influence each other in a reciprocal relationship (for example Davidowitz & Potgieter, 2016; Kinach, 2002; Rollnick, 2016). Other scholars view CK as part of PCK and see PCK as an integration of content and other knowledge categories rather than a transformation (for example Cochran, DeRuiter, & King, 1993; Kaya, 2009). Whether CK is seen as separate, or a component of PCK, it is an important component of teachers' knowledge for teaching and the quality of teachers' CK has bearing on the quality of their PCK (Davidowitz & Potgieter, 2016; Kind, 2009; Rollnick et al., 2008).

In the conceptualisation of TSKFT, topic specific content knowledge (CK) and topic specific PCK (TSPCK) form two separate, but related, knowledge domains, with TSPCK viewed as a transformation of the content. This indicates that teachers possess knowledge of the core concepts in the topic and how these are related, as well as the transformed form of the content for the purpose of teaching it, for example knowledge of effective representations, the big ideas and teaching sequence, and common alternative conceptions and how to address these.

Curricular saliency

Geddis, Onslow, Beynon and Oesch (1993) introduced the term 'curricular saliency' to describe knowledge of 'the importance of the topic to the overall curriculum' (p. 583). Mavhunga and Rollnick (2013) included curricular saliency in their conceptualisation of TSPCK and expanded on the concept by adding the identification and sequencing of the big ideas for the topic. This was in line with the work of Loughran and co-workers (Loughran, Berry, & Mulhall, 2006, 2012), where the starting point for thinking about teaching a topic is the identification of the big ideas.

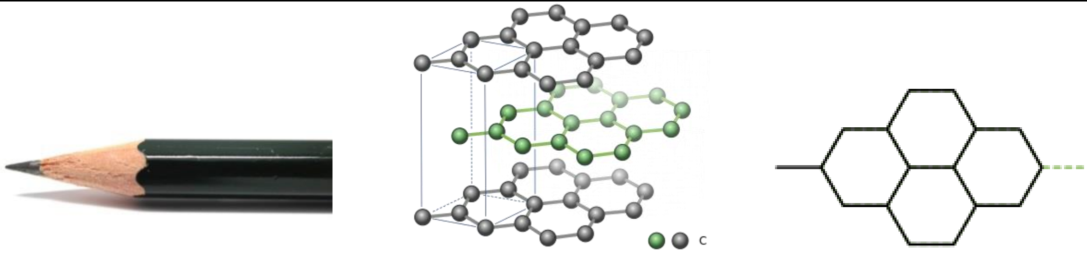
What is difficult to teach

Effective teaching includes knowing which concepts within a topic students find challenging, and are therefore more difficult to teach. The 'what is difficult to teach' component of TSKFT includes the ability to identify such concepts and knowing how to address them in teaching.

Representations

Knowledge of topic specific content representations includes the ability to choose effective ways to represent concepts to ensure conceptual understanding, and the ability to use the representations in such a way as to support student learning. This component can include knowledge of specific analogies and metaphors, effective examples, drawings, diagrams or physical models.

Chemistry can be represented at three different levels, namely the macroscopic, sub-microscopic and symbolic levels (Johnstone, 1991). The macroscopic level refers to the tangible and visible objects, for example a piece of graphite in a pencil. The sub-microscopic level represents the phenomena at atomic or molecular level (the arrangement of carbon in layers of six-membered ring structures and layers stacked onto each other) and the symbolic refers to our ‘short-hand’ of representing the phenomena in symbolic notation (for example lines drawn in inter-locking hexagon shapes to represent a layer of carbon atoms) (See Figure 2.7). Teachers need to know about these three levels of representation and how to use them in teaching.



(a) macroscopic (b) sub-microscopic (c) symbolic

Figure 2.7 Macroscopic, sub-microscopic and symbolic representations for graphite[2]

Knowledge of students’ prior knowledge

This component of TSKFT includes knowledge about students’ pre-conceptions of the topic which may support or impede future learning (Taber, 2000a). Teachers need to be aware of the most common alternative conceptions for a topic, how to identify these, and how to address them to support learning. This component overlaps with curricular saliency to some degree since the pre-knowledge that students need to have in place is linked to the topic. However, here the focus is on what students know, whereas curricular saliency is more focussed on the content.

Conceptual teaching strategies

Mavhunga and Rollnick (2013) view teachers’ knowledge of this component as the integration of their knowledge of the other components into a strategy that will enhance students’ conceptual understanding of the topic. Teachers draw together their knowledge of the curricular saliency, students’ prior knowledge, effective representations and what is difficult to teach, to derive a teaching strategy that will promote conceptual understanding of the topic under discussion.

[2] Images by Jozef Sivek Wikimedia Commons © CC-BY-SA 4.0

In summary, pedagogical content knowledge provides a theoretical framework for conceptualising the unique knowledge teachers possess. The TPK&S model specifies how various knowledge levels interact, and how teacher beliefs and orientations, contextual factors and student outcomes could influence knowledge for teaching. By adapting the TPK&S model at the topic specific level, a more detailed conceptualisation of topic specific knowledge for teaching is possible, providing an analytical framework to analyse the knowledge teachers draw from when teaching, planning for teaching, and reflecting on their teaching of a specific topic.

The next body of literature that was reviewed includes the development of science teacher knowledge and the factors influencing this development.

2.3 Development of science teacher knowledge

Many conceptualisations about the nature of science teacher knowledge, and more specifically PCK, have emerged over the past three decades, with many studies elaborating on what components PCK comprises, but far fewer studies investigating the development of PCK, the factors influencing the development, and the interactions between the components of PCK, to shed light on the mechanisms of how knowledge for teaching grows over time.

2.3.1 Factors influencing the development of knowledge for teaching

Teaching is a complex endeavour with many different experiences and influences playing a role in shaping a teachers' knowledge and practice. This study investigates the influence of teaching experience, academic qualifications and the type of school a teacher is teaching at, on teachers' knowledge for teaching.

Teaching experience

Loughran, Berry and Mulhall (2006) define PCK as 'the knowledge that teachers develop over time, and through experience' (p. 9) thereby placing strong emphasis on the role that teaching experience plays in the development of PCK. Hashweh (2005) elaborates on the positive influence that experience has on knowledge and teaching. Teachers with more experience have more knowledge of students and what they find difficult, a larger repertoire of instructional strategies, and more knowledge of resources to draw upon when planning for teaching. This leads to better developed pedagogical constructions and more effective teaching (Hashweh, 2005).

Geddis et al. (1993) compared the teaching practice of a pre-service teacher to a more experienced teacher and found that the experienced teacher was much more successful in identifying the areas that were difficult to teach, and subsequently were more able to use effective teaching strategies to support his students' learning than the pre-service teacher. De Jong, Van Driel and Verloop (2005) produced similar findings when they conducted a study to investigate the PCK of 12 Dutch pre-service teachers in teaching the links between properties of substances and corpuscular entities like atoms and molecules. The pre-service teachers were able to identify possible areas that they thought students find challenging, but only when they taught the topic for the first time did they appreciate just how difficult students found these aspects of the topic.

Teaching experience may also play a role in shifting teachers to become more student-focussed. Mulholland and Wallace (2005) conducted a longitudinal research study in Australia that followed an elementary teacher, Katie, through pre-service and 10 years into her teaching career. They found that thinking about students takes time to develop and requires reflection on the part of the teacher. Teachers therefore do not necessarily start out by thinking about their students, but are able to shift their thinking to consider student learning as they gain teaching experience.

Teaching experience also plays a role in the development of teachers' content knowledge. Arzi and White (2007) conducted a unique 17-year longitudinal study of secondary science teachers in Australia and found that the teachers had a much better understanding of the organisational structure and integration of the content over time. They also found that the school science curriculum was 'the most powerful determinant of teachers' knowledge, serving as both knowledge organiser and knowledge source' (Arzi & White, 2007, p. 2).

However, teaching experience is not a guarantee for the development of teacher knowledge. Friedrichsen, Abell, Pareja, Brown, Lankford and Volkmann (2009) studied four early career biology teachers in the United States and noted that the teachers relied heavily on general pedagogical knowledge, and that their teaching experience did not lead to the development of PCK. A similar finding was reported by Toerien (2013) in a study with an experienced science teacher teaching at a South African township school. The teacher's pedagogical knowledge and content knowledge developed over the three year period, but little gains in the teacher's PCK was observed.

Teaching experience is an important factor in the development of knowledge for teaching, and although it is not a guarantee for knowledge growth, it has the potential to expand teachers' content knowledge, influence the various components of PCK, as well as shift teaching practice to become more student-focussed.

Academic qualifications

There are two main routes to teacher certification in South Africa, namely a bachelor's degree in education, where content and pedagogy are studied simultaneously, or an academic degree in a field of specialisation, followed by a post-graduate teaching certification, where content and pedagogy are studied sequentially (Rollnick & Mavhunga, 2016). In both these routes, content training plays an important role. However, many science teachers have limited and fractured subject matter knowledge structures (Kind, 2014b) despite their training. Even experienced teachers have been found to hold alternative conceptions about basic science concepts (Kind, 2004). Pitjeng (2014) studied a group of 16 novice graduate science teachers in South Africa. She found that the teachers had low content knowledge of the particle model of matter, despite at least one year of undergraduate chemistry coursework. The teachers also displayed very low achievement on a PCK test. Kind (2014a) reported similar findings in a UK-based study where she investigated the influence of content training in biology, physics and chemistry on pre-service teachers' knowledge of the particle theory and changes of state, mass conservation, chemical bonding, mole calculations and combustion reactions. She concluded that non-chemists' content knowledge is insufficient for teaching chemistry concepts.

It appears that basic content training, for example a first-year university level course, may not be sufficient to teach difficult chemistry concepts at school level and that teachers themselves may hold alternative conceptions about chemical ideas, despite their tertiary level content training.

The influence of content knowledge on teachers' PCK have been investigated by many scholars, for example Käpylä, Heikkinen and Asunta (2009) studied the effect of the amount and quality of content knowledge on PCK for teaching photosynthesis and plant growth in Finland. They found that higher levels of content knowledge had positive influences on the teachers' PCK and that teachers were better able to identify students' conceptual difficulties. Teachers were also better able to pick out the important subject matter to include in their lessons. Kleickmann, Richter, Kunter, Elsner, Besser, Krauss and Baumert (2013) conducted a study in Germany where they investigated the influence of a teacher preparation programme on the development of teachers' content knowledge and PCK. They found that the level of teachers' content knowledge is an important factor in the development of PCK.

Rollnick (2016) conducted a study on experienced teachers in South Africa who were teaching about semiconductors, a topic they had not learned about in their undergraduate training, for the first time. The analysis of video recordings of lessons, journals and concept maps showed that the development of the teachers' content knowledge was closely related to the development of their PCK for the topic. However, when teachers did not have adequate levels of content knowledge, it hampered the development of PCK (Usak, Özden & Eilks, 2011; Rollnick et al., 2008).

In another South African study, Davidowitz and Potgieter (2016) took a quantitative approach to investigating the correlation between CK and PCK for teaching organic chemistry. They found a significant correlation between teachers' content knowledge and their PCK. Similar correlations were reported by Jüttner, Boone, Park and Neuhaus (2013) investigating the content knowledge and PCK of biology teachers in the US, and Krauss, Baumert and Blum (2008) studying mathematics teachers in Germany. In the United States, Nixon, Campbell and Luft (2016) studied the influence of teaching experience and content training on beginning teachers' content knowledge of the conservation of mass and chemical equilibrium. They found that teaching experience played an important role in expanding the teachers' content knowledge, especially in the beginning years.

It seems that sufficient content training is important and that teaching experience, content knowledge and PCK are intricately connected and that the one cannot be studied without also investigating the influence of the others. In this study content knowledge and PCK are viewed as closely related and the influence of teachers' content training on their knowledge for teaching will be investigated.

Type of school

A large variety of types of school are found globally. To name a few, in the United States schools are classified as either public or private, but with many subdivisions under each category, for example Christian, charter or magnet schools (Lubienski & Lubienski, 2008). In Germany school follow an academic or non-academic (vocational) track (Baumert et al., 2010) whereas in South Africa rural, township, ex-Model C and private schools are found (DBE, 2005). Despite this variety of schools, very few studies investigating the influence of the type of school on the development of teacher knowledge have been reported.

Tepner and Dollny (2012) studied German chemistry teachers from academic and non-academic track schools, and found that the teachers' content knowledge varied according to the type of school they taught at. In the non-academic schools, teachers had lower levels of content knowledge than in the more academically focussed schools. Baumert et al. (2010) reported similar findings with mathematics teachers in Germany. Teachers with lower content knowledge and PCK typically taught at the non-academic schools, whereas teachers with higher content knowledge and higher PCK more likely taught at the academic track schools. However, where teachers with well-developed PCK taught at non-academic schools they were more likely to have a pronounced influence on student performance. In Germany, non-academic schools more often served lower socio-economic communities, with academic schools serving higher income areas (Baumert, et al., 2010).

In South Africa, Rollnick and Mavhunga (2014) investigated a diverse group of teachers' content knowledge and PCK of chemical equilibrium. They found that teachers from middle class schools (private and ex-model C) were more likely to have high content knowledge and well-developed PCK, whereas teachers teaching at working class schools (township schools) more often had lower levels of content knowledge and PCK.

It seems that lower-income or less academic schools attract teachers with low content knowledge and PCK, whereas the more academically focussed schools attract teachers with higher content knowledge and PCK. However, due to a lack of studies focussing specifically on this area, it is not clear what the influence of the type of school is on the development of teachers' knowledge. The influence of the type of school, as a possible factor influencing the development of teachers' knowledge, was investigated in this study.

2.3.2 Interaction between components of TSKFT

Henze, Van Driel and Verloop (2008) noted that 'little is known about the process of PCK development, especially in experienced teachers and in the context of educational reform' (p. 1322). Most studies into the development of PCK investigate the influence of certain interventions on the teachers' knowledge growth or shifts in practice. For example, the use of experiential tasks (Atay, Kaslioglu, & Kurt, 2010), using Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) (Bertram & Loughran, 2012), peer coaching (Jenkins & Veal, 2002), mentoring (Achinstein & Fogo, 2015), or through teachers' use and design of curriculum materials (Chen & Wei, 2015; Rozenszajn & Yarden, 2014). Most studies thus focus on the nature of PCK at particular moments in time with fewer studies exploring the process or mechanism by which PCK develops.

A few studies are starting to uncovered these mechanisms by considering the interaction between PCK components. Kaya (2009) was one of the first scholars to investigate the interaction between PCK components. He used a survey and interviews of 25 pre-service teachers in Turkey to investigate their knowledge of teaching ozone layer depletion. He found that there were noticeable interactions between the teachers' knowledge of curriculum, students' learning difficulties, and instructional strategies, but that knowledge of assessment did not integrate with the other components. Padilla and Van Driel (2011) also found the interaction of the same components in their study of six university professors teaching quantum chemistry in the Netherlands.

Aydin and Boz (2013) studied the interaction between the components of PCK for two experienced chemistry teachers teaching redox chemistry and electrochemical cells. Knowledge of students and instructional strategies were central in the teachers' teaching, with knowledge of assessment and curriculum less prominent. The integration of the knowledge components was found to be at the topic specific level.

Park and Chen (2012) investigated the nature of the integration of components of PCK for teaching heredity and photosynthesis using the pentagon model for PCK (Park & Oliver, 2008). Four experienced biology teachers from the same high school in the United States were part of the study. The authors identified instances of explicit PCK, which they called PCK episodes, from transcripts of lesson observations. They found that the integration between the PCK components was topic specific and idiosyncratic. The components, namely knowledge of representations, instructional strategies and students' conceptions, were central, whereas knowledge of the curriculum and assessment were not as prominent. A didactic teaching approach inhibited the integration of some of the components, and high levels of PCK were more often linked to high levels of integration of the components.

Mavhunga (2015) also investigated the interaction of components of TSPCK for a group of pre-service teachers in South Africa by using specific teacher tasks to make the teachers' knowledge explicit. She found that the components of curricular saliency, student prior knowledge and representations most often interacted.

From the literature reviewed here, it seems that the general knowledge components, namely knowledge of assessment and curriculum, do not interact with the same frequency as the topic specific components of representations, student prior knowledge and curricular saliency. The interaction of components of teachers' topic specific knowledge appears to be linked to the development of their knowledge for teaching, but details about the mechanisms are still under-specified and therefore largely unknown.

2.3.3 Science teacher PCK learning progressions

One approach to understanding how teachers' knowledge develops is to map the different stages of development as knowledge progresses over time. The notion of learning progressions (LPs) (Heritage, 2008) has only recently been used to describe teacher learning (Friedrichsen & Berry, 2015). LPs can be defined as 'the successively more sophisticated ways of thinking about an idea that follow one another over a broad span of time' (Heritage, 2008; National Research Council, 2007). This is a relatively new research field and is typically used to identify the conceptual development of 'big ideas' in various topics, for example the nature of matter (Stevens, Delgado, & Krajcik, 2010), energy (Neumann, Viering, Boone, & Fischer, 2012) or force and motion (Alonzo & Steedle, 2009).

Learning progressions provide a promising framework for understanding student learning for key concepts in science (Alonzo & Gotwals, 2012; Duschl, Maeng, & Sezen, 2011). If teachers are viewed as life-long learners (Feiman-Nemser, 2001) then perhaps learning progressions could also be derived for teacher learning. This possibility was investigated by Schneider and Plasman (2011). They used PCK as a heuristic for teacher knowledge and conducted a literature review of the past 30 years of PCK research (1980 – 2010, a total of 91 articles). The aim was to identify possible learning progressions for five PCK categories taken from the Magnusson et al. model (1999) (see Appendix 1). They found that there were definitive trends, in some categories more than in others, but since the studies did not specifically aim to investigate progressions, many gaps still existed. However, they concluded that learning progressions could be a promising framework to think about teacher learning and how teacher knowledge progresses over time.

Two examples of PCK learning progressions that were identified are included below. For the component on representing science phenomena they found that teachers begin by thinking about multiple representations, and then perhaps expand their thinking to more ways to represent the phenomena, before thinking about how students may find these ideas difficult. However, further expansion of teachers' thinking into engaging students with the phenomena and linking it to what students find difficult was not reported in the literature.

For the component on teachers' knowledge about student ideas a fairly comprehensive learning progression was found, most likely as a result of a large number of research studies on alternative conceptions in science (Driver, 1989; Wandersee, Mintzes, & Novak, 1994). The following progression of teacher knowledge was identified:

1. Students do not have initial ideas relevant to science →

2. Students have initial ideas relevant to science, but these ideas are incorrect →
3. Students have initial ideas and it is important for teachers to know these ideas →
4. Students have initial ideas about science and it is important for teachers to look for these by listening to students, reading students' work, or reading the literature on student ideas →
5. Students think and develop their own ideas from multiple experiences in and out of school and these ideas are the basis of learning.

Schneider and Plasman (2011) further found that formal instruction played an important role in the development of teachers' thinking about student ideas. Teachers involved in pre-service and master's degree programmes progressed in their thinking, whereas teachers with extended classroom experience did not show the same progression and perhaps even regressed.

Research into PCK learning progressions was one of the central concerns at the PCK summit (Carlson et al., 2015). Emerging from the summit discussions, Friedrichsen and Berry (2015) explored the challenges and possibilities of framing teaching learning in terms of learning progressions. They concluded that although learning progressions provide a useful conceptualisation of how knowledge could develop, the linear nature of conceptual progression is not easily compatible with the complex and person-specific nature of the development of teacher knowledge. Furthermore, PCK is topic specific, and a possible learning progression for one topic cannot directly be transferred to another topic (Loughran et al., 2006). However, the idea of a number of learning sequences making up an overarching trajectory could be a productive approach to conceptualise teacher learning and the development of teacher knowledge. In answer to Schneider and Plasman's (2011) call for studies investigating PCK learning progressions, this study aims to identify learning sequences which form part of overarching developmental trajectories for teachers.

In summary, various factors play a role in the development of science teacher knowledge, with teaching experience playing the most important role. It seems that teaching experience is able to shift teachers' content knowledge and the interaction between the various components of TSKFT, but that education programmes, more so than teaching experience, are able to shift teacher thinking about student ideas.

2.4 Measuring science teacher knowledge

One of the major contributions of the PCK summit and the subsequent conceptualisation of the Model for Teacher Professional Knowledge and Skill (Gess-Newsome, 2015) was the distinction that was made between knowledge *for teaching* (canonical or collective PCK) and knowledge *in teaching* (personal PCK). As was discussed earlier in this chapter, canonical PCK is normative and can be evaluated and measured, whereas personal PCK cannot be measured, it can only be described, captured and portrayed. Topic specific knowledge for teaching (TSKFT) is similar to Topic Specific Pedagogical Knowledge (TSPK) and is therefore viewed as canonical or collective PCK.

2.4.1 Capturing and portraying personal PCK

PCK is tacit by nature (Hume & Berry, 2011; Van Driel, Verloop, & De Vos, 1998) and an internal construct which teachers find difficult to articulate (Kagan, 1990). Capturing and portraying personal PCK is therefore a challenging endeavour (Park & Suh, 2015). A major contribution was made by Loughran and co-workers (Loughran, Mulhall, & Berry, 2004) when they designed two instruments to assist teachers in identifying and articulating their PCK. The first instrument was called Content Representations (CoRes) where the teacher is required to identify the big ideas within each topic (Mulhall, Berry, & Loughran, 2003) and expand on the teaching of each big idea as guided by specific prompts. The second tool, the Pedagogical and Professional-experience Repertoire (PaP-eR) is used with the CoRe, and are 'specific accounts of practice that are intended to offer windows into aspects of the CoRe' (Loughran et al., 2006). The research community has taken up the use of CoRes, much more so than the PaP-eRs (Cooper, Loughran, & Berry, 2015), and especially in pre-service science teacher education (Hume & Berry, 2011, 2013; Nilsson & Loughran, 2012; Nilsson & Vikstrom, 2015), to assist teachers in articulating their knowledge for teaching and as a tool for professional development. Capturing personal PCK for different topics provides the research community with a collection of cases of best practice (Loughran et al., 2006, 2012) and contribute to the collective PCK for the topic.

Other methods used in capturing personal PCK include the video recording of lessons and subsequent scoring with a specially designed rubric (Park & Chen, 2012; Park & Oliver, 2008) or in-depth interviews on lessons taught using stimulated recall techniques (Bishop & Denley, 2007; Smith & Banilower, 2015).

2.4.2 Evaluating and measuring canonical PCK

Canonical or collective PCK is the PCK that is 'widely agreed upon and formed through research and/or collective expert wisdom of practice' (Smith & Banilower, 2015, p. 90). According to Smith and Banilower (2015), a reciprocal relationship exists between canonical

PCK and personal PCK, where canonical PCK becomes personal PCK through application, and 'as personal PCK accumulates across many teachers, it may become canonical' (p. 90).

The codification of the knowledge base for teaching is an important endeavour, as it builds the knowledge base to enhance students' understanding of the subject matter (Shulman, 1987). However, assessment requires an agreed upon standard. When assessing science content knowledge, canonical science provides the standard, but that which counts as high quality PCK for assessment purposes is still largely under-specified (Smith & Banilower, 2015).

A number of studies, many of which are large scale and span over a number of years, have been conducted to develop measuring instruments for PCK. In the Netherlands Rohaan, Taconis and Jochems (2009) designed a multiple choice instrument for PCK in technology education and in Germany Kirschner, Borowski, Fischer, Gess-Newsome and Von Aufschnaiter (2016) measured and evaluated physics teachers' CK and PCK using open ended questions. In South Africa, Rollnick and co-workers (Rollnick & Mavhunga, 2015) carried out extensive research on the development of measuring instruments for CK and PCK for a large number of topics. They made use of questionnaires with multiple choice and open-ended questions to measure the teacher's CK and TSPCK.

Although measuring instruments, like pen-and-paper tests, have the benefit of use with large groups of teachers, they are somewhat limited because they are dependent on what teachers are able to articulate about their knowledge (Loughran, 2012). Other techniques, like interviews, provide an alternative avenue for teachers to articulate their knowledge and can provide further insight into teacher knowledge (Smith & Banilower, 2015). Investigations into PCK therefore require a combination of approaches (Park & Suh, 2015). Pen-and-paper tests which are easy to administer to large groups of teachers can provide baseline information about teachers' CK and PCK. This can then be followed with interviews to provide a more complete picture of the teacher's knowledge for teaching a specific topic.

2.5 Chemical bonding: a central topic in chemistry

> *Chemistry is primarily concerned with the making and breaking of chemical bonds. Consequently rules of combination, systematics or reactivity, and, ultimately, theories of chemical bonding, have occupied central positions in the activity of chemists and in their scientific literature.* (Pimentel & Spratley, 1969)

Chemical bonding is a central topic in chemistry as it explains the interaction between matter and energy and links atoms to molecules and compounds to structures. The concepts of electrons, ionization energy, electronegativity, bonding, geometry, molecular structure, and stability, are central to many branches of chemistry, for example organic chemistry and analytical chemistry (Nicoll, 2001). Chemical bonding is therefore a key concept in introductory level chemistry courses and provides the foundation for further studies in chemistry.

2.5.1 Learning about chemical bonding

Chemistry is considered to be a difficult subject to learn. This is due to the integrated nature of chemistry concepts, but also because students do not necessarily construct the appropriate understandings of the fundamental concepts in chemistry (Johnstone, 1991; Nakhleh, 1992). Furthermore, chemistry is regarded as abstract (Taber, 2009), which contributes to the learning difficulties that students experience.

Central to understanding chemistry is conceptualising the nature of the chemical bond. The development of the chemical bonding concept has its origins in alchemy and developed over the centuries as our understanding of science expanded. When Dalton proposed the existence of atoms, chemical bonding rules, called valence rules, evolved, providing a way of categorising and predicting the bond types that form when atoms combine. Bonds were classified as covalent, ionic, metallic, coordinate, dative, chelate, bridge or hydrogen bonds, with the periodic table providing a basis for deriving the bonding rules. However, as more and more new compounds were made, the bonding classification system became inadequate, and it was evident that a unifying theory of chemical bonding was needed. When Rutherford proposed his nuclear atom where negatively charged electrons move around positively charged nuclei, it opened a new way of understanding bonding. Lewis started explaining chemical bonds in terms of electron sharing and schemes like the octet rule, and electron-dot diagrams came to the fore. Soon bonds were viewed as the net electrostatic force between protons and electrons. However, further advances in physics, particularly that of Einstein's discovery of the link between energy and mass ($E=mc^2$) and discoveries by other scientists like Davisson and Germer, de Broglie, and finally Schrödinger, set the scene for a quantum-mechanical view of the atom and the subsequent development of the molecular orbital bonding theory. Quantum mechanics is currently viewed as the most appropriate model for explaining the observable properties of atoms, ions and small molecules (Pimentel & Spratley, 1969; Poater, Sola & Bickelhaupt, 2006).

Learning about chemical bonding theories today can be paralleled to the development of bonding theories over the centuries. Understanding is built up and cannot start with the most complex model. Learning about chemical bonding at school level is scaffolded by starting with an atomic view, expanding it through Lewis' electron sharing view, until an electrostatic view is conceptualised. This then sets the scene for further expansion to a quantum-mechanical view of chemical bonding in tertiary studies.

As described above, the study of chemistry is a study of models and modelling (Justi & Gilbert, 2002; Van Driel & Verloop, 2002). Models help us describe chemical observations as accurately as possible. If the role of models in chemistry is not well-understood, it can contribute to the perceived difficulty of the subject (Özmen, 2004). Furthermore, models are often seen as the real phenomena, instead of a best estimation of the phenomenon, which creates further barriers to learning (Van Driel & Verloop, 1999).

Coll and Treagust (2001) investigated Australian students' mental models for chemical bonding using semi-structured interviews. Secondary school students (Grade 12), undergraduate and post-graduate students were given examples of covalent, ionic and metallic substances and asked to describe the bonding in the examples. The predominant explanation used for covalent bonding revealed an octet view, an electrostatic view was most often used for ionic bonds, and metallic bonding was explained using an electron-sea model. The physical properties of metals (malleability and electrical conductivity) and ionic substances (electrical conductivity of molten salts) could reasonably be explained using bonding models, but none of the groups could explain the boiling point differences in covalent compounds in terms of bonding. All the students, including post-graduates, preferred simple models, like the octet principle, despite having been taught more sophisticated models.

A large number of alternative conceptions related to chemical bonding have been identified in the literature, most of which were derived from the octet view of bonding (Taber, 1998). (See Table 2.2 for alternative conceptions pertaining covalent, ionic and metallic bonding, the concepts covered in this study. An expanded list is included in Appendix 2).

Table 2.2 Selected alternative conceptions for chemical bonding (Taber, 1998)

Chemical bonds form in order to produce filled shells. The formation of full shells is the driving force for bond formation.
Covalent bonding as electron sharing. Electrons are shared to achieve a full shell. A covalent bond is a sharing of electrons.
Ionic bonds are the transfer of electrons. Electrons are transferred to achieve a full shell. An ionic bond is a transfer of electrons.
Bonding dichotomy. There are only two kinds of bonds: covalent bonds and ionic bonds. Anything else is just a force and not a proper bond.
NaCl exists as molecules in a lattice with just forces between the molecules. (Ion-pair view)
An ionic bond only occurs between the atoms involved in the electron transfer. Thus, sodium ion forms one ionic bond with a chloride ion in solid sodium chloride and is involved in five forces with the other adjacent chloride ions.
Na^+ and other ions are stable because they have a filled outer shell.
Metals do not have real bonds, only forces.

Taber (1998, 2001, 2002, 2003) conducted an extensive study on the learning of chemical bonding with A-level[3] students in the United Kingdom. He found that the strongest and most persistent conception of chemical bonding is the octet rule. Students viewed the formation of a full electron shell as the driving force for bond formation. When the formation of compounds did not follow this rule, for example in metals, students found it difficult to explain their formation. The students also tended to classify bonds as either covalent or ionic, with nothing in between. This dichotomous classification of bonding was strongly engrained and even after learning about electronegativity and bond polarity, this classification was not expanded to include a continuum model for bonding (Taber, 1998). Furthermore, the students held multiple conceptions for chemical bonding and drew from different conceptions depending on what was asked. Integration and progression of the concepts seldom took place, or took place very slowly (Taber, 2001).

Taber (1998, 2002) identified four distinct explanatory principles used by the students in his study. The first and most basic was the *full shell explanatory principle*. Chemical bonding

[3] A-levels are a British advanced level education qualification that students take when they are seventeen or eighteen years old.

occurs to try and achieve a full shell (eight electrons in the outer shell) and therefore a stable structure. Covalent bonding is described as the sharing of electrons to create a full outer shell, or complete the valency of eight. Ionic bonding is described as electrons being donated or accepted to create a full outer shell. Atoms are found in pairs which 'belong' together and are packed in lattice structures with covalent bonds between the ion-pairs. This is sometimes referred to as the *molecular framework for ionic bonds*, and a well-known alternative conception is that sodium chloride is seen as a molecule (Barker & Millar, 2000; Taber, 1998). Compounds are often viewed as either covalent or ionic (bonding dichotomy). When polar bonds are described, it is seen as modified covalent bonds (since bonds can only be either covalent or ionic) or something in between covalent and ionic bonding. Sometimes polar bonds are just labelled as covalent bonds (Taber, 2002). This full shell principle is not necessarily seen as an incorrect view of bonding, but rather as a very basic view of bonding. If bonds are only viewed in this way, it can be limiting as students see the forces within structures and bonds as unrelated (Taber, 2001). Chemical bonding is therefore limited to systems that form full shells, and concepts like hydrogen bonding, intermolecular bonds and interaction between ions in solution cannot be explained. The concept of a metallic bond is often also problematic and some students view metallic bonding as 'not proper bonding' (Taber, 2003) because the sharing or transfer principle cannot be applied. Furthermore, viewing bonding as the 'need' to fill an outer shell is inherently anthropomorphic as there is no physical force which explains why systems should evolve towards a certain electronic configuration. The full shell principle possibly has its origin in an atomistic view of matter (Taber, 1998) and further explanations of systems, like chemical bonding, is a natural extension of the view of atoms as the building blocks of matter.

The second explanatory principle is the *minimum energy principle*. The view is that stability or a minimum energy is the driving force for bonding to take place. This view is derived from the full shell explanatory principle in that full shells are seen to form stable structures because they are at lower energy. It should be noted here that lower energy is indeed an underlying principle in bond formation, which is a more sophisticated view than what is described here. The focus here, according to Taber, is that lower energy is *the driving force* for bonding because atoms 'want' this stability or minimum energy.

The third explanatory principle is the *electrostatic explanatory principle* or Coulombic principle, where chemical bonds are seen as the net electrostatic force between positive and negative charges. The concept that a chemical bond is a force, or more precisely, an equilibrium of forces, is introduced. Covalent bonds are seen as a balance (equilibrium) between attractive and repulsive forces between positive ions and negative electrons. When the principle is applied to ionic bonds there are no discrete ion-pairs in a lattice, and the number of bonds depends on the co-ordination number of the atom and not the valency or ionic charge. Sodium can therefore form six bonds in NaCl and not just one bond. Metallic bonding can be explained as the forces between delocalised electrons and positive metal ions. In many school curricula, this principle is the target bonding model as it sets students up for further expansion of their understanding at tertiary level.

The fourth principle is the *orbital explanatory principle* with its origin in a quantum-mechanical view of the atom. At a basic level, electrons are found in atomic orbitals (e.g. s- or p-orbitals) which overlap when bonding takes place to form molecular orbitals. Orbital hybridisation explains the formation of some compounds like CH_4. Distinctions are no longer made between covalent, ionic and metallic bonding, but all bonds are seen in terms of the formation of resulting molecular orbitals. In metals, for example, atomic orbitals overlap to form delocalised valence orbitals hosting valence electrons which can freely move throughout the structure.

It is clear from Taber's study that the more naïve views of chemical bonding models are not incorrect, in other words, they are not seen as misconceptions per se, but rather as steps in the process of developing more sophisticated views of chemical bonding. This is echoed by Michaels, Shouse and Schweingruber (2008):

> What we call misconceptions may be necessary stepping stones on a path toward more accurate knowledge. They may coexist with some accurate ideas about the natural world. Mistaken ideas may be the only plausible way for a child to progress toward a more accurate understanding of scientific conceptions. (p. 44)

According to Taber (2010) alternative conceptions about chemical bonding appear to derive from instruction. Unlike experiential phenomena such as force or density, chemical bonding is not something students are exposed to in their everyday lives. Their first encounters with the concepts are in the school classroom.

2.5.2 Teaching about chemical bonding

'A teacher who is both familiar with common misconceptions, and who is able to anticipate where and when learning is likely to distort teaching, is well equipped to avoid some of the common learning difficulties in the subject.' (Taber, 2009, p. 13). Teachers find the teaching of chemical bonding challenging and difficult (Sibanda & Hobden, 2015). There are a number of aspects of chemical bonding that makes it difficult to teach. Teachers themselves may have naïve views about chemical bonding (Birk & Kurtz, 1999; Kind, 2004) making it challenging to teach a concept that they don't fully understand. Teachers' experiences are influenced by their own schooling (Brown, Friedrichsen, & Abell, 2013) and if teachers did not have to opportunity during their schooling, tertiary studies or professional development to expand their understanding of bonding, they may retain their naïve views.

Chemistry is a field where models are used extensively, as seen above. Teachers may have limited knowledge about the use of models in science and often focus their attention in class on the content of the model and not the nature of models and modelling (Henze, Van Driel, & Verloop, 2007; Van Driel & Verloop, 2002). Students and teachers often see models as miniature versions of the actual objects and do not appreciate the limitations and purposes of using models in chemistry (Levy Nahum, Mamlok-Naaman, Hofstein, & Krajcik, 2007). Furthermore, textbooks can support alternative conceptions and do not always portray chemical bonding models correctly (Bergqvist, Dreschler, De Jong, & Chang Rundgren, 2013; De Posada, 1999).

Chemical bonding is a topic where understanding is developed over time, through multiple models. Students need to be able to interpret multiple symbolic representations of a chemical bond (Taber, 2010). One of the goals in science teaching is to facilitate deeper understanding of the science content amongst students. According to Taber (2003) students start off with a very basic understanding of bonding, but, over time, they expand their understanding by including the more sophisticated models. The teaching of chemical bonding should therefore facilitate this expansion of students' content understanding, shifting their understanding beyond viewing bonds as shared or transferred electrons to seeing bonding as electrostatic interactions, and then as interactions between orbitals (Taber, 2002). However, teachers can only facilitate this conceptual progression if their own understanding is at, or beyond these target models.

Sibanda and Hobden (2015) conducted a study on South African teachers' planning of a teaching sequence for chemical bonding. They used a survey instrument with 227 physical sciences teachers and follow-up interviews with 11 of the teachers. They found that the teachers used mainly curriculum documents to determine a teaching sequence. The authors identified curriculum documents as a powerful vehicle for teacher support, especially in terms of sequencing concepts for teaching.

Levy Nahum et al. (2007) studied the teaching of chemical bonding in Israel and suggested a 'bottom-up framework' to support the conceptual learning of chemical bonding from atoms through the bonding continuum to structure and properties. Teachers can therefore be supported by writing a teaching sequence, like the bottom-up framework, into the curriculum documents.

2.6 Chemical bonding in the South African curriculum

South Africa has a spiral curriculum where topics are revisited and expanded upon over a number of years. The curriculum has conceptual progression as one of the main foci and scaffolds the expansion of the content over a number of years (DBE, 2011a, 2011b). Chemical bonding is a particularly good example, as the topic is revisited over five years. In Grades 8 and 9 students' prior knowledge in terms of knowledge about the atom and the periodic table is established. The formation of compounds and the writing of balanced equations are also included in Grade 9. In Grade 10 students are exposed to the basic ideas on bonding, introducing the three basic bonding models, namely covalent, ionic and metallic. In Grade 11 the content is expanded to include polar bonds, electronegativity, hydrogen bonding and intermolecular bonds. The link between bonding and energy is also introduced. Knowledge of chemical bonding is applied in Grade 12 to explain the structure-property relationship of organic molecules.

In terms of conceptual progression the Grade 8 and 9 content has an atomic underpinning. The starting point in Grade 8 is that 'an element is made up of atoms of the same kind' (DBE, 2011b, p.40) and that elements combine to form compounds. Distinctions are made between elements and compounds, and a compound is defined as 'a material that consists of atoms of two or more different elements chemically bonded together' (DBE, 2011b, p. 41). In Grade 9 the chemical bonding concept is expanded slightly and defined as 'the force that holds atoms together' (DBE, 2011b, p.41). For Grade 10 chemical bonds are divided into three distinct types strongly underpinned by an octet view. Covalent and ionic bonding is viewed as sharing and transfer of electrons, respectively, whilst metallic bonding is 'sharing a delocalized electron cloud among positive nuclei in the metal' (DBE, 2011a, p.25). In Grade 11 this is further expanded upon and a chemical bond is defined in terms of an electrostatic framework, namely 'the net electrostatic force' (DBE, 2011a p. 67) between atoms.

The conceptual shift written in the South African curriculum from Grade 8 to 11 is therefore aligned with the development of bonding models in history as elaborated upon in the previous section. South African teachers teaching Grades 10 and 11 should therefore have at least an electrostatic view of chemical bonding to facilitate student learning.

2.7 Summary

Over the past three decades the science research community has focussed on teacher knowledge and teacher learning, and substantial progress has been made in understanding the nature of teacher knowledge and how teachers use their knowledge in teaching. However, less is known about how this knowledge develops over time. Teachers' classroom teaching experiences and education training seem to play a role in developing their knowledge for teaching, but the mechanisms of how knowledge develops are still under-researched.

Teaching and learning to teach is a life-long activity that spans the entire career of a teacher (Feiman-Nemser, 2001). Learning progressions (National Research Council, 2007) provide a promising conceptualisation for teacher learning but seems to be limited due to their linear nature. Viewing teacher learning as a trajectory of change over time, instead of specific linear progressions, may be a more productive approach. Mapping these learning trajectories and the events that played a role in teacher learning can thus provide insight into how teachers' topic specific knowledge for teaching developed over time.

Pedagogical content knowledge (Shulman, 1986, 1987) provides a useful heuristic for teacher knowledge and a theoretical framework for this study. The Model of Teacher Professional Knowledge and Skill, including PCK (Gess-Newsome, 2015), categorises the professional knowledge base for teaching and proposes how teacher knowledge at a general and topic specific level, classroom practice, and student outcomes may interact. Drawing from conceptualisations of Mathematical Knowledge for Teaching by Ball et al. (2008) and Topic Specific Pedagogical Content Knowledge by Mavhunga and Rollnick (2013), the construct Topic Specific Knowledge for Teaching was specified in more detail to provide an analytical framework for the study.

Chemical bonding is a central topic within chemistry and foundational for further studies in chemistry. However, it is a topic that is conceptually dense and therefore challenging to teach and learn. Teachers need deep conceptual understanding, which includes knowledge of sophisticated bonding models, to facilitate student learning of the topic. Curriculum design which focusses on conceptual progression can provide support for teachers in teaching chemical bonding.

This chapter provided an overview of the literature on science teacher knowledge, with specific focus on pedagogical content knowledge, and how teachers develop their knowledge for teaching a specific topic and factors affecting their development. An overview of capturing and measuring knowledge for teaching was also provided. The chapter closed with a discussion of the learning and teaching of chemical bonding, a central concept in chemistry, and the focus topic for this study. The next chapter will elaborate on the methodological underpinnings of the study and provide a discussion of the data collection tools and analysis methods used.

Chapter 3 Methodology

This chapter provides an overview of the research methodology used in this study, the research methods chosen, and the data collection tools that were used. Details about the participants and the data collection and analysis techniques are also provided. The measures that were taken to ensure validity and trustworthiness of the data are discussed, before the chapter closes with a reflection on the ethical considerations for the study.

3.1 Introduction

This study aimed to map the learning trajectories of a group of physical sciences teachers in South Africa with respect to the development of their topic specific knowledge for teaching chemical bonding (TSKFT). The study was designed from a pragmatic research perspective (Johnson & Onwuegbuzie, 2004), and was conducted in three stages to answer the research questions posed in Chapter 1 (see Figure 3.1).

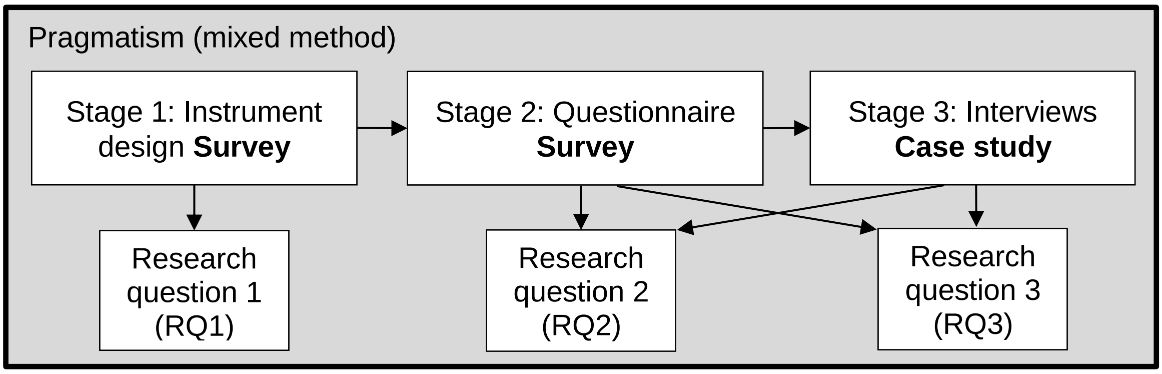


Figure 3.1 Outline of the research study

The first stage of the study involved the design and validation of a measuring tool for teachers' TSKFT (RQ1). The second stage involved administering the instrument to a larger sample of teachers to identify factors which influenced the quality of the teachers' TSKFT (RQ2). The third stage involved in-depth interviews to describe how the factors influenced the teachers' TSKFT (RQ3).

In the first stage of the study a survey approach (Cohen, Manion, & Morrison, 2011) was followed to gather information from a small group of teachers (N=17) for the purpose of validating the measuring tool. The qualitative teachers' responses to the measuring instrument were converted to quantitative data using a memorandum and a rubric, and the Rasch measurement model was used to convert ordinal data to linear Rasch measures. Statistical methods were then used to gather evidence for instrument validity and reliability to answer the first research question.

The second stage of the study used a survey approach to collect data from a larger sample of teachers (N=60) using the validated instrument from stage 1. Like in stage 1, the Rasch measurement model was again used to convert ordinal data to linear measures. The survey was done to obtain a baseline measure of the quality of teachers' knowledge and to identify factors that influenced the quality of the teachers' knowledge so as to answer the second research question.

In the third stage of the study ten high scoring teachers were selected from the sample of 60 teachers to participate in follow-up interviews. The selection of teachers was based on the findings from the survey and represented high achieving teachers from across the teaching experience spectrum. A case study design (Cohen et al., 2011) was used to gain insight into how different factors influenced the teachers' perceived shifts in TSKFT over their careers in order to answer the third research question.

A mixed methods approach (Johnson & Onwuegbuzie, 2004) was followed where sequential quantitative survey data and qualitative interview data were collected. Findings from the second stage informed the selection of participants for the third stage, and findings from stages 2 and 3 were triangulated and integrated to answer RQ2 and RQ3.

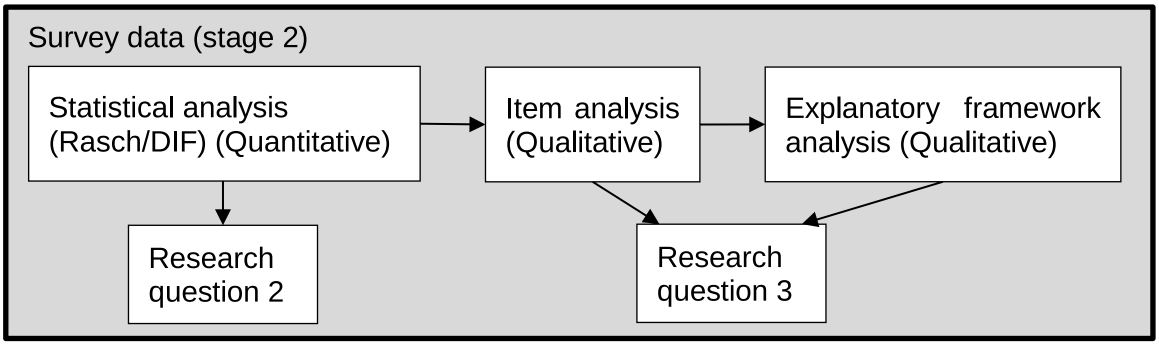


Figure 3.2 Survey analysis sequence

The survey data in the second stage of the study were analysed using three methods (see Figure 3.2). Firstly, the Rasch measurement model was used to determine the overall quality of teachers' TSKFT. A differential item analysis (DIF) was then performed to identify factors influencing the quality of the teachers' knowledge (RQ2). Secondly, a qualitative item analysis of the teachers' responses to the questionnaire was done to gain insight into how the factors influenced the development of teachers' knowledge and to identify trends in the quality of the teachers' knowledge with experience (RQ3). Thirdly, an explanatory framework analysis was performed to further understand how the factors influenced the teachers' knowledge (RQ3). See Appendix 36 on pages 312 – 319 for a descriptive of the explanatory framework analysis.

The survey generated simultaneous quantitative and qualitative data which was firstly statistically analysed, and then qualitatively analysed in a sequential quantitative-qualitative analysis sequence as can be seen in Figure 3.2.

The third stage of the study used a case study approach. Ten teachers participated and story-line interviews were used as data collection tools. This data collection method generated qualitative data (interview transcripts and story-line graphs) which were analysed in the following three ways (see Figure 3.3).

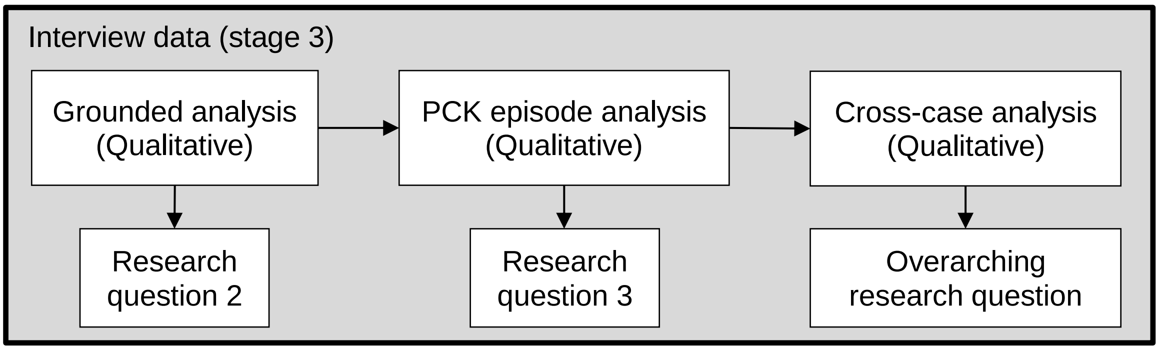


Figure 3.3 Interview analysis sequence

Firstly, the story-line interview transcripts and graphs were analysed following a grounded approach to identify the factors which played a role in the teachers' knowledge (RQ2). This served as a triangulation of findings from the second stage since two different sets of data were collected and analysed to answer the same research question.

Secondly a qualitative PCK episode analysis was performed to investigate how the factors influenced the perceived shifts in the teachers' knowledge (RQ3). Again this served as a triangulation of findings for RQ3 obtained in the item analysis and explanatory framework analysis mentioned above.

Lastly, a cross-case analysis was performed across the ten interviewed teachers, in the light of the findings from stage 2 and stage 3, to identify learning trajectories across the teachers to answer the final and overarching research question.

The rationale for choosing a mixed methods study and accompanying survey and case study approaches are now elaborated upon, and the design features of the data collection tools, sample selection and analysis techniques are discussed below.

3.2 Mixed methods as research methodology

This study involves qualitatively and quantitatively investigating teachers' topic specific knowledge for teaching chemical bonding, as well as the teachers' reflections on their learning to teach the topic over time. The methodological underpinning for a study investigating such complexity needs to allow for different approaches – both quantitative and qualitative – to adequately explore these phenomena.

Mixed methods design is defined as research in which 'the investigator collects and analyses 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. 7). Mixed methods therefore allows for different methodologies to be used in a single study (Cohen et al., 2011). In this study a sequential quantitative-qualitative mixed methods design (Teddlie & Tashakkori, 2009) was chosen as research methodology. A survey approach was used to gain an overall view of the quality of the teachers' knowledge, whilst further in-depth understanding of how the teachers developed their knowledge for teaching was achieved through interviews in a multiple case study approach.

3.2.1 Survey approach

Visser, Krosnick and Lavrakas (2000) define survey research as 'a specific type of field study that involves the collection of data from a sample drawn from a well-defined population through the use of a questionnaire'. Surveys are typically done on large scale to measure particular constructs within a representative sample of the population to be able to make generalisations. However, surveys can also be administered to a smaller population for a specific purpose, for example to identify participants for a second part of a study (Visser et al., 2000).

In this study a survey approach was used to gather quantitative and qualitative data within a specific population, namely Grade 10 and 11 physical sciences teachers in South Africa. The purpose was to obtain both a qualitative and quantitative baseline measure of the teachers' TSKFT. The survey results were also used to identify teachers to take part in a more detailed case study.

Visser et al. (2000) identify three sources of possible error when conducting surveys, namely coverage error, non-response error and measurement error. Coverage error refers to the bias that results from the sample not being representative of the entire population. Non-response error is the possible bias that exists because of the non-replies from some members of the sample, for example when some items in a questionnaire are not answered. Measurement error includes the limitations introduced by self-reporting, not reading questions or misinterpreting questions, incorrect capturing of data or ambiguous wording in the questions. These sources of possible error were considered and addressed in the design and administration of the questionnaire as elaborated upon from page 48 onwards.

3.2.2 Case study approach

A case study design was chosen for the third stage of this research study to capture teachers' perceptions of their learning over time, and to gain insight into the factors influencing the teachers' perceived knowledge for teaching about chemical bonding. Opie (2004) defines a case study as an 'in-depth study of interactions in a single instance in an enclosed system' (p. 74). This study involves data collection with physical sciences teachers teaching the same content to high school students in South Africa. The research questions probe the nature of learning to teach a specific topic and the teachers' perceived experiences of the learning process. To gain insight into the teachers' experiences over time, in-depth conversations afford rich descriptions and provide a more detailed understanding of their experiences and the factors they perceived to have influenced their experiences over their careers. Creswell (2014) view case studies as in-depth accounts which are informed by multiple data sources collected over a period of time. For this multiple case study ten interviews, ten questionnaires and 60 story-line graphs provided the data, with the data collected over an extended period of time.

When a case study design is adopted, data is collected in a particular context. Some scholars have critiqued case study methodology because it cannot deliver generalizability in the same sense that a traditional research design, sampling for representivity across a population, can (Yin, 2003). However, what case studies can offer is in-depth understanding of how various aspects within individual cases interrelate. When multiple cases are studied, correlations across cases can provide further understanding of the situation. Case study is thus uniquely placed to deliver explanatory theory. The potential transferability of the findings to other similar contexts can only be partly suggested, and ultimately is the responsibility of the reader, who can compare the case to another context. In this sense then, it has been argued that the case study is associated with its own particular forms of generalizability to theory (Flyvbjerg, 2006).

3.3 Methods of data collection

In a mixed methods study different data collection tools are needed to collect quantitative and qualitative data. This study used a survey approach to collect mainly quantitative data, and a case study approach to gather qualitative data as was described above.

A questionnaire was designed and validated in the first stage of the study, and then used to collect data in the second stage. Interviews, story-line graphs and questionnaire responses were used as the qualitative data collection tools in the case study. The story-line method was used in the interviews to support teachers in remembering and reflecting on past learning experiences. The design features, limitations and affordances of these data collection methods are discussed below.

3.3.1 Questionnaires

Questionnaires as research tools are widely used as a procedure for collecting information. They are useful for this purpose because they are relatively easy and economical to administer and can be used to ensure the standardisation of questions. Questionnaires can also be written for specific purposes (Opie, 2004), for example to screen participants, and are appropriate tools to gather large amounts of data in a relatively short period of time.

An important limitation in using questionnaires as tools to capture teacher knowledge is the fact that teachers find it difficult to articulate what they know. Furthermore, what they choose to write is only a partial reflection of the extent of their knowledge (Gess-Newsome, 2015; Loughran, 2012). Smith and Banilower (2015) identify questionnaires as effective strategies to collect data on teacher knowledge, but emphasise the need to supplement questionnaire data with other qualitative methods to provide teachers with different ways to articulate their knowledge.

A further limitation of administering questionnaires, especially if the questionnaire is long and includes open ended items, is that a low response rate is often obtained (Cohen et al., 2011). This was also reported in PCK studies, similar to this present study, that used questionnaires to gather teacher data, such as for example the study by Park and Suh (2015), or the collection of studies reported by Rollnick and Mavhunga (2015).

3.3.2 Questionnaire design

The purpose of the questionnaire in this study was to capture teachers' TSKFT as accurately and reliably as possible. The goal of the questionnaire design was therefore to maximise reliability and validity in order to maximise data quality. The overall design features, specifically in terms of addressing design limitations, are highlighted below, and a more detailed account of the validation and design procedures is provided in Chapter 4.

One of the most important limitations of using a questionnaire to capture teacher knowledge is that teacher knowledge is tacit (Gess-Newsome, 2015). In an attempt to address this limitation a variety of question types were included to give teachers the opportunity to express their knowledge in different ways. Closed questions, for example multiple choice items, are easy to administer (Smith & Banilower, 2015), whereas open ended questions provide more insight which is often impossible to obtain with closed questions (Krosnick & Presser, 2010). The questionnaire used a combination of two-tier multiple choice, short-answer as well as open ended questions. This generated better quality data than using multiple choice questions only, but it made the questionnaires time-consuming to complete and accounts to some degree for low response rates. Analysis of the open ended questions also required a coding scheme, with accompanying measures to ensure inter-rater reliability and accuracy of application of the coding scheme. More details on the development of the coding scheme and the reliability measures that were put in place are provided in Chapter 4.

In a further attempt to support teachers in articulating their knowledge, some questions were based on classroom scenarios to make the question contexts more familiar to teachers. Furthermore, teachers could answer the questionnaire in their own time. Where workshops were used to gather data, teachers were given as much time as they wanted to complete the questionnaire.

A number of strategies were employed to ensure a high response rate. Firstly my familiarity with the science teacher community through running teacher training workshops in South Africa, and particularly in the Western Cape, was useful. In the Western Cape I was able to send personal emails to about 60 teachers whom I knew from previously teaching in Cape Town, and through the teacher training workshops I ran as part of my previous employment. In Gauteng I arranged two teacher workshops and again could personally invite teachers who had attended previous workshops. I was also able to use the teacher networks at the two universities where the workshops were held. Teachers completed the questionnaires as part of the workshop, after which the teaching of chemical bonding was discussed and free teaching resources were provided to all participants. The combination of personal invitation, university networks and the running of workshops yielded 17 completed questionnaires for validation purposes and a further 60 questionnaires for the main survey sample.

A further limitation of using surveys is coverage error (Visser et al., 2000). A sample can never be fully representative of the population it represents and sample bias will always be present to some degree. Effort was made to obtain responses from teachers across the spectrum. A wide variety of teachers with teaching experience across the range participated, but not all types of schools were fully represented. For example, very few rural teachers participated because the workshops were held in metropolitan centres. Furthermore, bias may also be introduced when teachers volunteer as opposed to random representative sampling across the population.

When questionnaires are used there are often non-responses (missing values) which impacts the reliability and representivity of the data (Visser et al., 2000). Non-response behaviour is greater when teachers complete questionnaires unattended. The use of workshops was a design feature to reduce the non-response rate and teachers were encouraged to complete all the items. As a result only 33 out of 2078 responses (1.6%) were missing. More details about how missing values were dealt with in the analysis are provided in Chapter 4.

Measurement error needs to be considered when designing questionnaires (Visser et al., 2000). Pre-testing the questionnaire is an important component of questionnaire development as it reduces measurement error. The first step is usually to conduct an expert review to screen items and ensure unambiguous wording, after which a field test or pilot is done (Krosnick & Presser, 2010). Methods that do not employ pilot testing can only provide insight into possible problems, whereas methods that include pilot testing provide information about actual problems. In the design of this questionnaire a panel of experts, as well as a pilot test, were used to check the items and assessment of questions and limit ambiguity in the wording of questions, so as to ultimately limit measurement error. More details on this process are provided in Chapter 4.

The questionnaire used in this study is time-consuming to complete due to the scope and depth of knowledge probed. Questionnaire fatigue can therefore have an effect on the quality of the data. In an attempt to address possible questionnaire fatigue the order in which the questions were asked was carefully considered. Longer questions were placed earlier in the test, and shorter, potentially more familiar content knowledge questions were placed at the end of the test. It was noted that the response rate in the very last question was lower than for other questions, and teachers did not provide examples despite an explicit request to do so. This question was removed as part of the validation process, not due to the low response rate, but because the experts felt that the content was slightly beyond the scope of the test. However, the removal of this question also improved the response rate, and addressed the effect of questionnaire fatigue to some degree.

3.3.3 Interviews

Interviews provide flexible opportunities to probe for greater depth than that provided by questionnaires (Smith & Banilower, 2015). The focus of the research was not only to capture the level of teacher knowledge but also to gain insights into the thinking and reasoning that takes place in the process of acquiring knowledge, and the factors that played a role in the teachers' perceptions of their knowledge development. For this purpose interviews, and more specifically semi-structured interviews, were chosen as the most appropriate data collection tool.

Semi-structured interviews are pre-planned conversations guided by a set of initial questions, but which allow for deviation from the set questions (Opie, 2004). Semi-structured interviews therefore provide opportunities to explore matters that naturally arise in the conversation, yet also probe matters pre-determined by the interviewer. This was particularly important in this study as teachers needed to expand on specific pre-determined aspects of their TSKFT, yet have the freedom to expand on uniquely personal experiences which they considered significant in learning to teach the topic. A set of guiding questions were therefore used (see Appendix 3) to ensure that specific components of TSKFT are covered, but teachers were allowed to elaborate on specific events which they felt played a role in the development of their TSKFT.

According to Cohen, Manion and Morrison (2011), three sources of bias exist when interviews are used, namely the characteristics of the interviewer, the characteristics of the interviewee, and the substantive content of the questions.

Interviews are interpersonal constructions. It is therefore inevitable that the researcher will have some influence on the interviewee and therefore on the data. Establishing a good rapport between interviewer and interviewee (Cohen et al., 2011) is an important starting point for an effective interview. I was known to all the interviewees, either through my teaching experience in the Cape Town area, through running teacher workshops in my previous employment, or meeting the teacher at the data collection workshops a few months prior to the interview.

The semi-structured design of the interviews was used to reduce possible researcher bias. A set of pre-determined questions were used to guide the interview and to ensure the same basic interview structure for all the interviews. Interviews were voice-recorded and transcribed to provide a more complete record of what was said. A sample of a transcription is included in Appendix 4.

Kvale (1996) suggests that the interviewer should be knowledgeable about the subject matter to be able to ask effective questions. I have a background in chemistry teaching and was able to use my teaching experience in the design and execution of the interviews. However, having been a teacher may have influenced the power relations between myself and the interviewees, and interviewees may have been tempted to provide the answers that they think I wanted to hear (Cohen et al., 2011). I made an effort to explain to teachers that they are contributors to the research and not subjects of the research study. Teachers were free to choose the time and venue for the interview and could also choose which components of TSKFT they wanted to talk about first. Many interviews took place in public spaces like restaurants or coffee shops, or after hours in the teachers' classrooms.

Furthermore, the interview was based on the questionnaire which the interviewees completed beforehand. This was done to triangulate the data, but also to reduce content bias as teachers had already thought about the content that they were interviewed on. The timing of the interviews was important to further reduce content bias. Interviews were arranged soon after the teachers had taught chemical bonding so that they could reflect on the recent teaching experience.

The possible influence of sampling bias was considered in the selection of the interviewees. To minimise sampling bias, the selection of teachers was guided by their performance on the questionnaire in the first phase of the study, and teachers who scored in the top quartile were considered. All interviews were done face to face, which meant that some of the high scoring teachers could not take part in the interview stage, as they were not living in Cape Town. I travelled to Gauteng to interview four of the eight top-scoring Gauteng teachers to increase diversity in the sample, and to minimise sampling bias. More details about the interviewees are provided on page 57.

The reliability of interviews also extends to the way in which interviews are analysed. All interview data were transcribed by myself and then checked by the interviewees (see Appendix 4). However, transcriptions of interviews are still only partial representations of reality and considered to be interpretations of social situations (Kvale, 1996). The usefulness of interviews should therefore be considered, rather than their complete reliability. The purpose of the interviews in this study was to provide teachers with another opportunity, in addition to completing the questionnaire, to articulate their knowledge. The interview was therefore useful as it provided the teachers with such an opportunity. The teachers' comments in the interview could also be triangulated with the written answers in the questionnaire. The second purpose of the interview was for teachers to identify and elaborate on significant events which they perceived to have played a role in the shifts in their knowledge. Again the interview was a useful tool to provide teachers with the opportunity to elaborate on these events. Furthermore, the teachers' conversations could be triangulated with the story-lines they constructed to strengthen validity of the data. The use of story-lines is discussed below.

3.3.4 Interview protocol design

The purpose of the interview was two-fold: firstly it provided teachers with an additional opportunity to articulate their TSKFT, as described above. Secondly, it was used help teachers identify the factors which played a role in the development of their perceived knowledge for teaching chemical bonding in order to answer RQ2. It also required teachers to explain how the factors played a role in their perceived shifts in knowledge in order to answer RQ3.

During the interviews teachers were asked to elaborate on their experiences of teaching chemical bonding, focusing on the TSKFT components, namely topic content knowledge, content representations, curricular saliency, what is difficult to teach, their knowledge of student prior knowledge, and misconceptions in chemical bonding and conceptual teaching strategies. Designing an interview that requires such specificity was challenging as it required teachers to reflect and recall past events. The limitation of this approach is recognised here, and it is acknowledged that findings for this study can only be partial reflections of what really happened. To support teachers in recalling and reflecting on past learning experiences the story-line method (Gergen, 1988; Berry & Van Driel, 2013; Nilsson & Van Driel, 2011) was modified for TSKFT. Each teacher was required to draw a story-line for each of the components of TSKFT, retrospectively plotting perceptions of their learning over their careers. In the interview the teachers were then asked to identify and elaborate on the significant events or factors which they identified in their story-lines, and which they thought played a role in their learning to teach chemical bonding. The story-line method and its modification for use in this study is discussed below.

3.3.5 Story-lines

Story-lines 'represents a teacher's evaluation of a series of experiences or events' (Beijaard, Van Driel, & Verloop, 1999, p. 48). Teachers' evaluations are captured in the form of line 'graphs' as shown in Figure 3.4 on the next page.

The story-line method was first used by Gergen (1988) to investigate college students' feelings of general well-being. Beijaard, Van Driel and Verloop (1999) modified the story-line method for use in science education and conducted a study to evaluate the use of the method to elicit teachers' practical knowledge. Teachers were asked to evaluate their experiences over their careers and represent their perceptions on a graph. A line with a positive slope indicates a progressive period or positive feeling, a negative slope indicates a regressive period or negative feeling, and a flat line indicates a stable period or neutral feeling. A change in line direction may be an indication of an important event of change.

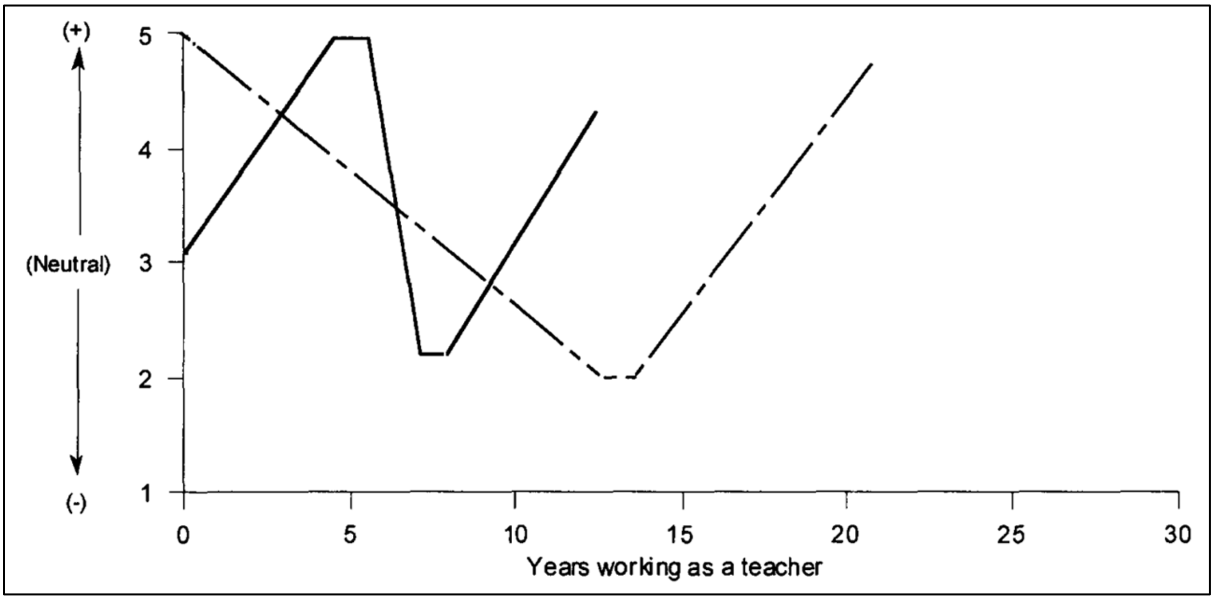


Figure 3.4 Example of a story-line graph from Beijaard, Van Driel and Verloop (1999)

Story-lines allow teachers to evaluate experiences and identity key turning points, or significant influences, in their teaching careers. They are quick and easy to construct and are able to capture extensive information in a single line. Furthermore, teachers drew the story-lines themselves and therefore had control over which events they were prepared to include. This reduced researcher bias and supports the notion of the teacher as a contributor to, as opposed to the subject of, a research study.

The disadvantage of story-lines is that it requires teachers to reflect on past experiences and therefore only reflect teachers' perceptions of selected experiences. This was a limitation of the study and the data obtained were at most perceptions of learning. Events were also limited to what teachers could remember. However, if teachers were able to recall an event many years after it had happened, and elaborate on how it influenced their teaching, it was considered a significant event in their careers.

Story-lines typically fit into the narrative research tradition and is used to capture teachers' stories (Nilsson & Van Driel, 2011). In this study, however, story-lines were used as tools to help teachers remember and reflect on past experiences. Teachers' stories were therefore not reported, but instead the significant events that they identified and elaborated upon were noted. The story-line method was therefore used slightly differently to its original intention, and to fulfil the role of a recall tool, the method had to be modified. This process is described below.

3.3.6 Story-line design

The purpose of the story-lines was to support teachers in reflecting on past experiences and link significant events to perceived shifts in their knowledge of specific aspects of teaching about chemical bonding. The intention was that the story-lines would be used in the interviews as a support and a recall tool. The story-line method was therefore adapted for use with TSKFT.

The first step in the design process was to test whether it was possible to draw a story-line for the components of TSKFT. Since I had teaching experience, I tried to construct six story-lines, based on recommendations provided by Beijaard, Van Driel and Verloop (1999) - one for each of the TSKFT components. Figure 3.5 shows one of the six story-lines, namely content knowledge.

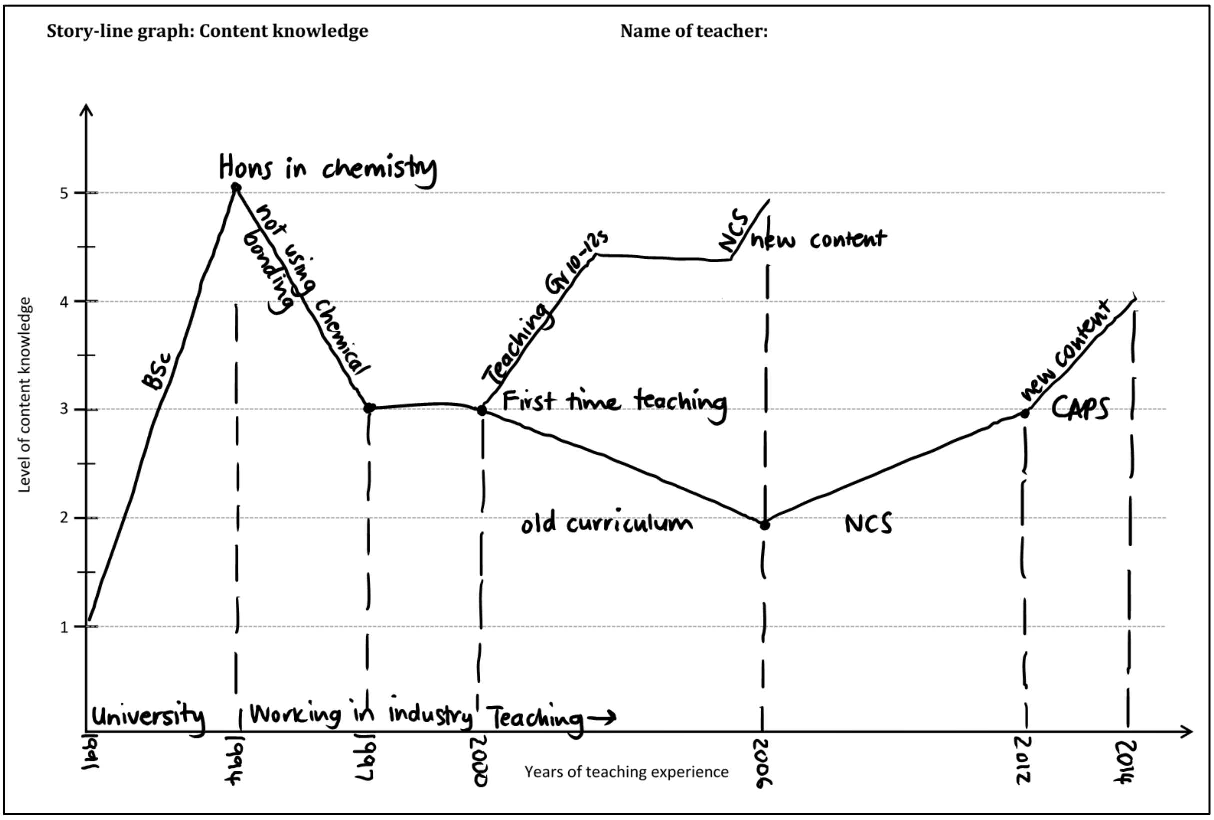


Figure 3.5 Example of a story-line on content knowledge

I was able to draw separate story-lines for each of the six components but felt the following features needed modification: the positive-neutral-negative description for the y-axis was problematic as I did not perceive my knowledge to be positive, but rather to increase or decrease. A flat line also did not indicate a neutral ‘feeling’, but rather a ‘no change’ reflection. I therefore changed the vertical axis to have an arbitrary scale of 1-5 based on a recommendation by Beijaard et al (1999). I also added a description to each graph to clarify what the teachers needed to include.

Draft instructions were then drawn up for drawing story-lines and these were tested by conducting a pilot interview with an experienced teacher. The interview protocol was also tested during this pilot. The teacher (RG5) who piloted the story-lines was also part of the reference group used in the validation of the measuring instrument described in Chapter 4. No further changes were made to the instructions for the story-lines or the interview, but it was suggested that the story-line templates and instructions be sent to the teachers before the interview so that they could reflect on significant events in their careers before the interview.

The initial idea was that the teachers would complete the story-lines before the interview took place and then discuss the graphs during the interview. However, this was not a practical arrangement as none of the teachers had the time to complete the story-lines beforehand. Instead they completed it during the interviews. This provided the opportunity to explain how the story-lines should be done, and facilitated natural ‘think-aloud’ opportunities in the interview while the teachers were constructing the lines.

It should be noted here that although teachers were asked to draw six different graphs, the intention was not to compartmentalise their knowledge, but rather to support them in thinking more explicitly about specific aspects of teaching chemical bonding. Teachers were better able to do this than was initially anticipated, and only one teacher was not able to draw two of the story-lines (curricular saliency and what is difficult to teach). Another benefit of drawing six different story-lines, was that often the same event would be mentioned in more than one story-line. This provided stronger evidence of the significance of the event and facilitated triangulation of the findings.

Beijaard et al. (1999) found that one of the challenges in using story-lines was that teachers found it difficult to locate a specific experience in time, and that the ordering of experiences were challenging. In this present study the exact timing of an event was not as important as the event itself, and the influence of the event on teachers perceived shifts in knowledge. Less focus was therefore given to precisely locating the event in time, and more focus on how the event influenced their knowledge.

The use of story-lines in the interviews contributed to minimising researcher bias in the study, since the evaluation of the relevance of an event was done by the teacher and not by the researcher.

3.4 Participants

All the participants in this study were consenting Grade 10 or 11 physical sciences teachers, or pre-service teachers in a teacher certification programme to become physical sciences teachers. The participants can be divided into three groups:

- The *validation group* consisting of 17 participants who completed the TSKFT instrument for validation purposes in the first stage of the study.
- The *survey group* consisting of 60 participants who completed the validated TSKFT instrument in the second stage of the study.
- The *interview group* consisting of ten experienced physical sciences teachers who took part in story-line interviews in the third stage of the study. This group was a sub-set of the survey group mentioned above.

Sampling

Sampling constitutes who, what, where and when participants for a study are chosen. Two types of sampling are found, namely probability (random) and nonprobability (purposive and convenience) sampling (Cohen et al., 2011). Probability sampling is more often used in studies which aim to generalise results from the sample to the larger population, whereas in nonprobability sampling the researcher intentionally includes (or excludes) a section of the wider population.

Different sampling approaches were used in this study. In the first stage of the study, nonprobability convenience sampling was used to select teachers to complete the questionnaire for the purpose of instrument validation. No generalisations of the findings were needed, as the sample was chosen for a specific purpose.

The second stage of the study used a mixed method approach where survey and case study designs were used. It is common for mixed methods studies to use more than one kind of sampling and different sample sizes (Teddlie & Tashakkori, 2009).

The survey design required some level of representivity in terms of gender, province and teaching experience. However, the findings were not meant to be generalised across the population of teachers. Some aspects of a random sampling approach were used as any physical sciences teacher could participate, but not all physical sciences teachers had equal chance of being invited to participate, since the invitations were restricted to teachers who had attended previous workshops and whose contact details were available. Nonprobability sampling was therefore used, but an attempt was made to have a good spread, especially in terms of teaching experience. Table 3.1 summarises the demographic information of the validation and survey samples.

Table 3.1 Demographic information for the validation and survey sample

Demographic information		Validation sample	Survey sample	Code used for DIF analysis
Gender	Female	10	27	F
	Male	7	33	M
Province	Western Cape	11	31	WC
	Gauteng Province	6	29	GP
School type	Not currently teaching / never taught before	3	16	NOT TEACH
	Rural school	0	2	RURAL
	Township school	2	9	TOWNSHIP
	Ex-Model C school	8	24	EXMODELC
	Private school	4	9	PRIVATE
Highest chemistry content level	Not known / did not declare	0	11	UNKNOWN
	Chemistry first year level	1	23	CHEM1
	Chemistry second year level	7	5	CHEM2
	Chemistry third year level / major in chemistry	7	16	CHEM3
	Chemistry fourth year level or higher	2	5	CHEM4
Highest teaching qualification	Academic science degree with no teaching qualification	5	15	NO ED QUAL
	Academic science degree with a one-year professional teaching qualification (PGCE or HDE)	6	21	PGCE/HDE
	Bachelors of education (BEd)	3	12	BEd
	Honours level (e.g. BEd Honours)	3	5	BEd Hons
	Master’s degree level (e.g. Master’s degree in Education)	0	4	MASTERS
	Teaching diploma without an academic degree	0	3	TEACH DIP
Teaching experience	Pre-service teachers	3	12	0 YEARS
	Beginning teachers	4	9	1-3 YEARS
	Mid-career teachers	2	12	4-10 YEARS
	Late career teachers	6	13	11-20 YEARS
	Veteran teachers	2	14	21+ YEARS

A good balance between male and female teachers was achieved. Due to logistical constraints sampling could only take place in the metropolitan centres in the Western Cape (Cape Town) and Gauteng Province (Pretoria and Johannesburg). As a result only two rural teachers and very few township teachers participated, and most of the teachers came from privileged teaching environments (private and well-functioning ex-model C schools).

No information on race was systematically collected, but deductions suggest that there were 31 white participants, 21 African, 7 coloured (mixed race) and 1 Indian teacher in the survey sample. A third of the survey sample were African teachers, but very few (6) of these teachers scored above the mean. One of the male teachers from this group (T45) was purposively included in the interviews. Appendix 5 provides a table with all the participants, with the African participants who scored above the mean indicated with an asterisk.

The aim of the study was to map learning trajectories and for this reason a good spread of teaching experience was important. The teachers were divided into five teaching experience categories, following the guidelines provided by Schneider and Plasman (2011): *pre-service teachers* (no teaching experience except during teaching practice), *beginning teachers* (1-3 years' teaching experience), *mid-career teachers* with some experience (4-10 years) and teachers with much experience (11+ years). Since the teachers in this study were relatively experienced and to provide a more detailed view of their teaching experience, this last category was divided into two, namely *late career teachers* with 11-20 years' teaching experience and *veteran teachers* with 21 or more years' teaching experience. The beginning teacher category had the least number of teachers. This was the most difficult category to find teachers for, possible due to the challenges new teachers face when starting their careers (Luft, Dubois, Nixon, & Campbell, 2015).

The third stage of the study involved a case study where purposive and convenience sampling was used to select teachers for the interviews. The interview sample was pre-determined by the survey sample in what Teddlie and Tashakkori (2009) defines as sequential mixed method sampling. Only teachers who took part in the survey were eligible for the case study. The selection process was guided by teachers' performance on the test, and to ensure a spread of teaching experience, sampling for variation occurred. Teachers scoring above the mean and who had four or more years' teaching experience were considered. The aim was to have an equal number of male and female participants with representation from both provinces. For this purpose I travelled to Gauteng to interview four of the ten teachers. Teachers from each of the teaching experience categories (4-10 years, 11-20 years and 21+ years) were selected, and as mentioned earlier, one teacher, despite obtaining a slightly lower total score, was selected as he was one of the few African teachers who scored above the mean for the test and was willing to participate in an interview. Table 3.2 provides a summary of the interview sample.

Teachers were continually selected and interviewed until data saturation occurred (Onwuegbuzie & Leech, 2007) until no new categories emerged. This resulted in the final interview sample consisting of a total of ten teachers, five males and five females. The group represented a spread of chemistry qualifications. High scoring teachers more often had further education qualifications, for example honours or master's degrees in education, and this was also reflected in the spread of highest teaching qualification of the interview group.

Table 3.2 Participants taking part in interviews

Teacher code	Pseudonym (years' teaching experience)	Pro-vince	Gen-der	School type	Highest chemistry level	Highest teaching qualification	Rasch person measure (mean= 0.21)	Overall ranking
T28	Adrian (4)	WC	M	EXMODELC	CHEM2	PGCE/HDE	2.64	1
T26	Simon (12)	GP	M	EXMODELC	CHEM2	MASTERS	2.44	3
T58	Doreen (16)	GP	F	EXMODELC	CHEM3	HONOURS	1.98	4
T40	Alicia (24)	WC	F	PRIVATE	CHEM3	MASTERS	1.89	5
T44	Glenda (22)	GP	F	PRIVATE	CHEM1	HONOURS	1.71	6
T01	Natalie (10)	WC	F	PRIVATE	CHEM1	MASTERS	1.71	7
T41	Stephanie (14)	WC	F	PRIVATE	CHEM3	PGCE/HDE	1.37	14
T59	Desmond (30)	WC	M	EXMODELC	CHEM1	TEACH DIP	1.20	17
T43	Jonathan (5)	WC	M	EXMODELC	CHEM1	MASTERS	1.04	21
T45	Vuyo (5)	GP	M	EXMODELC	CHEM1	HONOURS	0.63	25

3.5 Data collection and data handling

The data collection procedure for stages 1 and 2 were similar, as they both involved the administering of questionnaires. Both stages made use of workshops and personal email invitations as the strategies to invite participants. At the workshop the purpose of the study and meaning of the knowledge components were discussed. Teachers who were invited via email received a written description which explained the meaning of each of the components of the questionnaire.

The 17 teachers in the validation group participated as follows:

- Six teachers completed questionnaires at a workshop in Johannesburg.
- Nine teachers completed questionnaires at a workshop in Cape Town.
- Two teachers responded after personal invitation via email.

The 60 participants in the survey sample were invited as follows:

- Twenty-five teachers completed questionnaires during workshops in Gauteng (Johannesburg and Pretoria).
- Twenty-three teachers completed questionnaires as a result of email invitations.
- Twelve questionnaires were completed by physical sciences PGCE students at the University of Cape Town.

All instrument responses were captured in a spreadsheet. The accompanying memorandum and rubric were used to code the responses (see Chapter 4 for the design of the memorandum and rubric). The original scripts were used for the first round of coding and codes were captured next to each typed response in the spreadsheet. The coding procedure is described in more detail in Appendix 6. Once the responses for all the teachers were coded, the coding for each question was checked by comparing the codes for each item to all the other codes for the same item. This process ensured that all the code 4s were of a similar level, all the code 3s were similar etc., and that the rubric was consistently interpreted across all the teacher responses. This process was facilitated by the spreadsheet design, where all responses to the same item were in the same column. The purpose of this procedure was to limit researcher bias where the teacher's response to one category could influence the researcher's coding in another category. To further strengthen the coding procedure, selected questionnaires were moderated by two other researchers, and the inter-rater reliability statistics were determined. This is reported in Chapters 4 and 5.

The moderated codes for all the participants were then collated into a spreadsheet to be submitted for statistical analysis as described in the next section. A copy of this spreadsheet, showing the final TSKFT scores, is available in Appendix 7.

The third stage of the study involved story-line interviews as data collection tool. Ten teachers participated in the interviews as described above. The interviews were voice recorded and transcribed. Interviews lasted an average of 85 minutes (SD=13) and included the drawing of the story-lines. *NVivo 10*, a qualitative data analysis software package (QSR International, 2012) was used to code the data.

3.6 Data analysis

A mixed methods study requires different approaches at the data analysis stage in order to integrate findings and provide a more holistic view to study the phenomena under investigation (Greene, Caracelli, & Graham, 1989; Tashakkori & Creswell, 2007). In this study data were analysed statistically as well as thematically to generate new knowledge through the synthesis of findings from these different approaches. Figure 3.6 summarises the data analysis sequence and research questions addressed by each analysis method.

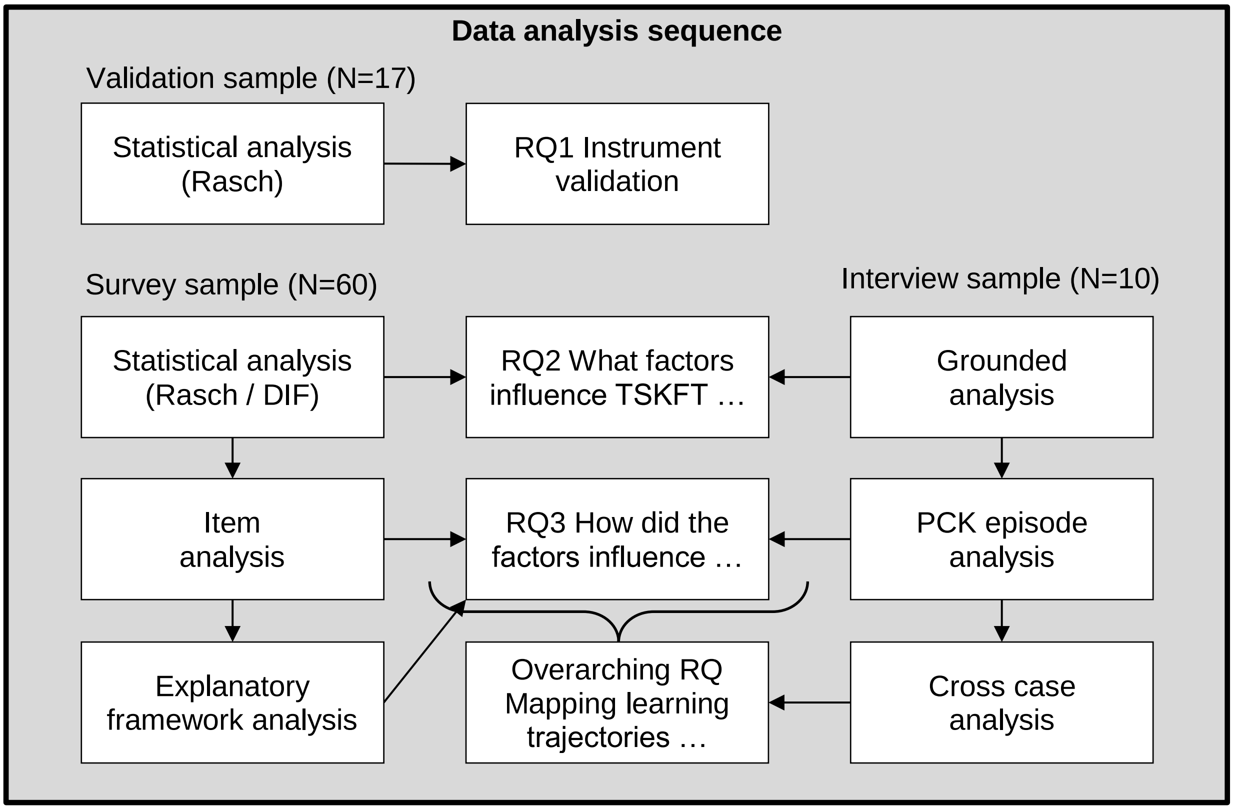


Figure 3.6 Data analysis sequence to answer the research questions

3.6.1 Statistical data analysis

Statistical data analysis was used in the first stage of this study to validate the measuring instrument, and in the second stage to describe the quality of the teachers' TSKFT and identity the factors that played a role in the quality of the teachers' TSKFT. The Rasch measure model was chosen as the statistical data analysis method.

Rasch analysis

The Rasch measurement model, named after the Danish mathematician Georg Rasch, is a psychometric model for analysing categorical data, such as questionnaire responses, as a function of the trade-off between person ability and item difficulty (Rasch, 1960). The data generated in this study were non-linear (ordinal) due to the nature of teacher knowledge and the types of questions included in the questionnaire. The Rasch measurement model converts ordinal raw scores into linear measures of teacher competence (Boone, Townsend & Staver, 2011), and provides an appropriate method of analysing the questionnaire data. *Winsteps* (Linacre, 2014), a statistical package using the Rasch measurement model, reports person measures and item difficulties on the same linear scale, which allows for direct comparisons.

The questionnaire included a variety of item types, as was explained earlier, to address the tacit nature of teacher knowledge and provide multiple opportunities for teachers to articulate their knowledge. As a result, the questionnaire consisted of polytomous items, and therefore required a polytomous Rasch model for the analysis (Andersen, 1995). The polytomous model is a generalisation of the dichotomous model and can be applied in contexts in which successive integer scores represent categories of increasing competency. The Partial Credit Model (Masters, 1982) is the polytomous Rasch model used in this study.

The first and second stages of the study generated data from a survey questionnaire which included both 'direct answers' and explanations of their choice of answers. The data from the questionnaires were transformed from qualitative written answers to quantitative data using a rubric and memorandum. The design of these data conversion tools are described in more detail in Chapter 4.

Winsteps applies the Rasch measurement model to transform ordinal data to linear scores before standard statistical tests, such as a principle component analysis and Cronbach's alpha, are performed. One such test, namely differential item functioning, or DIF, is discussed in more details below as it played a prominent role in this study.

DIF analysis

Differential item functioning (DIF), is a statistical characteristic of an item that shows the extent to which the item may be measuring different abilities for members of separate subgroups (Badia, Prieto, & Linacre, 2002). The average item scores for subgroups having the same overall score on the test are compared to determine whether the item is measuring in essentially the same way for all subgroups. A DIF analysis provides an indication of unexpected behaviour of items on a test and is used to identify potential item bias.

DIF was used in two ways in this study. Firstly, as part of the statistical analysis (reported in Chapter 4) to gather evidence for a valid and reliable test. Statistically significant DIF may indicate that items show bias with respect to some subgroups (for example female teachers). A valid test should not discriminate against groups for which the test does not intend to discriminate, for example in this study whether the participants were male or female, or teach in Gauteng or the Western Cape, should not influence their performance.

'Although Rasch theory is highly quantitative, applying it effectively to a specific problem requires deep qualitative thought and reflection (Boone, Townsend, & Staver, 2011, p. 260). When DIF is detected for an item, a qualitative analysis of the responses is performed to provide insight into whether the item is problematic, and should be deleted, or whether it is indicative of a separate issue. This qualitative approach was used in the second stage of the study to gain insight into which subgroups performed statistically differently and for which items. In a DIF analysis the performance of a sub-group is compared with their expected performance which is obtained from the overall performance of the subgroup on the test as a whole. If the group performs unexpectedly higher or lower, the item is flagged for DIF. For example, if pre-service teachers are expected to achieve low scores for an item, but do not, then DIF is detected. In the second stage of the project the data were analysed for DIF for the different teaching experience categories to identify sub-groups who may perform in an unexpected way. Where DIF was detected the result were qualitatively interpreted (see the next section on qualitative analysis) to gain insight into why this was the case, and to shed light on possible trends in performance related to teaching experience. This addressed the second research question by identifying factors that influenced the teachers' TSKFT. The analysis and results of this analysis are reported in Chapter 5.

3.6.2 Thematic data analysis

The quantitative analysis described above was followed with a series of qualitative analyses to further investigate the statistically significant findings in what Collins, Onwuegbuzie and Sutton (2006) identify as qualitative follow-up interaction analysis. The Rasch measurement model provided a measure of the overall performance of the sample, as well as factors which may have influenced the performance of teachers. Subsequent qualitative analysis of the instrument responses from all the teachers provided insight into the quality of their TSKFT as well as the effect of the factors on the shifts in TSKFT with respect to teaching experience.

Item analysis and explanatory framework analysis

The validated TSKFT instrument for chemical bonding was administered to 60 teachers in the second stage of the study. A qualitative item analysis and explanatory framework analysis were performed using the 60 questionnaire responses as data source. The conceptualisation of TSKFT and accompanying six knowledge components, as described in Chapter 2, provided the analytical framework for the item analysis. The items in the questionnaire were organised based on the six knowledge components, providing an organising framework for the analysis. The teachers' performance on each of the items could be compared for the different teaching experience categories. The findings from the item analysis are presented in Chapter 5.

The initial intention was to only analyse the teachers' responses through a qualitative analysis of each of the items, but the teachers' responses to the items revealed the use of distinct explanatory principles (Taber, 1998, 2001). In a pragmatic approach to gain insight into how the different factors influenced the shifts in teachers' knowledge as teachers gained teaching experience, an explanatory framework analysis was performed. Taber's (1998, 2001) notion of explanatory frameworks, as described in Chapter 2, was used as the framework to analyse the data. Details about the analysis process and the findings from the explanatory framework analysis are presented in Chapter 5.

The two analysis methods mentioned here used the same data source, but different approaches, to gain insight into the teachers' TSKFT to answer RQ2 and RQ3. The item analysis involved a qualitative analysis of quantitative data, whilst the explanatory framework analysis involved a qualitative approach.

The third stage of the project used a different data source to the previous two stages (interview data from ten selected participants) to also answer RQ2 and RQ3. The data analysis methods were also different, and included a thematic analysis using a grounded approach, followed by a more detailed PCK episode analysis.

Thematic analysis using a grounded approach

Data sources for the third stage of the project include interview transcripts and story-line graphs. In addition, the teachers' responses to the questionnaire were used as secondary data source, for triangulation purposes. A grounded analysis of the interview transcripts and accompanying story-line graphs was done using *NVivo 10* interview analysis software (QSR International, 2012). The data were repetitively coded and constantly re-arranged (Lincoln & Guba, 1985) to identify emerging patterns and themes. A description of the process is included in Appendix 8. A coding framework, or codebook, was also developed (Adair & Pastori, 2011), and is included in Appendix 9. The findings from the thematic analysis are presented in Chapter 6.

The thematic analysis identified the salient factors which the teachers perceived to have influenced the shifts in their TSKFT. To gain insight into how these factors played a role in the development of TSKFT, PCK episodes were identified for each teacher and analysed.

PCK episode analysis

PCK episodes (Park & Chen, 2012) are instances of explicit PCK identified in lesson observations or teachers' spoken or written accounts of their teaching. Mavhunga (2015) identified PCK episodes in the written reflections of pre-service teachers in her study on the nature of interactions of the components of topic specific PCK. Park and Chen (2012) identified

PCK episodes in the instructional practices of biology teachers which they captured through video recordings. In this present study PCK episodes were identified in interview data as teachers reflected on how they teach chemical bonding and how they perceived their knowledge for teaching had shifted over time.

The process of identifying and analysing PCK episodes is described in Appendix 10. The PCK episode analysis shed light on how the various factors influenced each teacher's TSKFT, providing a different analysis method to answer RQ3.

The findings from the analysis for each individual teacher could now be compared across all ten teachers to identify trends across the teachers. The final qualitative cross-case analysis allowed for the identification of learning trajectories for the group of teachers involved in this study.

Cross-case analysis

The thematic analysis and PCK episode analysis described above identified various factors which influenced teachers' TSKFT and shed light on how the factors influenced each teacher's TSKFT. In the final analysis, these emerging patterns were compared across the ten interviewed teachers and the findings from stage 2 and stage 3 were integrated to answer the main research question, namely mapping the learning trajectories for the teachers involved in this study. A discussion of the findings from this final cross-case analysis is presented in Chapter 7.

3.7 Data quality

All research methods have strengths, but also inherent weaknesses. By using multiple methods to investigate a phenomenon the strengths from each method complement each other, and the weaknesses counteract each other (Greene et al., 1989). By intentionally designing a study to include two or more methods the results from one method can clarify results from another method and reduce bias by triangulating results from the different methods. This improves data quality and increases the overall validity of the findings.

The quality of data in mixed methods research is determined by the quality of the data in each of the separate strands. According to Teddlie and Tashakkori (2009) 'if the data of the individual strands is valid and credible, then the mixed study will have a high overall data quality' (p. 209). The assessment of the quality of the data that were generated was determined by each of the individual qualitative and quantitative strands.

3.7.1 Validity and reliability of quantitative data

Rigour in research is an important component of any study. In quantitative studies, rigour refers to the validity and reliability of measurement and the measuring instruments used.

Validity

Validity is defined as 'the extent to which a concept is accurately measured in a quantitative study' (Heale & Twycross, 2015, p. 66). There are two major types of validity that needs to be considered in this study, namely content validity and construct validity (Heale & Twycross, 2015).

Content validity refers to the extent to which an instrument covers the content it is intended to cover. A subset of content validity is *face validity*, where experts are consulted to determine whether an instrument measures the content it is intended to measure. Content validity can be strengthened by clearly demarcating the boundaries of the intended content.

In this study the content was bound by canonical science which defines the topic of the study, namely chemical bonding, and topic specific pedagogical content knowledge for which a clear definition and knowledge components were specified by Mavhunga and Rollnick (2013). Experts in the fields of chemistry and chemistry education formed part of a reference group who were consulted to establish face validity.

Construct validity refers to whether inferences can be drawn from test scores related to the concept being tested (Heale & Twycross, 2015). If a person obtains a high score on a test, does it mean that this person truly has a high level of knowledge? Evidence for construct validity can be gathered by showing that the instrument measures a single underlying construct (unidimensionality) and that the result of the test instrument is aligned with the theoretical assumptions of the construct. For example, it is expected that knowledge of conceptual teaching strategies would be the most difficult component for TSPCK since it requires teachers to draw together their knowledge of all the other components. It is also expected that experienced teachers would find the TSPCK items less challenging than the conceptual content knowledge items, as research studies have shown that TSPCK develops with experience (Van Driel, De Jong, & Verloop, 2002), and that teachers often have misconceptions about the topic they teach (Nicoll, 2001).

Reliability

Reliability refers to the accuracy of the instruments used – the extent to which an instrument consistently produces the same results if it is repeatedly used in similar situations. A person completing the same test more than once should obtain the same result each time. The reliability of an instrument can be indicated by showing a high degree of internal consistency and equivalence (Heale & Twycross, 2015).

Internal consistency refers to the extent to which the items on a scale measure one construct. Internal consistency is most often reflected by Cronbach's coefficient alpha (KR-20) (Cortina, 1993; Nunnally, 1978), where a value >0.80 indicates good internal consistency, and a value >0.90 provides evidence of a highly consistent instrument. A further measure of internal consistency of an instrument is the person and item separation indices (Linacre, 2014). Accurate measurement requires a wide spread of person ability, as well as a wide range of item difficulty. *Winsteps* calculates person and item separation and reliability indices. A person separation index >2.0 and person reliability index >0.8 provides a measure of a reliable test. An item separation index >3.0 and item reliability index >0.9 are also indicative of a high measure of test reliability (Linacre, 2014).

Equivalence is assessed through inter-rater reliability. A reliable test is one which is independent of the test evaluator. The level of independence can be determined by comparing assessment from different test evaluators and reporting the inter-rater reliability as represented by Cohen's Kappa (McHugh, 2012). McHugh (2012) suggests Kappa values between 0.60 and 0.79 to denote moderate agreement, with values between 0.80 and 0.90 suggesting strong agreement, and values >0.90 as almost perfect agreement.

Evidence for content and construct validity, as well as internal consistency and equivalence, are provided in Chapter 4, where the development and validation of the measuring instrument are discussed in more detail.

3.7.2 Trustworthiness of qualitative data

Trustworthiness is a concept introduced by Lincoln and Guba (1985) to represent many of the quality measurements in qualitative research. The authors identify four criteria for trustworthiness of qualitative data, namely credibility, transferability, dependability and confirmability.

Credibility

Credibility is defined as the extent to which findings are congruent with the data presented (Lincoln & Guba, 1985). Human beings are the primary instruments of data analysis in qualitative research and carry inherent biases which makes them unable to capture the objective truth (Merriam, 2009). However, qualitative researchers can use a number of strategies to increase the credibility of their findings.

Triangulation is the most common strategy used. Triangulation includes the use of multiple data collection methods, multiple data sources, multiple investigators and multiple theories (Cohen et al., 2011)

The use of different data collection methods and data sources strengthens the credibility of the findings as findings from one data source can be validated by findings from a different source. This study used different data collection methods, both quantitative (questionnaires) and qualitative (interviews) data collection tools, and multiple data sources (questionnaire responses, interview transcripts, and story-line graphs). Data were also collected at different points in time to ensure that deductions are not based on one-off events.

I was the main investigator in this study. Since I am an experienced physical sciences teacher my involvement was viewed as a strength in this study. Familiarity with the culture of participants increases the credibility of a study (Shenton, 2004). However, my background can also introduce bias. To reduce researcher bias a reference group consisting of content experts, education research experts and teachers were set up. Throughout the data analysis process various members of the reference group were consulted. They were part of the instrument design process, they moderated the questionnaire responses, assisted in analysing the interview data and were part of the cross-case analysis. This process increased accountability, helped me sharpen the process of analysis and deduction and reduced personal biases and false perceptions that may lead to invalid conclusions.

The same data (for example questionnaire responses) were also analysed using different methods (an item analysis and an explanatory framework analysis) to triangulate findings, as was described in earlier in this chapter. The reliability of coding the participants' responses from the questionnaires was established through discussions, and by including co-researchers in the coding process. Sample responses were coded until consensus was built around the interpretation and application of the categories and operational definitions, and inter-rater reliability measures were recorded.

Lastly, credibility is strengthened when participants have the freedom to choose to participate (Shenton, 2004). Teachers were invited and had the choice to take part or not. Many teachers chose not to participate. During the interviews I aimed to establish rapport with the participants and made it clear that there are no right or wrong answers, and that they are participants in the research project and not 'subjects of an experiment'. The semi-structured design of the interviews was also such that participants could choose what they wanted to include in their story-line interviews.

Transferability

Transferability in qualitative studies can be compared to external validity in quantitative research, and can be defined as the extent to which the findings of one study can be applied to other situations (Merriam, 2009). Lincoln and Guba (1985) assert that in comparison to how a quantitative researcher establishes external validity by determining statistical confidence limits, the qualitative researcher can only provide thick descriptions of the context, making it possible for researchers wishing to replicate findings to make judgements about the extent to which the study is transferable.

Yin (2003) argues that case studies tend to seek analytical generalizability rather than statistical generalizability. Analytical generalizability refers to the case's ability to contribute to the expansion and generalization of the theory. A single case can help the researcher understand cases or situations which are similar. It therefore provides the opportunity to test a theory in more than one empirical case rather than generalise the findings of a few cases to others in general. In this study the teachers could represent many other teachers with similar teaching experience and qualifications, teaching the same content and working in similar circumstances.

Dependability

Dependability in qualitative research is analogous to reliability in quantitative research. Lincoln and Guba (1985) argue that since there can be no validity without reliability (in quantitative research) credibility cannot be shown without showing dependability. A demonstration of credibility should be enough to establish dependability. However, researchers should be explicit about how they have established both aspects of trustworthiness in their studies (Shenton, 2004). The inclusion of an audit trail showing how the data was gathered and processed can enable other researchers to repeat the work if necessary. In this study a detailed description of the research design and sample selection have been provided. The design and final versions of all the data collection tools were included, and the various coding schemes and data analysis procedures were also described in detail (see Chapters 4-6 and the Appendices).

Confirmability

The concept of confirmability is comparable to objectivity in quantitative research (Shenton, 2004). Although it is acknowledged that the researcher can never be fully objective in qualitative research, steps must be taken to help ensure as far as possible that the work's findings are the result of the experiences and ideas of the participants, rather than the characteristics and preferences of the researcher. As mentioned above, triangulation can play an important role to reduce researcher bias. As previously discussed, multiple data collection methods and data sources, as well as triangulation of data analysis approaches, were employed to reduce researcher bias and ensure that the findings and deductions emerge from the data and not from the researcher's own ideas.

3.8 Research ethics

Throughout the study I strived to protect the rights of the participants and ensure that the results and consequences of this study do not cause harm to any of the participants. Ethical clearance from the University of Cape Town was obtained prior to commencing with this study. A copy of the ethics application is included in Appendix 11.

The following measures were put in place to protect the rights of the participants:

Informed consent and voluntary participation

Teachers were invited to participate in the study. Participation was therefore voluntary and took place in the teachers' free time. The participants were able to withdraw from the study at any stage without the need to justify themselves. It can be noted that none of the participants withdrew from the study. The participants were also fully informed about the purpose of the study, as well as the procedures and time involved. Informed consent was obtained from all participants.

Privacy and confidentiality

All communication with the teachers, including documents, recordings and transcripts of interviews, were handled confidentially, and were not made available to anyone except those directly involved in the study. To ensure anonymity the teachers' names and the names of the schools involved were replaced with pseudonyms in this document.

3.9 Conclusion

The focus of this study was to map the learning trajectories of physical sciences teachers as they reflect on how and why their topic specific knowledge for teaching chemical bonding shifted over their careers. The study aimed to investigate teacher knowledge and teacher learning, both complex phenomena which are best captured by using different research approaches. A sequential mixed methods design, employing survey and case study approaches, was chosen as the research design for the study. Quantitative data analysis was followed by a series of qualitative analysis techniques to gain insight into the teachers' perceived shifts in knowledge for teaching.

The study was divided into three stages. The first stage involved the design of a valid measuring instrument for TSKFT. Seventeen physical sciences teachers took part in the survey and the statistical analysis of their questionnaire responses using the Rasch measurement model provided evidence for the validity of the measuring instrument.

In the second stage the validated measuring instrument was administered to a further 60 participants. As in the first stage, ordinal data were converted into linear measures using the Rasch measurement model, and statistical analyses provided a measure of the extent and quality of the teachers' TSKFT. A differential item functioning (DIF) analysis identified a number of factors which influenced the teachers' TSKFT. The subsequent qualitative item analysis and explanatory framework analysis of the questionnaire responses provided a deeper understanding of how the factors influenced the teachers' TSKFT.

The third stage of the study involved interviews with a selected group of ten teachers to further gain insight into how and why they perceived their TSKFT to shift over time. A thematic analysis of the teachers' interview transcripts and story-line graphs, followed by a more detailed PCK episode analysis, revealed how various factors influenced the teachers' perceived shifts in TSKFT. The final cross-case analysis synthesized the findings from the second and third stages to answer the overall research question, by identifying various learning trajectories for the teachers.

A number of different measures were put in place to ensure high quality data for this study. These measures informed the entire study, including the choice of methodology and research methods, the design of data collection tools, the sampling choices, and the data analysis procedures. In the next three chapters, the findings from the three stages are presented, followed by the final cross-case analysis and discussion in Chapter 7.

Chapter 4 The development of a valid instrument for measuring topic specific knowledge for teaching chemical bonding

Chapter 2 situated the study within the larger context of research into teacher knowledge, its development and the tools to measure and describe what teachers know about teaching specific topics. It also provided a framework for identifying and analyzing topic specific knowledge for teaching. Chapter 3 described the methodological underpinnings for the study. This chapter describes the development of a valid and reliable measuring tool for topic specific knowledge for teaching chemical bonding to answer the first research question in this study.

4.1 Introduction

The first three chapters of this thesis outlined the purpose, theoretical underpinnings and methodological rationale for this study. The boundaries within which the study takes place, namely knowledge for teaching a specific topic, has been outlined and framed within the larger framework for teacher professional knowledge.

Before embarking on investigating and mapping the learning trajectories for teachers' topic specific knowledge for teaching (TSKFT), a valid and reliable instrument for measuring such knowledge needs to be designed. The first research question was formulated to address this requirement.

TSKFT is conceptualised as comprising of two domains, namely content knowledge of the topic (CK), and knowledge of transformation of the content for the purpose of teaching (TSPCK). Measuring tools for CK and TSPCK have been designed for other topics, for example in chemical equilibrium (Mavhunga & Rollnick, 2013), electrochemistry (Ndlovu, 2014), organic chemistry (Davidowitz & Vokwana, 2014), particle model of matter (Pitjeng, 2014), stoichiometry (Malcolm & Mavhunga, 2016), and electric circuits (Zimmerman, 2016). These studies provide evidence that valid tools for measuring these constructs can be designed. The measuring instrument for this study followed a similar design process to the abovementioned studies, and consisted of items probing the teachers' understanding of chemical bonding per se (CK), as well as teachers' knowledge of transforming the content for the purpose of teaching (TSPCK).

This chapter provides an overview of the design process and then describes in detail how each of the steps were executed, while paying attention to content and face validity (Cohen et al., 2011). The chapter concludes with a statistical analysis to provide evidence for construct validity and test reliability (Linacre, 2014).

4.2 Overview of the design process

The development process for the measuring instrument largely followed the 'rational method' of constructing a test (Oosterveld & Vorst, 1996), where the focus was on optimizing content validity in a logical and intuitive way.

Empirical data and judgements of experts are of particular importance in the item construction process (Rohaan et al., 2009). For this reason a reference group was assigned. The reference group consisted of six individuals. Two individuals (RG1 and RG2) had many years' experience as teacher educators, and were considered to be education specialists. RG1 was the supervisor for this study and has extended teaching experience as a school teacher before becoming a teacher educator. RG2 was the co-supervisor for this study and has extended experience as teacher educator and in the design of measuring instruments for TSPCK, and supervising research projects on the development of PCK.

Two further individuals were included as content and teaching specialists (RG3 and RG4), as they both have PhDs in chemistry and have had many years' teaching experience teaching first year chemistry at tertiary level. They have both been recipients of awards in teaching excellence at their respective universities. Both individuals were also chemistry education researchers, and were included in this group for their content expertise, as well as their teaching experience at tertiary level. RG4 had also been the supervisor of a research project on the development of a measuring instrument for TSPCK in organic chemistry, and thus provided additional insight to the instrument design process.

Lastly, two high school chemistry teachers were included (RG5 and RG6). RG5 had many years' teaching experience at high school level and is a native English speaker. RG6 had only one year teaching experience, and was an English second language speaker. RG6 was included to provide the perspective of an early career teacher, as well as for his ability to comment from a language perspective.

Similar to Rohaan et al. (2009), the development of the instrument followed a multi-step process. The focus throughout the design process was to produce a test that was both valid and reliable, and which can be used to assess group performance. This was necessary since the focus of the research study was to investigate learning trajectories for groups of teachers. An overview of the design process is presented in Figure 4.1.

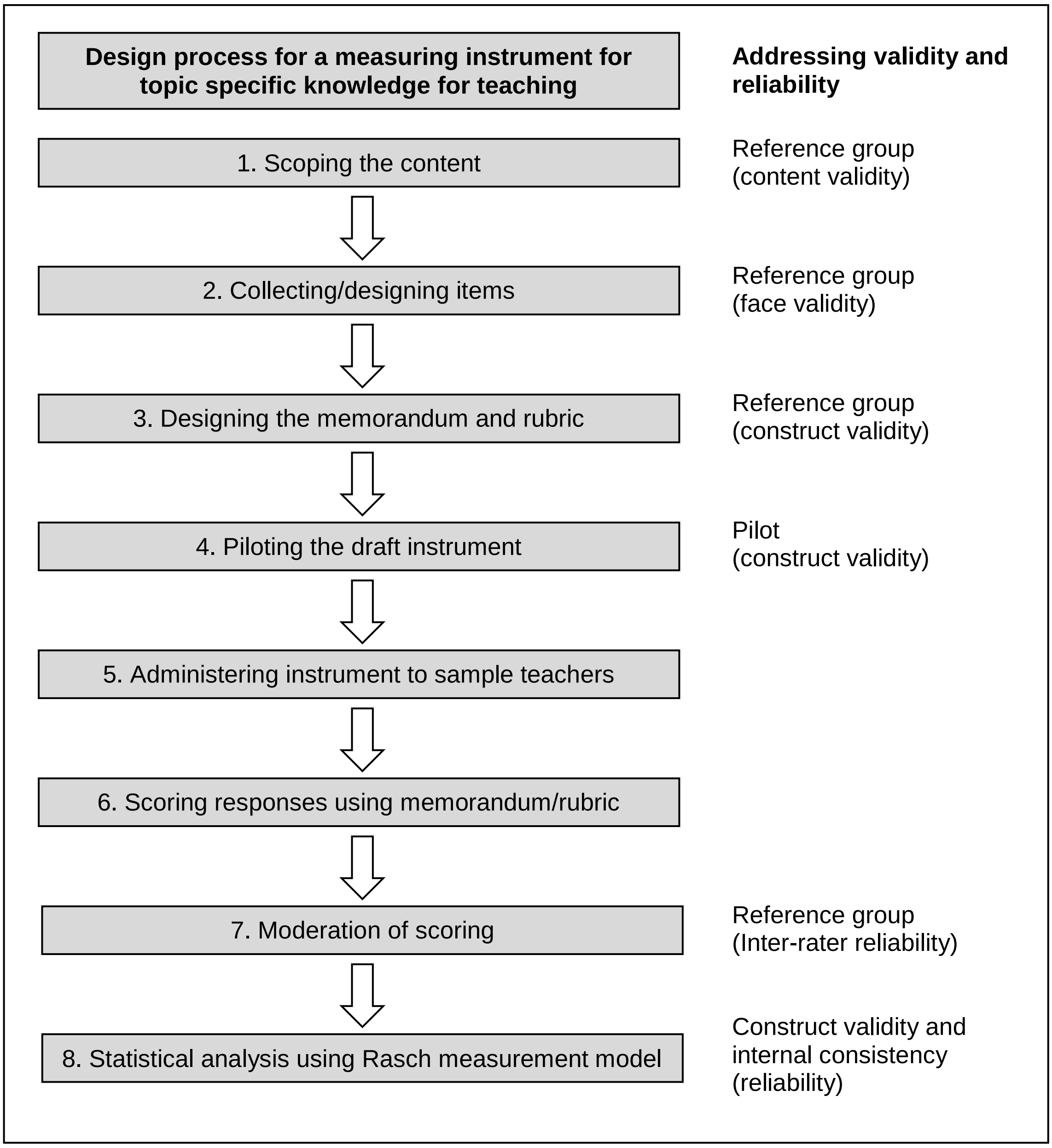


Figure 4.1 Process flow diagram for the development and validation of an instrument to measure topic specific knowledge for teaching chemical bonding

Each step of the process outlined above will now be discussed in more detail.

4.3 Stage 1: Scoping of the content

The first step in the design of a valid instrument is to ensure the adequate and representative coverage of the content, as this is essential for content validity. The content for the chemical bonding instrument included content from both the content knowledge (CK) and topic specific pedagogical content knowledge (TSPCK) domains.

The scope and depth of CK were guided by two main sources. The first was the South African curriculum documents. The two latest curriculum documents for physical sciences, namely the National Curriculum Statement (NCS) Grade 10-12 Physical Sciences (DBE, 2003) and the Curriculum and Assessment Policy Statement (CAPS) Grade 10-12 Physical Sciences (DBE, 2011a), were consulted. Basic knowledge about atoms and atomic combinations are learned in Grade 8 and 9, with basic chemical bonding models taught in Grade 10 and expanded upon in Grade 11. In Grade 11 more emphasis is also placed on the bonding continuum and viewing bonding as an electrostatic force between positive and negative ions. Electronegativity, polar bonds, intermolecular bonds, and the link between energy and bonding are also covered in Grade 11. Extracts from the curriculum documents can be found in Appendix 12 (NCS) and Appendix 13 (CAPS). The second source for CK was the work of Taber, who published a large number of papers on the teaching and learning of chemical bonding (for example, Taber & Coll, 2002; Taber & Watts, 1996; Taber, 2003), and produced a set of resource materials for the Royal Society of Chemistry on alternative conceptions and confronting them in teaching (Taber, 2002). These resources are framed in terms of the big ideas for the topic, and are well-known and widely used.

The initial decision was to include the full spectrum on interatomic interactions, including chemical bonding theories, intermolecular bonds, and hydrogen bonding, as the content scope. This would provide the full bonding spectrum, and knowledge about the continuum across all bonds types could be probed. However, it also represents a very large body of knowledge. After consultation with members of the reference group, it was decided to narrow the scope and only use content covering the basic concepts for chemical bonding in Grades 10 and 11, and not any content on intermolecular bonds or hydrogen bonding. The following topics, based on the big ideas for teaching chemical bonding, were therefore covered:

- The nature of a chemical bond (what is a chemical bond and why bonding takes place) (question CK2 in the instrument).
- Basic chemical bonding models, namely covalent bonding, ionic bonding and metallic bonding. This includes the bonding continuum from pure covalent, through polar bonds, to ionic bonding, including electronegativity, but excluding intermolecular bonds (questions CK3, CK4 and CK5).
- The link between physical properties, energy and bonding (questions CK4 and CK5).
- Alternative conceptions based on the content mentioned above and outlined in the literature review on the teaching and learning of chemical bonding in Chapter 2 (question CK1).

The content for the TSPCK items was guided by the Mavhunga and Rollnick model (2013), as it provided a clear definition and useful categories for the identification of the transformation of content for the purpose of teaching. The components were described in detail in the literature review in Chapter 2, and are listed here for ease of reference. The instrument included items on each of the following components:

- Representations (REP)
- Curricular saliency (CS)
- What is difficult to teach (WDT)
- Student prior knowledge, including misconceptions (LPK)[4]
- Conceptual teaching strategies (CTS)

The teachers' knowledge about the abovementioned content areas were probed in the CK part of the instrument, and then their knowledge of transforming the same content was probed in the TSPCK part of the instrument. The content covered in the CK questions therefore corresponded to the content needed to answer the TSPCK items. For example, the teachers' knowledge about the bonding found in graphite was probed in the CK section, and how they would teach about graphite in the TSPCK section; or teachers' conceptions of ionic bonding was probed, as well as their ability to identify student alternative conceptions. Once the content was specified, the next step was to identify suitable items to adequately cover the content areas.

4.4 Stage 2: Collecting and designing items

Chemical bonding is a central topic in chemistry (Coll & Taylor, 2002; Levy Nahum et al., 2007), and forms part of every introductory chemistry course. Since the 1980s a substantial amount of research has been done on identifying alternative conceptions in chemistry, and chemical bonding was one of the topics covered (Coll & Treagust, 2003a; Taber, 2002; Tan & Treagust, 1999).

4.4.1 Collecting and designing of CK items

For the purpose of the CK item design, the literature was searched to find suitable test items. Tan and Treagust (1999) designed and validated a two-tier instrument probing alternative

[4] The term 'learner' was used throughout the questionnaire as this is term familiar to teachers in South Africa, however, 'students' is used throughout this thesis.

conceptions in chemical bonding. Four of the items (Items 1, 3, 5 and 6) were considered appropriate for this instrument. The other items probed content that was outside the content scope and chosen alternative conceptions for this study, and were therefore not included. This formed the first CK question (CK1). An example is shown in Figure 4.2, and the complete questionnaire is included in Appendix 14.

1.2 Element C (electronic configuration 2,8,8,18,2) and element E (electronic configuration 2,7) react to form an ionic compound CE_2.

A TRUE

B FALSE

Reason:

1. The atom of C will share one pair of electrons with each atom of E to form a covalent molecule CE_2.
2. A macromolecule is produced consisting of covalently bonded atoms of C and E.
3. Atoms of C will each lose two electrons and twice as many atoms of E will each gain one electron to form an ionic compound CE_2.
4. An atom of C will lose one electron to an atom of E to form an ionic compound CE.

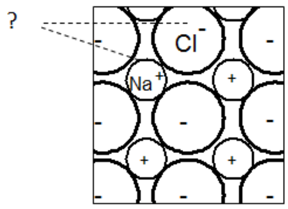
Figure 4.2 Example of a two-tier multiple choice question (from Tan and Treagust (1999))

For the second CK question (CK2), the teachers' knowledge about the nature of a chemical bond was probed. Two options for this question were included in the first draft of the instrument. The first option was taken from Taber (2002), and is shown in Figure 4.3. A diagram representing a particular type of bond was provided, and teachers were asked to identify and describe the interactions involved. Similar questions to the example in Figure 4.3, probing the other bonding models, were also included in the draft instrument.

2.2 The diagram on the right represents part of a layer in a sodium chloride lattice. Which, if any, of the following labels can be used to identify the interaction between the two parts of the system shown:

	Yes?	No?	Unsure?
Attraction	☐	☐	☐
Force	☐	☐	☐
Bonding	☐	☐	☐
Chemical bond	☐	☐	☐

(please tick one box in each row)



Do you think this type of interaction is given a particular name/label? If so, how would you label this type of interaction?____

Describe this interaction in your own words. Give as much detail as you can:

____

____

____

Figure 4.3 Example of a question on ionic bonding (from Taber (2002))

An alternative question was designed for CK2. The question was shorter and more concise in probing the nature of a chemical bond (see Figure 4.4). Both options were included in the draft questionnaire for discussion with the reference group.

Question 2: (alternative)

2.1 What is a chemical bond?

____

____

____

2.2 Draw a picture to illustrate your answer above.

2.3 Why do atoms bond with each other?

____

____

____

2.4 Can the bond between two atoms be both covalent and ionic? Explain your answer.

____

____

____

____

Figure 4.4 Example of open ended question probing the nature of a chemical bond

The last three questions, CK3, CK4 and CK5, probed the teachers' understanding of chemical bonding models. New questions had to be designed, since most of the available instruments for chemical bonding probed alternative conceptions and not content knowledge per se. Each question probed a different bonding model, namely covalent bonding (CK3), metallic bonding (CK4.1 & CK4.2), and ionic bonding (CK5.1). The CAPS curriculum also emphasises the link between chemical bonds and physical properties of materials, and this aspect was included in CK4.3 and CK5.2. Item CK4.3 referred to the kind of bonding model in aluminium, and asked the teachers to explain the malleability of metals by referring to the bonding model found in metals. CK5.2 required teachers to explain why solid magnesium bromide has a high melting point.

The draft instrument was then given to the two chemistry teachers from the reference group, RG5 and RG6. The teachers were asked to write the test, after which the items were discussed and problem areas identified. For example, CK1.2 used strontium as an example (Element C in Figure 4.2). The teachers felt that this was outside the curriculum and it was changed to calcium, an element with similar electronic configuration and electronegativity. The first option for CK2 (see Figure 4.3) was taken out, mainly to reduce the length of the instrument and the wordiness of the question. The teachers further noticed that only covalent and ionic bonding was covered in CK1, and as a result an additional question (CK1.3) on metallic bonding was added. This was a newly designed question, also a two-tiered design, similar to the questions already used in CK1. The teachers also requested more writing space and suggested some layout changes for some of the TSPCK items, and these requests were addressed accordingly. The draft instrument was then discussed with the content and education experts in the reference group. Item CK4.3 was felt to be too narrow in scope and it was broadened by giving teachers more options to choose from. The first version read: ‘Make use of the properties of this bond and explain why a piece of aluminium is malleable’. This was changed to: ‘Aluminium is malleable, ductile and conducts electricity. Based on the type of bonding you described in 4.2, explain one of these properties of aluminium’. One of the content experts, drawing from her experience in designing a similar test for organic chemistry, also felt that the instructions to the first question needed to be clearer and space for answers was needed. This was changed as can be seen in Figure 4.5.

Chemical Bonding Content Knowledge

Question 1: For each of the questions below, choose an option from A or B, and a reason for your choice from 1, 2, 3 or 4. Circle your answer in the space provided, e.g.

A (B)	1 2 3 (4)

1.1 Sodium chloride exists as a molecule.

A TRUE

B FALSE

My reason for choosing A or B is:

1. The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.
2. After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chlorine ion.
3. Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.
4. Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

My answer is:	A B	1 2 3 4

Figure 4.5 Modified instructions to CK1 and space for teachers’ answers

4.4.2 Collecting and designing TSPCK test items

Research literature about the teaching of chemical bonding in South Africa (Roche, 2013; Sibanda & Hobden, 2015) and other countries, for example Sweden (Bergqvist et al., 2016) and Croatia (Vladusic et al., 2016), was consulted for the design of the TSPCK items.

A number of similar instruments for CK and TSPCK have been designed, as was mentioned in the introduction. The guidelines provided by these prior studies were very useful in the design of items for the chemical bonding instrument. To ensure adequate coverage of the TSPCK content, five sections, each covering a different component of TSPCK, were included as follows:

Section 1: Representations (REP)

Teachers were provided with a number of representations which are commonly used to represent chemical bonding content. In the first item teachers were asked to identify the strengths and weaknesses of each representation as a teaching tool (Q1.1). They were asked to identify the representation they prefer, provide a reason for their choice (Q1.2a&b), and explain how they would use it in teaching about chemical bonding (Q1.2c). Teachers also had the option of providing their own preferred representation, and then explain why they chose it.

In the first draft eight different representations were included. The representations included various bonding models, as it is known that teachers are unaware of the importance of models in the teaching of chemistry (Bergqvist, Drechsler & Chang Rundgren, 2016). It also covered all three levels of representing chemistry according to Johnstone (1991), namely symbolic, sub-microscopic, and macroscopic. After discussion with the reference team only six of these representations were retained. Representations were sourced from the literature (for example Gilbert & Treagust, 2009), school textbooks to make it familiar to teachers, and first year level textbooks. A Google image search also provided a wide variety of representations to choose from. Representations 1 and 6 were symbolic representations, 2 and 3 were sub-microscopic, and 4 and 5 can be considered macroscopic. This was the first question in the instrument. It was anticipated that this would be the most familiar question, and therefore the easiest, so it was placed first to put teachers at ease. The six representations are included in the draft instrument in Appendix 15.

Section 2: Curricular Saliency (CS)

Curricular saliency refers to a teacher's knowledge about identifying and sequencing the big ideas for teaching a topic. It also includes knowing which ideas are more important, how these big ideas and sub-ordinate ideas are related, and why the topic is important to learn.

For the CS items a list of ideas, in the form of propositional statements, were provided. Teachers had to choose three statements which, in their opinions, were the most important ideas that underpin the content, and which were central in teaching for understanding chemical bonding (CK2.1). Teachers then had to sequence their chosen ideas and provide reasons for the sequencing (CK2.2). The next question asked them to draw a mind map to show how these concepts are related (CK2.3). The last question probed their thinking about why they considered chemical bonding an important topic to learn (CK2.4).

The list of the big ideas and sub-ordinate ideas from CK2.1 is provided in Figure 4.6.

A. Ionic bonding takes place when electrons are transferred.
B. The chemical bonds in a substance determine its structure.
C. A chemical bond is an electrostatic interaction between a positive and a negative charge.
D. Energy is required to break bonds and energy is released when bonds are formed.
E. Electronic structure influences how atoms bond.
F. Polar covalent bonding takes place when electrons are shared unequally.
G. Chemical bonds are formed to create stability.
H. Substances may be molecular or network structures.
I. There is a spectrum of electron sharing in chemical bonds.
J. Sodium chloride forms a three-dimensional crystal structure due to ionic bonding.
K. Covalent bonding takes place when electrons are shared equally.

Figure 4.6 List of big ideas and sub-ordinate ideas in chemical bonding

Individual semi-structured interviews on the teaching of chemical bonding were conducted with two experts (RG3 and RG4) from the reference group. This was to elicit their views on the big ideas in teaching chemical bonding, what is difficult to teach, prior knowledge required by students before they can learn about chemical bonding, and conceptual teaching strategies. The interview protocol is included in Appendix 16. Sources such as Taber & Coll (2002), Slotwinski (1997a, 1997b) and Dilley (1991), were also consulted to identify the big ideas for teaching.

A list of 20 propositional statements was then formulated, and after further consultation with the education experts (RG1 and RG2), agreement on the four most important statements was reached. Ideas B, C, E and G were considered the most important big ideas. A further seven statements were chosen as sub-ordinate ideas. This formed the final list for the draft instrument as shown in Figure 4.6.

Section 3: What is difficult to teach (WDT)

Knowledge about what is difficult to teach is important when planning to teach a topic (De Jong et al., 2005). In this section teachers were provided with concepts that were thought to be difficult to teach. Teachers were asked to choose any three of the given concepts and explain why they thought it was difficult to teach. The initial list included three concepts which were drawn from my own experience teaching about chemical bonding. Three additional spaces where provided for teachers to fill in their own ideas. After consultation with the reference group (RG1, RG2 and RG4) it was felt that more guidelines should be provided. Five concepts were therefore included (metallic bonding, ionic bonding, polarity of bonds, bond energy and what is a molecule) with space for an additional two concepts should teachers want to add their own ideas.

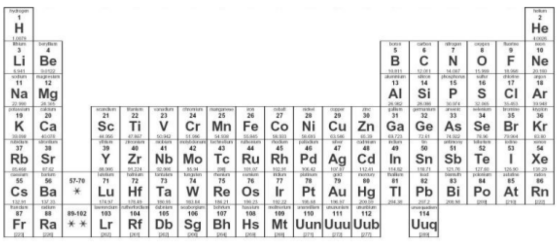
Section 4: Student prior knowledge (LPK)

Items in this section needed to probe teachers' knowledge of what their students know and are required to know before the topic is taught. This includes teachers' knowledge of student alternative conceptions, as well as teachers' knowledge about how to address alternative conceptions in teaching.

The first item under LPK probed the teachers' knowledge about which concepts are most important for students to act as prior knowledge for learning about chemical bonding. An open-ended question into the required prior knowledge for bonding was formulated (see Appendix 15) and discussed with content experts RG3 and RG4. From the discussion knowledge about the periodic table was identified as the most important prior knowledge that is necessary before chemical bonding is taught. Five ideas within the topic of the periodic table were formulated from the discussions with the experts, and these were given to teachers as options to choose from. Teachers had to choose the most important single idea that they considered essential as prior knowledge for chemical bonding (question Q4.1 in Figure 4.7). They were also required to give reasons for their choice (Q4.1b), and to explain how they would use their choice in a lesson (Q4.1c).

Section 4: Learners' prior knowledge

4.1 Learners need to know about the Periodic Table before chemical bonding can be taught. Some of the ideas that are discussed in the section on the Periodic Table are shown below. Which one of these is the **most important** when **you teach** about chemical bonding for the **first time**? Give a **reason** for your answer and explain **how you would use it** in your teaching.



A: Metals are on the left hand side and non-metals are on the right hand side of the Periodic Table.

B: Elements in the same group have similar chemical properties.

C: The electronic configuration of atoms can be deduced from the Periodic Table.

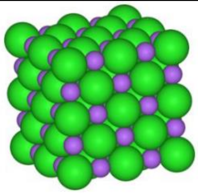
D: The properties of substances can be deduced from the position of the elements in the Periodic Table.

E: Noble gases are found in group 18 and have a full electron shell.

Figure 4.7 Question 4.1 on teachers' knowledge of student prior knowledge

The second LPK item probed teachers' knowledge of student alternative conceptions in chemical bonding (Q4.2). Knowledge of students' naïve conceptions is an important starting point to move students forward in their understanding of a concept. Shulman (1986) highlighted this in his original conceptualisation of PCK, and a substantial amount of research has been done to identify students' alternative conceptions over the past three decades (for example Driver, Asoko, Leach, Mortimer, & Scott, 1994). The topic of ionic bonding is known for many alternative conceptions (Özmen, 2004) and was chosen as the content for this section. For this item a classroom scenario is sketched, and three hypothetical student statements were provided. Teachers were asked to identify and explain the problem with each statement. The three items were taken from the instrument designed by Taber (2002), and since they were all students' statements, they were used as is. One example is included in Figure 4.8, and the complete question can be found in Appendix 15.

4.2 In a class test learners were asked to explain ionic bonding in a sodium chloride crystal lattice. The following answers are from learner scripts. Each answer contains a misconception or incorrect statement.



Identify and **explain** the problem with each statement.

Statement from the learner	Identify and explain the problem with each statement.
A chloride ion is attracted to one sodium ion by a bond and is attracted to up to five other sodium ions just by forces.	

Figure 4.8 LPK question on teachers' knowledge of student alternative conceptions

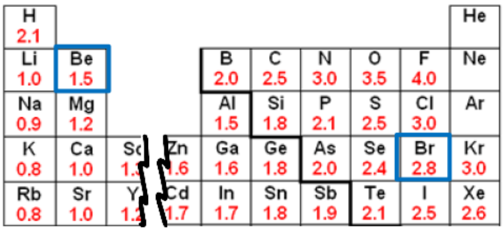
Section 5: Conceptual teaching strategies (CTS)

TSKFT describes the knowledge that teachers possess and draw from when planning for teaching (Aydeniz & Kirbulut, 2014). It is therefore important to ground items in classroom practice. For the items on conceptual teaching strategies, this was even more prominent as teachers needed to bring together their knowledge of all other components when they respond to the CTS items.

Teaching scenarios were provided for the CTS items, as can be seen in Figure 4.9. The first item was drawn from my experience as a teacher and covers the bonding dichotomy (Q5.1). The second item highlights the link between chemical bonding and the physical properties of materials, a link that is strongly emphasised in the CAPS curriculum (DBE, 2011a) (Q5.2). In both the items teachers were asked to describe how they would teach about the issue at hand. They were asked to specifically elaborate on which content they would include, the order of teaching the content in, the ideas that students typically find difficult and how they would address these, and the representations, analogies, examples or pictures that they would use in their teaching.

5.1 During a lesson, a learner asks the following question:

He read on the internet that beryllium bromide ($BeBr_2$) forms an ionic bond because it is a bond between a metal and a non-metal. However, the Periodic Table shows the electronegativity difference between the atoms as 1.3, which makes the bond a covalent bond, according to the rule they have learned in class: 1,3 is less than 1,7, the 'cut-off value' for ionic bonds. Which type of bond is formed in beryllium bromide?



How would you teach about this in a lesson? Consider the following in your response: what teaching strategy will you follow, what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, examples or analogies will you use.

Figure 4.9 Question 5.1 from the CTS section of the instrument

The draft instrument (Appendix 15) was now ready for the piloting stage. Table 4.1 summarises the content covered by all the items, and the accompanying codes used for analysis. The input from the reference team played an important role in the design of items for the draft instrument, and provides justification for face validity and content validity. Professional judgements were made about which items were deemed most suitable for inclusion in the draft version of the instrument. Frequent discussions with the reference group, especially the education experts, took place throughout the design of the items. The next step was to design the marking memorandum and scoring rubric.

Table 4.1 Summary of the content covered in the chemical bonding instrument

TSKFT	Type of question	Question number	Item code	Description of the item
Content knowledge (Alternative conceptions in chemical bonding)	Two-tier multiple choice	CK1	CK1.1 CK1.2 CK1.3 CK1.4 CK1.5	Alternative conceptions: Metals and non-metals form molecules Ionic compounds exist as molecules formed by covalent bonding Atoms in a metal 'provide' the physical properties In graphite, atoms are delocalised, and can slip over each other to conduct electricity Metals and non-metals form strong covalent bonds
Content knowledge (The nature of a chemical bond)	Open ended	CK2	CK2.1 CK2.2 CK2.3 CK2.4	What is a chemical bond? Drawing a diagram to illustrate what a chemical bond is Why do atoms bond? Can a bond be both covalent and ionic? (dichotomous view of chemical bonding)
Content knowledge (Covalent bonding model)	Open ended	CK3	CK3.1 CK3.2 CK3.3 CK3.4	Writing a balanced equation for the formation of ammonia Identifying the bonding type in ammonia Describing the bonding type in ammonia Drawing a diagram of the ammonia molecule
Content knowledge (Ionic bonding model)	Open ended	CK4	CK4.1 CK4.2 CK4.3	Identifying the bonding type in aluminium metal Describing the bonding in aluminium metal Explaining a physical property of aluminium metal
Content knowledge (Metallic bonding model)	Open ended	CK5	CK5.1 CK5.2 CK5.3	Identifying and explaining the bonding type in magnesium bromide Explaining why magnesium bromide has a high melting point Distinguishing between molecular and ionic solids
Representa-tions	Open ended	1.1 1.2a&b 1.2c	REP1 REP2 REP3	Strengths and weaknesses of the representation Choice and reason for choosing representation Use of representation in teaching
Curricular saliency	Semi-closed and open ended	2.1 2.2 2.3 2.4	CS0 CS1 CS2 CS3	Choice of three most important big ideas Ordering of the three most important big ideas Big ideas mind map Importance of bonding
What is difficult to teach	Open ended	3.1	WDT	What is difficult to teach about certain concepts
Student prior knowledge	Semi-closed and open ended	4.1a 4.1b 4.2 4.3	LPK0 LPK1 LPK2 LPK3	Choice of LPK Reason for choice of LPK Use of choice in teaching Identifying alternative conceptions for chemical bonding
Conceptual teaching strategies	Open ended	5.1 5.2	CTS1 CTS2	Teaching strategies for teaching about the bonding in beryllium bromide Teaching strategies for teaching about the bonding in graphite

4.5 Stage 3: Designing the instrument scoring tools

Two tools were designed to score teachers' responses to the items. A marking memorandum was designed for the CK items and a rubric for the TSPCK items.

4.5.1 Designing the marking memorandum for the CK items

A marking memorandum was drafted with the focus on awarding credit for conceptual understanding. The draft memorandum was then discussed with the two teachers from the reference group (RG5 and RG6), and one of the content specialists (RG4), to check for accuracy of the content and appropriate mark allocation. The teachers gave valuable input into possible answers that could be expected, but very few changes to the memorandum were suggested. The comments were mainly around exactly where individual marks should be allocated. Each question added up to a total of 10 marks, with the questionnaire totalling 50 marks. As suggested by the reference group, care was taken to allocate marks to specific aspects within an answer, and specific marks were indicated as such on the memorandum. An example is shown in Figure 4.10. The full draft memorandum is available in Appendix 17.

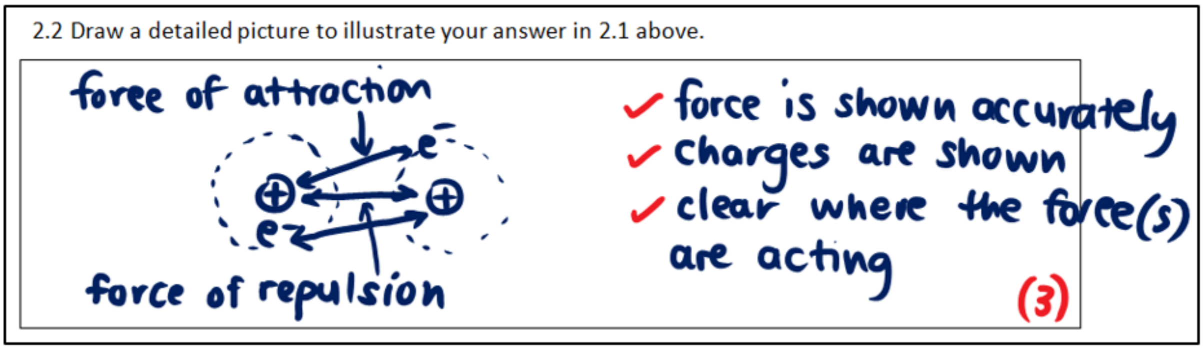


Figure 4.10 An example of the mark allocation for the CK instrument

4.5.2 Designing a scoring rubric for the TSPCK items

The rubric formed an integral part of the instrument design as it was the tool that was used to convert qualitative responses to quantitative data for analysis. The first draft of the rubric was compiled simultaneously with the design of the items for the instrument (stage 2). Notes were made as to the kind of responses that could be expected and initial general descriptors were formulated. Mavhunga & Rollnick (2013) defined four levels of competency for TSPCK, based on categories from Park and Oliver (2008). These level were Limited (level 1), Basic (level 2), Developing (level 3), and Exemplary (level 4). The challenge was to design descriptors that were specific enough to distinguish between different levels of competence, yet general enough to account for the variety in teacher responses. The rubrics for other measuring instruments, for example instruments for organic chemistry (Davidowitz & Vokwana, 2014), chemical equilibrium (Mavhunga & Rollnick, 2013), the particle model of matter (Pitjeng, 2014) and electric circuits (Zimmerman, 2016), were consulted for guidelines on the wording of descriptors. These studies provided descriptors for the quality indicators for each category. The descriptors were also discussed with the education experts (RG1 and RG2) before the pilot version was finalised. An example of the 'What is difficult to teach' (WDT) category is shown in Figure 4.11. Space was provided to code each response under a sub-total (3.1, 3.2 and 3.3 in the example), before deriving an overall total for the category code in the last column.

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Subtotal	Total
What makes topic difficult to teach WDT	3.1 & 3.2 & 3.3 • Reasons not given or not applicable	3.1 & 3.2 & 3.3 • Reasons given are broad or generic and not linked to the specific concept under discussion, for example 'abstract' or 'the learners don't understand'	3.1 & 3.2 & 3.3 • Reasons given are specific and related to prior knowledge of students or common misconceptions	3.1 & 3.2 & 3.3 • Reasons given are specific and related to prior knowledge of students or common misconceptions • Reasons given link the concept with other gatekeeping concepts that when not fully understood adds to the difficulty of the concept regarded as difficult, for example electronegativity linked to polarity of bonds	3.1 3.2 3.3	WDT

Figure 4.11 Extract from the rubric for the WDT category

The draft version of the chemical bonding instrument, accompanying memorandum and rubric were finalised and were ready for use in the pilot stage. The draft versions can be found in Appendices 15, 17 and 18.

4.6 Stage 4: Piloting the draft instrument

The draft instrument was given to six practicing chemistry teachers to complete. The teaching experience from this group ranged from 1 year to 16 years' teaching experience. Teachers worked on their own in the same venue and had unlimited time to complete the instrument. The teachers were then invited to comment on the items. Very few suggestions were made, except for a request to modify the writing space for some questions. The answers from this pilot group were also used to check the memorandum. The mark allocations for some of the questions were revised. The pilot teachers' responses to the TSPCK items were scored using the draft rubric. The responses were of varying depth which assisted in testing the functioning of the rubric categories. Since the pilot group consisted of only six teachers, representative sample answers for each level in each category could not be included for the next version of the rubric. This was done after all the teachers in the final sample were scored.

Changes were made to some rubric descriptors for clarity, for example 'use of the representation contributes to understanding and links to further teaching' was added as an additional descriptor for level 4 in item 1.2b (see Figure 4.12). Heading descriptions, for example 1.1 *Strengths and weaknesses*, were added as indicated in bold in Figure 4.12.

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Subtotal	Total
Representations REP	**1.1 Strengths and weaknesses** • Able to identify appropriate strengths and weaknesses for none or one of the representations. [If the description is detailed, then code as 2.]	**1.1 Strengths and weaknesses** • Able to identify appropriate strengths and weaknesses for two or three of the representations. [If the description is detailed, then code as 3.]	**1.1 Strengths and weaknesses** • Able to identify strengths and weaknesses for four or five of the representations [If the description is very detailed, then code as 4.] • Reasonable reasons without going into specifics [e.g. terms such as 'abstract', limitation/ limited', 'confusion' are used]	**1.1 Strengths and weaknesses** • Able to identify appropriate strengths and weaknesses for all six representations • Appropriate reasons are provided for most representations • Aware of misconceptions being introduced, e.g. anthropomorphism	1.1	REP1
	1.2a Reason for choice • Reason for choice is inappropriate, incomplete, vague or difficult to follow	**1.2a Reason for choice** • Reason for choice is appropriate, but limited to a single consideration	**1.2a Reason for choice** • Reasons for choice include two or more levels of consideration, e.g. ease of use, effectiveness to confront misconception, learner context, explanatory power • Links to the concept are clear and appropriate	**1.2a Reason for choice** • Reasons for choice include more than two levels of consideration as well as limitations of the representation • Links to the concept under discussion are clear and appropriate and includes connections to further concepts	1.2a	REP2
	1.2b Use in lesson • No discussion on how the representation is going to be used or suggested use inappropriate or unworkable	**1.2b Use in lesson** • Suggested procedure lacks logic or clarity or is limited • Teaching approach is basic and does not include a conceptual orientation	**1.2b Use in lesson** • Suggested procedure shows logic and a satisfactory explanation on how the chosen representation is going to be used • There is some evidence of a conceptual orientation	**1.2b Use in lesson** • Suggested procedure is clear, logical and shows strong conceptual orientation • Use of the representation contributes to understanding and links to further teaching.	1.2b	REP3

Figure 4.12 Changes to the rubric after piloting

The instrument, rubric and memorandum were finalised and ready for administering to a larger sample of teachers. The complete instrument consisted of 18 pages (6 pages for CK and 12 pages for TSPCK). A cover letter, letter of consent, and a one-page demographic information page also formed part of the package. These documents are included in Appendices 19-20.

4.7 Stage 5: Administering the instrument to sample teachers for validation

Seventeen physical sciences teachers (seven male and ten female) assisted in the validation of the instrument. The teachers were drawn from two provinces in South Africa, namely Gauteng (six teachers) and the Western Cape (11 teachers). Their teaching experience varied from no teaching experience to 30 years' teaching experience, with an average of 9.6 years (SD = 9.2 years). The demographic information of the participants are shown in Table 4.2. Three participants were not teaching at school level. V6 worked for an education company and is a chemistry school textbook author. V11 was enrolled for an Honour's degree in Education, while V12 was lecturing at a university physics department, and therefore not teaching at school level. His school teaching experience was taken as zero years. Two teachers were teaching at township schools, eight at ex-Model C schools and four were from private schools. The teachers' highest chemistry qualification were spread from a first year level chemistry (Chem1) to an honours or higher level (Chem4), with most of the teachers qualified with a second or third year level chemistry. Five teachers didn't have any teaching qualification, three of whom were mentioned above. V5 and V17 were both enrolled in a PGCE programme. Four teachers had a higher diploma in education (HDE), three teachers had a post-graduate certificate in education (PGCE), and three teachers had a bachelor's degree in education (BEd). The remaining three teachers had an honour's degree in science education (BSc Ed Hons).

Table 4.2 Demographic information for the teacher sample for instrument validation

Teacher code	Gender	Province	Type of school	Teaching experience at school level	Highest chemistry qualification	Highest education qualification
V1	M	WC	Ex Model C	11	Chem3	HDE
V2	F	WC	Ex Model C	19	Chem3	HDE
V3	F	WC	Ex Model C	9	Chem3	PGCE
V4	F	WC	Township	30	Chem2	HDE
V5	M	WC	Private	1	Chem3	No Ed Qual
V6	F	WC	Not teaching	0	Chem4	No Ed Qual
V7	F	WC	Private	2	Chem2	BEd
V8	M	WC	Private	12	Chem3	No Ed Qual
V9	F	WC	Ex Model C	25	Chem3	PGCE
V10	F	WC	Private	2	Chem2	No Ed Qual
V11	M	GP	Not teaching	0	Chem1	BEd
V12	M	GP	Not teaching	0	Chem4	BEd
V13	F	GP	Township	4	Chem2	BSc Ed Hons
V14	M	GP	Ex Model C	15	Chem3	HDE
V15	M	GP	Ex Model C	15	Chem2	BSc Ed Hons
V16	F	GP	Ex Model C	17	Chem2	BSc Ed Hons
V17	F	WC	Ex Model C	1	Chem2	No Ed Qual

4.8 Stage 6: Scoring responses using the rubric

The teachers' responses to the CK items were marked using the memorandum and the TSPCK items were scored with the rubric. The individual raw scores for each teacher on each item are shown in Table 4.3.

A small number of missing responses - 8 out of 578 responses (or 1.4 percent) - were found from teachers who scored very low overall. Missing CK items were allocated zero marks and missing TSPCK items were coded at a level 1, as the assumption was that the teachers did not have the knowledge to answer the question. On average the teachers were at a level 3 (developing) for the TSPCK items, while the average score for the CK items was 70.1 percent.

Table 4.3 Initial teacher raw scores for instrument validation (N=17)

Teacher Code	CK 1.1	CK 1.2	CK 1.3	CK 1.4	CK 1.5	CK 2.1	CK 2.2	CK 2.3	CK 2.4	CK 3.1	CK 3.2	CK 3.3	CK 3.4	CK 4.1	CK 4.2	CK 4.3	CK 5.1	CK 5.2	CK 5.3	REP1	REP2	REP3	CS0	CS1	CS2	CS3	WDT	LPK0	LPK1	LPK2	LPK3	CTS1	CTS2
V1	1	2	2	2	2	3	3	2	2	2	2	2	2	2	4	4	3	3	4	4	4	4	3	4	3	4	4	4	3	3	3	3	4
V2	2	2	0	1	2	2	3	2	2	2	1	2	3	2	2	3	3	2	4	4	3	3	4	4	3	3	4	4	3	2	2	2	2
V3	2	2	0	2	2	2	2	2	2	2	1	2	2	2	3	2	3	2	4	2	2	2	3	3	2	2	2	2	2	2	3	1	2
V4	2	2	2	2	0	3	0	2	0	2	2	3	2	2	3	0	2	1	2	3	3	3	3	3	3	3	3	4	2	2	3	2	2
V5	2	2	0	2	1	1	2	2	1	2	2	2	2	2	1	1	3	1	4	2	2	2	1	2	2	3	2	3	2	2	2	2	2
V6	2	2	2	2	2	2	3	2	3	2	2	3	3	2	3	3	3	3	4	4	3	3	4	4	4	3	3	4	3	3	3	3	3
V7	0	0	1	1	0	1	1	0	2	0	1	1	2	2	1	1	1	1	2	2	2	2	3	2	2	3	1	2	2	2	1	2	2
V8	2	2	2	2	2	2	2	0	2	2	1	1	2	2	3	3	2	3	4	4	3	4	1	2	2	3	3	2	2	2	3	2	3
V9	2	2	1	2	2	3	3	2	2	2	2	1	2	2	3	3	3	2	2	4	2	3	3	3	3	3	4	4	2	2	3	2	3
V10	0	2	1	1	2	1	1	1	2	2	1	1	3	2	1	3	1	1	2	4	2	3	4	3	2	3	2	4	3	2	3	3	3
V11	1	1	1	0	1	1	0	2	0	2	1	1	2	2	2	0	0	1	0	2	2	2	3	2	2	2	1	3	2	2	1	1	1
V12	2	2	1	2	2	3	2	2	2	2	1	2	3	2	3	4	3	3	4	4	4	3	3	3	3	4	4	3	2	3	4	3	3
V13	2	2	1	2	2	3	1	2	2	2	1	3	2	2	4	3	3	3	4	4	2	3	3	3	4	2	2	4	3	3	1	3	3
V14	2	2	1	2	2	2	0	2	0	2	1	2	0	2	3	1	1	2	4	3	3	3	3	2	1	3	3	3	2	3	3	2	3
V15	2	2	2	2	2	3	3	2	2	2	1	1	2	2	4	4	2	3	4	4	4	3	4	3	3	3	4	4	3	3	2	3	4
V16	2	2	2	1	2	2	3	2	2	2	1	3	3	2	3	4	2	1	4	4	4	4	4	4	3	3	4	4	4	4	3	4	3
V17	2	0	2	1	1	1	0	1	1	0	1	1	0	2	2	2	1	1	4	2	3	1	3	3	3	2	2	4	4	2	3	1	2

4.9 Stage 7: Moderation of scores

Once all the responses from the participants were coded, the coding was moderated. One of the education experts (RG2) acted as the moderator. Three scripts were moderated, one low, one medium, and one high scoring teacher (T11, T14 and T16).

The rubric and marking memorandum were discussed with the moderator to clarify any interpretive issues. To ensure consistent application of the rubric and memorandum, one instrument was coded together, and the codes were discussed until agreement on the interpretation of the rubric was reached. The codes were collated in a spreadsheet (see Appendix 21) and submitted for statistical analysis. The average pairwise Cohen's kappa (κ) was calculated using *ReCal* (Freelon, 2010), a free online inter-rater reliability calculator. Inter-rater reliability, as represented by Cohen's kappa, was found to be good ($\kappa = 0.72$) (McHugh, 2012) and the average percentage agreement was 78.8 percent. A summary of the results are shown in Appendix 22.

Reduction of items

Some item reduction took place at this stage, mainly as a result of the discussion of the memorandum and teacher responses to specific items. It was noted that for two of the TSPCK items (Q2.1a and Q4.1a) the teachers had to choose an answer and then explain their choice in the following question. The suggestion was to combine these consecutive items as they probed the same knowledge.

CK items 2.1 and 2.2 also probed the same knowledge. Teachers were asked to firstly describe what a chemical bond is, and then draw a diagram. The suggestion was to combine the two items into one. The same applied to CK3.2 and CK4.1, where teachers had to identify a bond type and then describe it in the next item. Again the items were combined.

Lastly, it was decided that CK3.1 did not test chemical bonding, but rather knowledge of stoichiometry. This item was therefore removed from the test. CK5.3 related to network solids, and as it was felt that this was slightly outside of the content scope, this question was also removed.

Table 4.4 Final raw scores for instrument validation

Teacher Code	CK 1.1	CK 1.2	CK 1.3	CK 1.4	CK 1.5	CK 2.1	CK 2.3	CK 2.4	CK 3.3	CK 4.2	CK 4.3	CK 5.1	CK 5.2	REP 1	REP 2	REP 3	CS 1	CS 2	CS 3	WDT	LPK 1	LPK 2	LPK 3	CTS 1	CTS 2
V1	1	2	2	2	2	4	2	2	4	4	4	3	3	4	4	4	4	4	4	4	3	3	3	3	4
V2	2	2	1	1	2	4	2	2	3	2	3	3	2	4	3	3	4	3	3	4	3	2	2	2	2
V3	2	1	1	2	2	3	2	2	3	3	2	3	2	2	2	2	3	2	2	2	2	2	3	1	2
V4	2	2	2	2	1	3	2	1	3	3	1	2	1	3	3	3	3	3	3	3	2	2	3	2	2
V5	2	2	0	2	0	3	2	1	3	1	1	3	1	2	2	2	2	2	3	2	2	2	2	2	2
V6	2	2	1	2	2	4	2	3	4	3	3	3	3	4	4	4	4	4	3	3	3	3	3	3	3
V7	0	0	0	1	0	2	0	2	2	1	1	1	1	2	2	1	2	2	3	1	2	2	1	2	2
V8	2	2	2	2	2	3	0	2	2	3	3	2	3	4	3	4	2	2	3	3	2	2	3	2	3
V9	2	2	1	2	2	4	2	3	3	3	3	3	2	4	2	3	3	3	3	4	2	2	3	2	3
V10	0	2	1	1	2	2	1	2	2	1	3	1	1	4	2	3	3	2	3	2	3	2	3	3	3
V11	1	1	0	0	1	1	2	0	2	2	1	0	1	2	2	2	2	2	2	1	2	2	1	1	1
V12	2	2	1	2	2	4	2	2	3	3	4	2	3	4	4	3	3	3	4	4	2	3	4	3	3
V13	2	2	1	2	2	3	2	2	3	4	3	3	3	4	2	3	3	4	2	2	3	3	1	3	3
V14	2	1	1	2	2	2	2	1	2	3	1	1	2	3	3	3	2	1	3	3	2	3	3	2	3
V15	2	2	2	2	2	4	2	2	2	4	4	3	3	4	4	3	3	3	3	4	3	3	2	3	4
V16	2	2	2	1	2	4	2	2	3	3	4	3	1	4	4	4	4	3	3	4	4	4	3	4	3
V17	2	0	2	1	1	1	1	1	1	2	2	1	1	2	3	1	3	1	2	2	3	2	3	1	2

Thirteen CK items and twelve TSPCK items remained. The memorandum, rubric and instrument were modified accordingly, and all responses were recoded taking the abovementioned changes into consideration. The final codes for all teachers and 25 items are included in Table 4.4, and were submitted for statistical analysis as described in stage 8.

4.10 Stage 8: Statistical analysis

In this final stage of the development of an instrument to measure TSKFT, evidence for construct validity and instrument reliability was gathered. The Rasch measurement model was used to convert ordinal raw scores to linear measures (Bond & Fox, 2015) using *Winsteps* statistical software, *Ministep* version 3.81.0 (Linacre, 2012).

The Rasch Partial Credit Model was applied to the data, since a polytomous scale was used to score the responses. The following order of analysis, as guided by Linacre (2014) and Tennant and Conaghan (2007), was followed:

1. Item function
2. Category function
3. Dimensionality
4. Item and person misfit
5. Item separation
6. Differential item functioning (DIF)
7. Item difficulty and person performance
8. Instrument reliability

Item Function

The first step in the analysis was to ensure that all items were aligned in the same direction and that all items had positive correlations - high knowledge (exemplary level) should be scored high, and low knowledge (limited level) should be scored low. *Winsteps* provides a point-measure correlation to investigate this. Positive correlations were found for all items and varied from 0.34 to 0.88, as shown in Figure 4.13. This meant that all items were aligned in the same direction.

ITEM STATISTICS: CORRELATION ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASURE-A CORR.	PTMEASURE-A EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	ITEM
21	44	17	-.57	.38	1.20	.7	1.29	.9	.34	.63	64.7	56.2	LPK1
3	21	17	2.67	.37	1.33	1.0	1.41	1.1	.36	.66	35.3	56.5	CK 1.3
7	28	17	1.69	.38	1.10	.4	1.15	.5	.41	.65	64.7	55.9	CK 2.3
1	28	17	1.69	.38	1.02	.2	.94	-.1	.43	.65	52.9	55.9	CK 1.1
9	47	17	-1.00	.38	1.49	1.4	1.53	1.5	.49	.64	58.8	53.4	CK3.3
23	43	17	-.43	.38	1.36	1.1	1.36	1.1	.49	.63	35.3	56.5	LPK3
19	49	17	-1.30	.39	.70	-.9	.71	-.9	.56	.64	58.8	54.5	CS3
4	27	17	1.83	.38	.65	-1.0	.66	-1.0	.57	.65	64.7	55.8	CK 1.4
8	27	17	1.83	.38	1.17	.6	1.10	.4	.58	.65	64.7	55.8	CK 2.4
18	45	17	-.72	.38	.90	-.2	.91	-.2	.60	.64	64.7	55.5	CS2
5	27	17	1.83	.38	.62	-1.2	.57	-1.3	.67	.65	64.7	55.8	CK 1.5
22	42	17	-.29	.38	.48	-1.8	.47	-1.8	.68	.63	64.7	55.9	LPK2
15	48	17	-1.15	.38	.79	-.6	.78	-.6	.69	.64	52.9	52.9	REP2
12	35	17	.70	.38	1.48	1.3	1.49	1.3	.70	.63	35.3	57.7	CK 5.1
2	30	17	1.41	.38	.35	-2.4	.33	-2.5	.71	.65	82.4	56.5	CK 1.2
13	32	17	1.13	.38	1.20	.7	1.21	.7	.71	.64	41.2	57.4	CK 5.2
10	45	17	-.72	.38	1.17	.6	1.20	.7	.72	.64	41.2	55.5	CK 4.2
17	50	17	-1.45	.39	.66	-1.1	.64	-1.2	.72	.65	70.6	55.9	CS1
16	48	17	-1.15	.38	.70	-.9	.71	-.9	.74	.64	76.5	52.9	REP3
24	39	17	.13	.38	.74	-.7	.78	-.6	.75	.63	64.7	56.7	CTS1
11	42	17	-.29	.38	2.27	2.9	2.37	3.0	.79	.63	35.3	55.9	CK 4.3
25	45	17	-.72	.38	.51	-1.7	.51	-1.7	.81	.64	64.7	55.5	CTS2
14	56	17	-2.41	.42	.87	-.3	.73	-.7	.84	.63	70.6	62.7	REP1
20	48	17	-1.15	.38	1.04	.2	1.02	.2	.86	.64	41.2	52.9	WDT
6	51	17	-1.60	.39	.98	.0	.97	.0	.88	.65	64.7	57.3	CK2.1
MEAN	39.9	17.0	.00	.38	.99	-.1	.99	-.1			57.4	55.9	
S.D.	9.5	.0	1.36	.01	.41	1.2	.43	1.2			13.6	1.9	

Figure 4.13 Item correlation order

Category Function

It is important to ensure that item categories function adequately since a partial credit model was used. Responses were coded on an increasing scale, for example from 1 to 4. This means that persons who score 1 has less knowledge than those who score 2, and those scoring 2 has less knowledge than persons scoring 3, etc. *Winsteps* provides item category measures to check whether all the categories for each item were aligned in the same direction (sequentially from 1 to 4 for example). An initial analysis revealed that one of the categories (CS2) had reversed ordering, as indicated in Figure 4.14 on the next page. The scoring of this item was revised and the data were recoded before further analysis was performed. The category ordering improved, as can be seen in Figure 4.15 on the next page.

Furthermore, it was noted that items CS2 and LPK2 had narrow category separation between categories 3 and 4 as shown by the arrows in Figure 4.14. The scoring of these two categories was also revised and all responses recoded. The category ordering showed improvement, as can be seen in Figure 4.15.

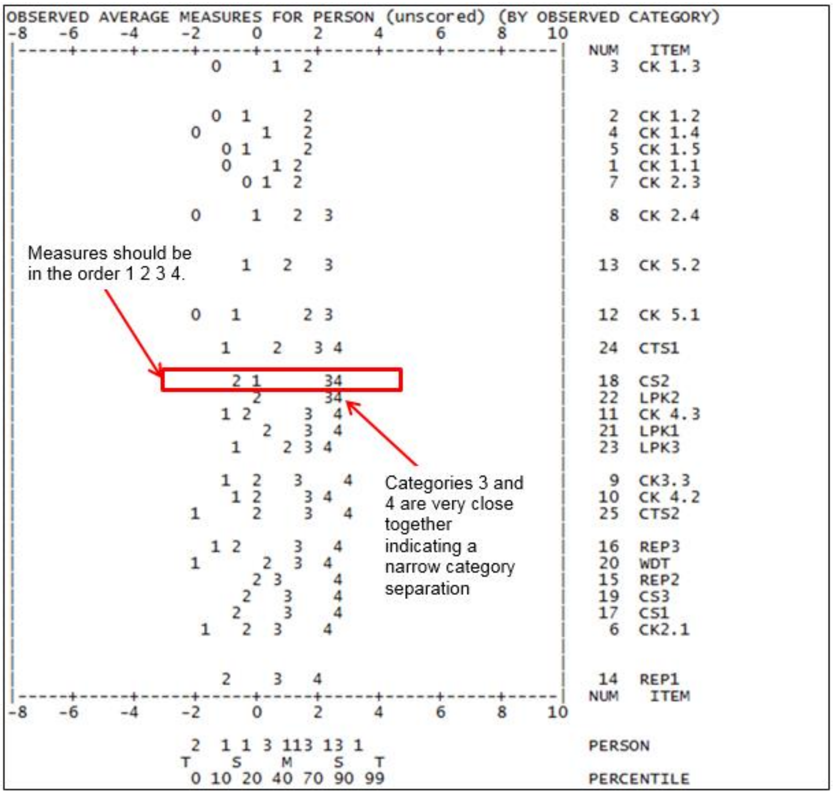


Figure 4.14 Initial item category measure

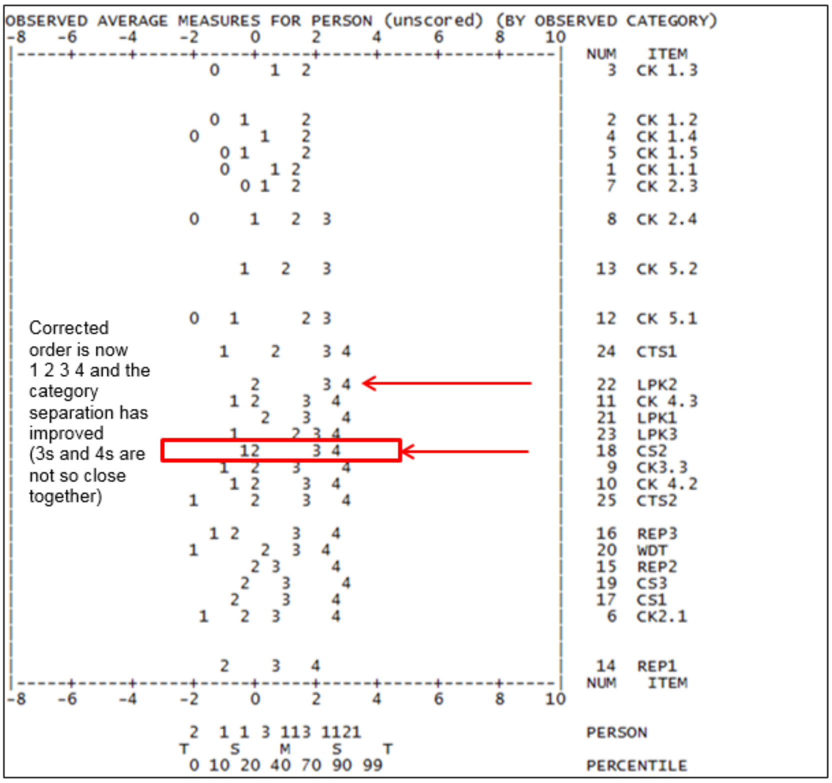


Figure 4.15 Final item category measure

Dimensionality

The first assumption of the Rasch measurement model is that a single construct, namely TSKFT, is measured. To provide evidence for unidimensionality it needs to be shown that items function independently. A principal component analysis of the residuals can provide evidence that items function independently (Smith, 2002). *Winsteps* was used to construct two sub-sets of data from a principal component analysis by identifying the items which load positively (Set 1), to the items which load negatively (Set 2). The loadings are included in Figure 4.16. The items were then correlated and the largest standardised residual correlations were identified as per Figure 4.17. A large positive correlation (>0.7) indicates highly dependent items, and a large negative correlation (<-0.7) indicates items that are likely to misfit (Linacre, 2004). All correlations in Figure 4.17 were between 0.7 and -0.7, providing evidence that items functioned independently.

CONTRAST 1 FROM PRINCIPAL COMPONENT ANALYSIS
STANDARDIZED RESIDUAL LOADINGS FOR ITEM (SORTED BY LOADING)

CON-TRAST	LOADING	MEASURE	INFIT MNSQ	OUTFIT MNSQ		ENTRY NUMBER	ITEM
1	.74	-1.83	.96	.96	A	6	CK2.1
1	.69	-.68	.99	1.01	B	18	CS2
1	.54	-2.76	.85	.69	C	14	REP1
1	.46	.44	1.29	1.39	D	12	CK 5.1
1	.44	2.14	.60	.56	E	2	CK 1.2
1	.42	-.84	.92	.97	F	9	CK3.3
1	.35	1.62	.93	.93	G	8	CK 2.4
1	.33	-1.33	.80	.83	H	16	REP3
1	.32	-.52	1.41	1.46	I	11	CK 4.3
1	.32	.12	.84	.88	J	24	CTS1
1	.10	1.11	1.15	1.16	K	13	CK 5.2
1	.06	-1.33	1.03	1.01	L	20	WDT

LOADING	MEASURE	INFIT MNSQ	OUTFIT MNSQ		ENTRY NUMBER	ITEM
-.70	3.39	1.09	1.10	a	3	CK 1.3
-.58	-.52	1.60	1.58	b	23	LPK3
-.54	1.97	1.28	1.19	c	1	CK 1.1
-.50	-1.49	.94	.92	d	15	REP2
-.47	-.37	.59	.58	e	22	LPK2
-.37	-.52	.94	.96	f	21	LPK1
-.28	2.14	.63	.59	g	5	CK 1.5
-.26	2.14	.82	.82	h	4	CK 1.4
-.26	-.84	1.23	1.26	i	10	CK 4.2
-.25	1.97	1.31	1.33	j	7	CK 2.3
-.11	-1.49	.87	.90	k	19	CS3
-.10	-1.66	.74	.72	l	17	CS1
-.10	-.84	.58	.58	M	25	CTS2

Figure 4.16 Principal component analysis of the residuals output table

LARGEST STANDARDIZED RESIDUAL CORRELATIONS
USED TO IDENTIFY DEPENDENT ITEM

CORREL-ATION	ENTRY NUMBER	ITEM	ENTRY NUMBER	ITEM
.68	6	CK2.1	12	CK5.1
.63	11	CK4.3	14	REP1
.62	17	CS1	21	LPK1
.59	9	CK3.3	18	CS2
.52	14	REP1	16	REP3
-.68	18	CS2	23	LPK3
-.62	4	CK1.4	11	CK4.3
-.60	1	CK1.1	14	REP1
-.58	3	CK1.3	9	CK3.3
-.57	1	CK1.1	24	CTS1
-.56	6	CK2.1	21	LPK1
-.55	4	CK1.4	14	REP1
-.53	7	CK2.3	14	REP1
-.53	3	CK1.3	6	CK2.1
-.52	1	CK1.1	11	CK4.3
-.51	7	CK2.3	11	CK4.3
-.50	9	CK3.3	11	CK4.3
-.50	13	CK5.2	17	CS1
-.49	3	CK1.3	18	CS2
-.49	5	CK1.5	6	CK2.1

A large positive correlation (>0.7) indicates highly dependent items

A large negative correlation (<-0.7) indicates items that are likely to misfit.

Figure 4.17 Standardised residual correlations

Item and Person Misfit

The next step was to identify any misfitting persons or items. *Winsteps* provides item and person statistics, ranking items and persons according to INFIT and OUTFIT values. INFIT detects unexpected behaviour affecting responses to items near the person's measurement level, whereas the OUTFIT statistic is more sensitive to unexpected behaviour by persons on items far from the person's ability. These values indicate whether items and persons are productive for measurement and whether any item or person should be omitted from the test. INFIT and OUTFIT are reported as mean square (MNSQ) and standardised values (ZSTD). Guidelines for interpreting MNSQ values are provided by the Winsteps Manual (Linacre, 2014) and included in Figure 4.18. MNSQ values are indicated in columns 6 and 8 in Figure 4.19 (for items) and Figure 4.20 (for persons). All items were found to be within the 0.5 to 1.5 MNSQ range (Figure 4.19) and were deemed productive for measurement, except for LPK3 which was marginally outside the range. All persons measures (Figure 4.20), except V17, were within the productive measurement range.

ZSTD is useful to interpret MNSQ values greater than 1.5, especially when working with small sample sizes and short tests, both of which are applicable in this study. The ZSTD values were examined for item LPK3 and were found to be 1.7 (INFIT) and 1.6 (OUTFIT), respectively. The ZSTD values for V17 were found to be 2.0 (INFIT) and 2.1 (OUTFIT), respectively. Since the MNSQ values were only marginally outside the 1.5 cut-off, and since the ZSTD values were very close to 2.0, as suggested by Baghaei and Amrahi (2011), LPK3 and V17 were not removed from the sample.

Value	*Meaning*
>2.0	Off-variable noise is greater than useful information. Degrades measurement. Always remedy the large misfits first.
>1.5	Noticeable off-variable noise. Neither constructs nor degrades measurement
0.5 - 1.5	Productive of measurement
<0.5	Overly predictable. Misleads us into thinking we are measuring better than we really are. (Attenuation paradox.). Misfits <1.0 are only of concern when shortening a test

Figure 4.18 Guideline for interpreting MNSQ values (Winsteps Manual (Linacre, 2014))

ITEM STATISTICS: MISFIT ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASURE-A CORR.	PTMEASURE-A EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	ITEM
23	43	17	-.52	.40	1.60	1.7	1.58	1.6	A .49	.69	41.2	57.6	LPK3
11	43	17	-.52	.40	1.41	1.2	1.46	1.3	B .84	.69	47.1	57.6	CK4.3
12	37	17	.44	.41	1.29	.9	1.39	1.1	C .75	.68	41.2	61.3	CK5.1
7	28	17	1.97	.42	1.31	.9	1.33	1.0	D .43	.69	64.7	60.3	CK2.3
1	28	17	1.97	.42	1.28	.9	1.19	.6	E .44	.69	58.8	60.3	CK1.1
10	45	17	-.84	.40	1.23	.8	1.26	.8	F .73	.69	52.9	57.3	CK4.2
13	33	17	1.11	.41	1.15	.5	1.16	.6	G .70	.68	58.8	60.4	CK5.2
3	20	17	3.39	.42	1.09	.4	1.10	.4	H .59	.69	64.7	62.2	CK1.3
20	48	17	-1.33	.41	1.03	.2	1.01	.1	I .87	.70	41.2	56.9	WDT
18	44	17	-.68	.40	.99	.1	1.01	.1	J .74	.69	58.8	57.3	CS2
9	45	17	-.84	.40	.92	-.1	.97	.0	K .65	.69	64.7	57.3	CK3.3
6	51	17	-1.83	.42	.96	.0	.96	.0	L .89	.71	58.8	61.0	CK2.1
21	43	17	-.52	.40	.94	-.1	.96	.0	M .49	.69	58.8	57.6	LPK1
15	49	17	-1.49	.41	.94	-.1	.92	-.2	l .72	.70	58.8	57.7	REP2
8	30	17	1.62	.42	.93	-.1	.93	-.1	k .65	.68	58.8	61.0	CK2.4
19	49	17	-1.49	.41	.87	-.3	.90	-.2	j .55	.70	58.8	57.7	CS3
24	39	17	.12	.40	.84	-.4	.88	-.2	i .74	.68	64.7	59.8	CTS1
14	56	17	-2.76	.45	.85	-.3	.69	-.7	h .85	.70	70.6	65.7	REP1
16	48	17	-1.33	.41	.80	-.5	.83	-.4	g .84	.70	76.5	56.9	REP3
4	27	17	2.14	.42	.82	-.4	.82	-.4	f .57	.69	64.7	60.6	CK1.4
17	50	17	-1.66	.41	.74	-.8	.72	-.8	e .72	.70	64.7	60.0	CS1
5	27	17	2.14	.42	.63	-1.1	.59	-1.3	d .74	.69	64.7	60.6	CK1.5
2	27	17	2.14	.42	.60	-1.2	.56	-1.4	c .75	.69	76.5	60.6	CK1.2
22	42	17	-.37	.40	.59	-1.4	.58	-1.4	b .67	.68	58.8	57.9	LPK2
25	45	17	-.84	.40	.58	-1.4	.58	-1.4	a .80	.69	64.7	57.3	CTS2
MEAN	39.9	17.0	.00	.41	.98	.0	.97	.0			59.8	59.3	
S.D.	9.5	.0	1.58	.01	.26	.8	.28	.8			9.2	2.1	

Figure 4.19 Item misfit table

PERSON STATISTICS: MISFIT ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASURE-A CORR.	PTMEASURE-A EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	PERSON
17	41	25	-.98	.35	1.68	2.0	1.75	2.1	A .43	.69	44.0	64.7	V17
10	52	25	.31	.33	1.39	1.4	1.42	1.4	B .66	.67	40.0	57.5	V10
5	46	25	-.38	.34	1.35	1.2	1.34	1.1	C .52	.68	48.0	63.2	V5
13	65	25	1.72	.33	1.27	1.0	1.19	.7	D .56	.68	68.0	59.9	V13
14	53	25	.42	.33	1.11	.5	1.15	.6	E .57	.66	44.0	57.0	V14
8	61	25	1.29	.33	1.05	.3	1.10	.4	F .63	.67	60.0	57.8	V8
16	75	25	2.84	.34	1.06	.3	1.00	.1	G .81	.70	72.0	60.0	V16
7	33	25	-1.94	.35	1.01	.1	1.00	.1	H .72	.69	48.0	58.7	V7
11	32	25	-2.06	.35	1.01	.1	1.00	.1	I .62	.69	64.0	57.1	V11
3	53	25	.42	.33	.94	-.1	.96	.0	h .47	.66	44.0	57.0	V3
4	57	25	.86	.33	.78	-.8	.81	-.7	g .67	.67	68.0	56.7	V4
15	73	25	2.61	.34	.79	-.7	.74	-.9	f .75	.70	64.0	59.0	V15
2	64	25	1.61	.33	.71	-1.1	.68	-1.2	e .81	.68	64.0	60.0	V2
12	72	25	2.49	.34	.69	-1.2	.65	-1.3	d .84	.70	60.0	59.5	V12
1	79	25	3.32	.35	.67	-1.3	.63	-1.4	c .90	.71	84.0	60.0	V1
9	66	25	1.83	.33	.66	-1.3	.65	-1.3	b .75	.68	68.0	60.1	V9
6	75	25	2.84	.34	.49	-2.3	.50	-2.1	a .88	.70	76.0	60.0	V6
MEAN	58.6	25.0	1.01	.34	.98	-.1	.97	-.1			59.8	59.3	
S.D.	14.2	.0	1.60	.01	.31	1.1	.32	1.1			12.5	2.1	

Figure 4.20 Person misfit table

Item Separation

The next step in the analysis was to check that the item hierarchy was as intended, as this can provide evidence for construct validity. Items that were expected to be difficult should end up as being difficult and easy items should end up as being easy. *Winsteps* provides expected score means for all items, ranking the items from most difficult to least difficult. The item separation table is shown in Figure 4.21. The content knowledge items were all found to be more difficult than the TSPCK items, except for the four items indicated in the figure. This was expected as the CK items had a strong conceptual focus. CK1 testing for alternative conceptions was the most difficult of the content knowledge questions. This is well in line with research, which has shown that teachers often have alternative conceptions about the topics they teach (Nicoll, 2001).

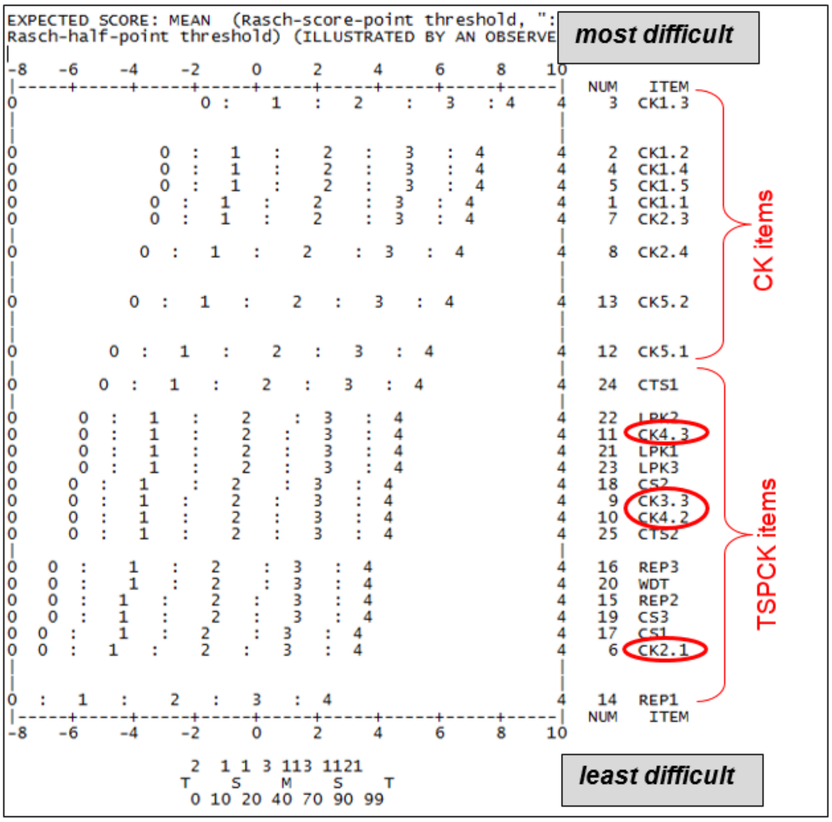


Figure 4.21 Item separation table

The teachers in the validation sample had an average of 9.6 years' teaching experience and it was expected that they would find the TSPCK questions relatively easy. TSPCK develops over time, as was reported by a number of researchers (for example Berry, Loughran, & Van Driel, 2008; Loughran, 2012; Van Driel, Verloop, & De Vos, 1999), and elaborated upon in Chapter 2.

The items on covalent bonding and metallic bonding (CK3.3, CK4.2 and CK4.3) were found less challenging than ionic bonding (CK5.1 and CK5.2). It is well-documented that ionic bonding is a difficult concept (Taber, 2002), and it was expected that teachers would find it more challenging than the other bonding models. Lastly, item CK2.1 (what is a chemical bond), was found to be one of the easiest items. A possible explanation could be that the question probed very familiar content. This concept is covered repeatedly at school level in Grades 9, 10 and 11, and it was expected that teachers would be able to provide a definition for the concept.

One of the conceptual teaching strategies questions (CTS1) was the most difficult TSPCK item, with the student prior knowledge items (LPK) ranked second, third and fourth for TSPCK. The conceptual teaching strategies items were expected to be the most difficult as teachers needed to draw knowledge of all the other aspects together to answer the items. This was also found in the design of other similar instruments (for example Mavhunga & Rollnick, 2013), where CTS and LPK were the most difficult items.

The above findings provided evidence for construct validity, as the item hierarchy was strongly aligned with the expected difficulty levels.

Differential item functioning

The item performance for different person classes was investigated to identify any item bias, also referred to as differential item functioning (DIF). This analysis determined if items performed statistically different for different groups of respondents, and sheds light on the performance of different person classes to each of the items. For the purpose of validating an instrument DIF should not be detected. Items should not discriminate between male and female teachers, or teachers in different provinces, since all teachers are teaching the same curriculum.

Two person factors, namely gender and province, were investigated. A summary of the number of teachers in each of classes and the codes used for the DIF analysis are summarised in Table 4.5.

Table 4.5 Classes for person factors for the DIF analysis for the validation sample

Demographic information		Number of teachers	Code used for DIF analysis
Gender	Female	10	F
	Male	7	M
Province	Western Cape	11	WC
	Gauteng Province	6	GP

In a DIF analysis, the item difficulty for one group in the sample is compared to the item difficulty for all the other groups combined. DIF results are considerably influenced by sample size and since this sample was very small in comparison to typical Rasch analyses, the results need to be interpreted with caution.

A DIF size greater than 0.50 indicates the possibility of DIF (Linacre, 2014), but the DIF size needs to be statistically significant. Statistical significance is indicated by a t-value > 2.0 and a probability less than 0.05.

Winsteps generates a set of DIF analysis tables to analyse potential DIF for different person classes. The DIF tables for gender and province are included in Appendix 23 and Appendix 24. No statistically significant DIF was detected for gender and province.

Item difficulty and person performance

The Rasch measurement model places person measures and item difficulty on the same linear scale for comparison (Boone & Rogan, 2005). The Wright map, or person-item map, gives an indication of the interaction between item difficulty and person measures. The Wright map for the data is shown in Figure 4.22. On the left of the map person performance is indicated in rank order, with the highest performing teachers at the top, and the lowest performing teachers at the bottom. V1, V16 and V6 scored the highest, while V11 and V7 obtained the lowest scores.

The person and item performance mean values are indicated by 'M' on the left and right of the central line. The person mean was 1.01 with the item mean set at zero. One and two standard deviations from each mean are indicated by ±S and ±T, respectively. The person mean was higher than the item mean, as highlighted by the rectangle on the map. This is an indication that the test was set at a slightly easier level than the average person ability in this sample.

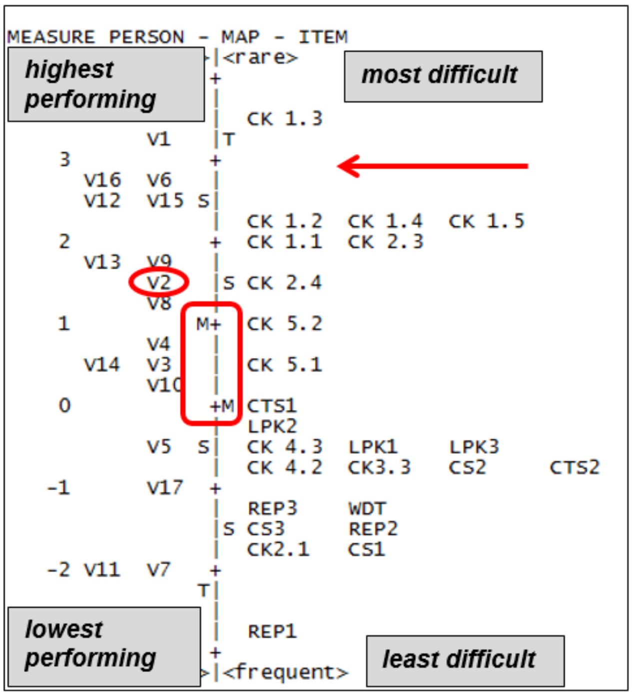


Figure 4.22 Wright map for the validation sample

The items are indicated on the right hand side of the map, also in rank order, from most difficult at the top to least difficult at the bottom. CK1.3 (metallic bonding), found at the top of the ranking, was the most difficult item, and REP1 (identifying strengths and weaknesses of representations of chemical bonding), at the bottom of the ranking, was the easiest item.

There was a good person and item spread. However, a gap in item difficulty was found between the top item CK1.3 and the next items (CK1.2/1.4/1.5), as indicated by the arrow in the figure. Ideally items should be spread out evenly.

The performance of individual persons can also be derived from the Wright map - for example, person V2 had a 50 percent chance of providing the correct answer to item CK2.4 (indicated with the circle on the map), but a less than 50 percent chance of providing correct answers for CK1.1 and CK2.3.

From the evidence provided here, it can be concluded that the items in the instrument were of acceptable difficulty level, resulting in a good spread of person performance and item difficulty.

Summary Statistics

So far it was shown that the item and person measures fitted the model and that the model measured a single underlying construct. There were no misfitting items or persons and the person responses were recoded until all items aligned, and item categories functioned adequately.

The last step was to determine whether the test was reliable and fit for use with larger groups. *Winsteps* generates a summary statistics table which summarises the key statistical indicators. This table is shown in Figure 4.23.

```
     SUMMARY OF 17 MEASURED PERSON
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT         OUTFIT    |
|          SCORE      COUNT    MEASURE   ERROR     MNSQ   ZSTD   MNSQ   ZSTD  |
|-----------------------------------------------------------------------------|
| MEAN      58.6       25.0       1.01     .34      .98    -.1    .97    -.1  |
| S.D.      14.2         .0       1.60     .01      .31    1.1    .32    1.1  |
| MAX.      79.0       25.0       3.32     .35     1.68    2.0   1.75    2.1  |
| MIN.      32.0       25.0      -2.06     .33      .49   -2.3    .50   -2.1  |
|-----------------------------------------------------------------------------|
| REAL RMSE    .36 TRUE SD    1.56  SEPARATION  4.37  PERSON RELIABILITY  .95 |
|MODEL RMSE    .34 TRUE SD    1.57  SEPARATION  4.63  PERSON RELIABILITY  .96 |
| S.E. OF PERSON MEAN = .40                                                    |
-------------------------------------------------------------------------------
PERSON RAW SCORE-TO-MEASURE CORRELATION = 1.00
CRONBACH ALPHA (KR-20) PERSON RAW SCORE "TEST" RELIABILITY = .95

     SUMMARY OF 25 MEASURED ITEM
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT         OUTFIT    |
|          SCORE      COUNT    MEASURE   ERROR     MNSQ   ZSTD   MNSQ   ZSTD  |
|-----------------------------------------------------------------------------|
| MEAN      39.9       17.0        .00     .41      .98     .0    .97     .0  |
| S.D.       9.5         .0       1.58     .01      .26     .8    .28     .8  |
| MAX.      56.0       17.0       3.39     .45     1.60    1.7   1.58    1.6  |
| MIN.      20.0       17.0      -2.76     .40      .58   -1.4    .56   -1.4  |
|-----------------------------------------------------------------------------|
| REAL RMSE    .43 TRUE SD    1.52  SEPARATION  3.54  ITEM   RELIABILITY  .93 |
|MODEL RMSE    .41 TRUE SD    1.52  SEPARATION  3.72  ITEM   RELIABILITY  .93 |
| S.E. OF ITEM MEAN = .32                                                      |
-------------------------------------------------------------------------------
ITEM RAW SCORE-TO-MEASURE CORRELATION = -1.00
425 DATA POINTS. LOG-LIKELIHOOD CHI-SQUARE: 742.79
  with d.f. in the range 381  to 425, prob.=.0000
Global Root-Mean-Square Residual (excluding extreme scores): .5856
UMEAN=.0000 USCALE=1.0000
```

Figure 4.23 Summary statistics table

The internal consistency of the instrument, as reflected by Cronbach's coefficient alpha (KR-20), was very high at 0.95. The person and item reliability indices, as estimated by the Rasch measurement model, were 0.95 and 0.93 respectively. Both these values were well within the statistical limit of 0.85 for individual use, and 0.70 for group use (Tennant & Conaghan, 2007).

The summary statistics table also provides an item and person separation factor which gives an indication of whether the instrument is fit for wider use. The person separation index was 4.37 and the item separation index was 3.54. Both values were well within the suggested minimum of 1.5 (for group use) and 2.5 (for individual use) (Tennant & Conaghan, 2007). The statistical analysis indicates that the instrument can be used with confidence with larger groups of teachers as well as to predict individual teacher performance. The final instrument, rubric and memorandum are included in Appendices 25-27.

4.11 Conclusion

The first research question in this study requires the development of a valid and reliable instrument for measuring TSKFT for chemical bonding. This chapter elaborated on the design and validation of such an instrument.

The instrument consisted of two parts, one measuring content knowledge (CK) and the other the transformation of content knowledge, namely topic specific pedagogical content knowledge (TSPCK). The rigorous design process involved various measures to ensure a valid and reliable instrument: a reference group of experts was used, a pilot was conducted, scoring was moderated, and the final instrument was subjected to statistical analysis using the Rasch measurement model. The statistical analysis revealed issues with category ordering and some items were recoded to improve the fit.

The validity and reliability of the instrument was shown by providing evidence for unidimensionality, showing acceptable infit and outfit statistics, a good spread of item difficulties across a range of person abilities, and a high index of person separation. These factors contributed to a high degree of internal consistency, and therefore a reliable instrument (Tennant & Conaghan, 2007). Face validity and content validity was strengthened by regular consultations with a reference group during the development process. The absence of misfitting items suggested strong content as well as construct validity. Content knowledge questions were found to be more challenging than the TSPCK questions. This was expected since the CK questions had a strong conceptual focus. Items probing alternative conceptions were the most difficult. The conceptual teaching strategies items were the most difficult of the TSPCK items, in line with the expectation for TSPCK, providing further evidence for construct validity (Kane, 2001). No differential item functioning was detected for gender and province.

In summary, a valid and reliable instrument for the measurement of topic specific knowledge for teaching chemical bonding was designed. The instrument can be used with confidence on the larger population of physical sciences teachers, as well as to predict individual teacher performance.

The next chapter reports on administering the valid instrument to a larger sample of teachers (N=60), and the accompanying data analysis of their instrument responses to answer the second and third research sub-questions.

Chapter 5 Analysis of the instrument responses

Chapter 4 described the development and validation of a measuring tool to determine the scope and depth of teachers' topic specific knowledge for teaching chemical bonding. The validated instrument was administered to 60 physical sciences teachers and the data was quantitatively and qualitatively analysed. This chapter reports on the three data analysis procedures that were used, namely a quantitative differential item functioning (DIF) analysis, a qualitative item analysis, and an explanatory framework analysis.

5.1 Introduction

This study set out to map teacher learning trajectories by capturing the most significant influences over the careers of teachers. Pedagogical content knowledge acts as a theoretical framing for the study. Topic specific knowledge for teaching (TSKFT), a construct derived for this study to describe the topic specific knowledge teachers possess and employ in planning to teach and in the act of teaching, acts as the analytical framework for the study.

An instrument to measure TSKFT was developed and validated, as described in Chapter 4, and administered to a sample of physical sciences teachers in two provinces in South Africa. This chapter investigates the teachers' responses to the questionnaire items in more detail. A qualitative analysis of the responses was done to describe the teachers' conceptual understanding of chemical bonding and their knowledge of the transformation of the content for the purpose of teaching. The various explanatory principles that the teachers chose to use when answering the questions provided insight into their TSKFT. The relationship between the teachers' choice of explanatory framework and the various teacher factors (teaching experience, chemistry content training, teaching qualification and school type) are investigated to identify trends and possible trajectories. Firstly, however, a quantitative Rasch analysis, and differential item functioning (DIF) analysis, which identified a number of factors playing a role in the development of TSKFT, is presented.

5.2 Rasch analysis of survey responses

The validated instrument for measuring TSKFT was administered to 60 physical sciences teachers (from here referred to as the survey sample), as was described in Chapter 3. The teacher responses were coded using the specially designed memorandum and rubric, and the coding was moderated by two of the members of the reference group (RG1 and RG2). The inter-rater reliability was calculated using *ReCal* (Freelon, 2010). Cohen's kappa value was found to be excellent ($\kappa = 0.82$) and the average percentage agreement was 87 percent. The codes were collated in a spreadsheet and the Rasch measurement model was applied in exactly the same manner as was described for the validation sample data in Chapter 4, using the *Winsteps* software package.

Item and category function were checked and no misfitting items or persons were found. Item separation was good and no differential item functioning was observed for gender or province. Stronger evidence for unidimensionality was found for this larger sample of teachers compared to the validation sample, as can be seen in Figure 5.1. A principal component analysis and a comparison of the standardized residual correlations revealed stronger item independence and items that are less likely to misfit when compared to the validation sample data.

LARGEST STANDARDIZED RESIDUAL CORRELATIONS
USED TO IDENTIFY DEPENDENT ITEM

CORREL-ATION	ENTRY NUMBER	ITEM	ENTRY NUMBER	ITEM
.48	2	CK1.2	5	CK1.5
.43	17	CS1	18	CS2
.40	10	CK4.2	11	CK4.3
.38	15	REP2	16	REP3
.36	21	LPK1	22	LPK2
.36	3	CK1.3	5	CK1.5
.34	14	REP1	16	REP3
.33	3	CK1.3	4	CK1.4
.32	17	CS1	19	CS3
-.41	3	CK1.3	23	LPK3
-.41	3	CK1.3	24	CTS1
-.38	4	CK1.4	10	CK4.2
-.36	10	CK4.2	17	CS1
-.36	11	CK4.3	19	CS3
-.35	1	CK1.1	17	CS1
-.35	11	CK4.3	22	LPK2
-.35	5	CK1.5	20	WDT
-.34	5	CK1.5	24	CTS1
-.34	2	CK1.2	16	REP3
-.34	5	CK1.5	16	REP3

A large positive correlation (>0.7) indicates highly dependent items. These values are lower than the values found for the validation sample data, indicating stronger item independence.

A large negative correlation (<-0.7) indicates items that are likely to misfit. These values indicate better fitting items than for the validation sample data.

Figure 5.1 Standardised residual correlations for survey sample data

The summary statistics table for the survey data is included in Figure 5.2. The internal consistency of the instrument was very high (Cronbach's coefficient alpha = 0.95), and person and item reliability was excellent at 0.95 and 0.96, respectively. Very high person and item separation indices were found (4.20 and 4.95), indicating that the test can be used to predict person performance with confidence for this sample. The mean person and item measures were also closer together (0.20 and 0.00) than with the smaller validation sample, indicating a test difficulty level better aligned to the average ability of the group.

```
TABLE 3.1 Final data file all items.xlsx          ZOU293WS.TXT  Mar 12   9:14 2016
INPUT: 60 PERSON  25 ITEM  REPORTED: 60 PERSON  25 ITEM  5 CATS  MINISTEP 3.81.0
--------------------------------------------------------------------------------

     SUMMARY OF 60 MEASURED PERSON
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE   ERROR      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      52.6      25.0        .20     .29       .98    -.1    .99     .0 |
| S.D.      15.8        .0       1.32     .01       .26     .9    .26     .9 |
| MAX.      81.0      25.0       2.65     .32      1.55    1.8   1.54    1.7 |
| MIN.      19.0      25.0      -2.67     .29       .56   -1.9    .55   -1.9 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .30 TRUE SD    1.28  SEPARATION  4.20  PERSON RELIABILITY  .95 |
|MODEL RMSE    .29 TRUE SD    1.28  SEPARATION  4.40  PERSON RELIABILITY  .95 |
| S.E. OF PERSON MEAN = .17                                                   |
-------------------------------------------------------------------------------
PERSON RAW SCORE-TO-MEASURE CORRELATION = 1.00
CRONBACH ALPHA (KR-20) PERSON RAW SCORE "TEST" RELIABILITY = .95

     SUMMARY OF 25 MEASURED ITEM
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE   ERROR      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN     126.4      60.0        .00     .19       .99    -.1    .99    -.1 |
| S.D.      28.6        .0        .99     .00       .22    1.2    .21    1.2 |
| MAX.     167.0      60.0       1.76     .19      1.36    1.9   1.36    1.9 |
| MIN.      76.0      60.0      -1.43     .18       .69   -1.9    .69   -1.9 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .20 TRUE SD     .97  SEPARATION  4.95  ITEM   RELIABILITY  .96 |
|MODEL RMSE    .19 TRUE SD     .97  SEPARATION  5.17  ITEM   RELIABILITY  .96 |
| S.E. OF ITEM MEAN = .20                                                     |
-------------------------------------------------------------------------------
ITEM RAW SCORE-TO-MEASURE CORRELATION = -1.00
1500 DATA POINTS. LOG-LIKELIHOOD CHI-SQUARE: 3066.57
  with d.f. in the range 1413  to 1500, prob.=.0000
Global Root-Mean-Square Residual (excluding extreme scores): .6834
UMEAN=.0000 USCALE=1.0000
```

Figure 5.2 Summary statistics table for the survey sample

The average raw scores compared well with the validation sample. The average TSPCK level was ‘developing’ (level 3), the same level as for the validation group. The average CK score was 74.6 percent, slightly higher than the 70.1 percent of the validation group. The survey group was a slightly more experienced group than the validation group, with an average teaching experience of 11.7 years (SD = 10.4) compared to 9.6 years (SD = 9.2) for the validation group.

The item difficulty findings compared very well with the findings for the validation sample (see the Wright map in Figure 5.3). The CK items were also found more difficult than the TSPCK items; alternative conceptions items were the most difficult CK items; and the conceptual teaching strategies items were again found to be the most difficult TSPCK items.

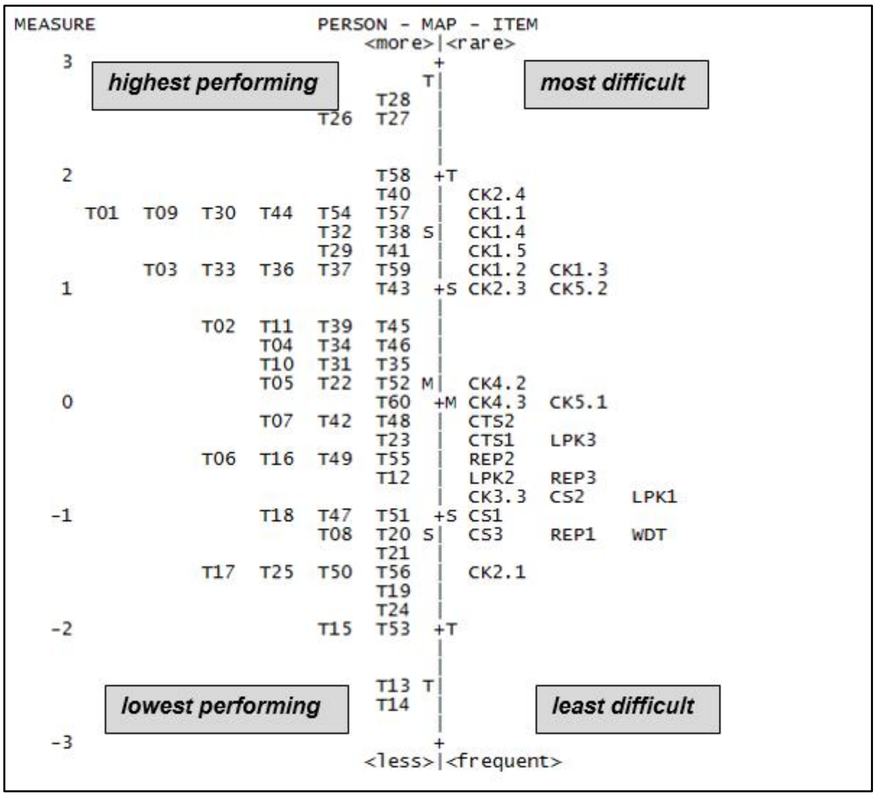


Figure 5.3 Wright map for the survey sample

The second research question asks for the identification of factors which may have influenced the quality of the teachers' TSKFT. A differential item functioning analysis is typically used to check whether items discriminate against specific person factors. In this study the test should not discriminate against gender or the province in which teachers are teaching. During the routine DIF analysis of the survey sample it was noted that some items displayed DIF for some of the other person factors - for example, certain teaching experience categories. This meant that some teachers performed statistically better (or worse) than what is predicted by the analysis and opened the possibility of identifying teacher factors which influenced the teachers' TSKFT. In a pragmatic approach to answering the second research question, this preliminary finding was further investigated and a more extensive DIF analysis was performed. This is reported in the next section.

5.3 Differential item functioning (DIF) analysis

As part of the demographic information collected from the teachers, information was gathered on the type of school the teachers were teaching at, their highest level of content training, their education qualification, and the number of years' teaching experience they had. This data was captured as person factors and included in the Rasch analysis. A detailed DIF analysis was done to identify which items performed statistically different and for which person factors. Table 5.1 summarises the various person factors classes and number of teachers in each class, as well as the codes used in the DIF analysis.

Table 5.1 Classes for person factors for the DIF analysis for the survey sample

Demographic information		Number of teachers	Code used for DIF analysis
Gender	Female	27	F
	Male	33	M
Province	Western Cape	31	WC
	Gauteng Province	29	GP
School type	Not currently teaching/never taught before	16	NOT TEACH
	Rural	2	RURAL
	Township	9	TOWNSHIP
	Ex-Model C	24	EXMODELC
	Private	9	PRIVATE
Highest Chemistry Content Level	Not known	11	UNKNOWN
	Chemistry first year level	23	CHEM1
	Chemistry second year level	5	CHEM2
	Chemistry third year level / major in chemistry	16	CHEM3
	Chemistry fourth year level / honours level	5	CHEMHons
Highest Teaching Qualification	Academic science degree with no teaching qualification	15	NO ED QUAL
	Academic science degree with teaching qualification (PGCE or HDE)	21	PGCE/HDE
	Bachelors of education (BEd)	12	BEd
	BEd honours	5	BEd Hons
	Master's degree level	4	MASTERS
	Teaching diploma without an academic degree	3	TEACH DIP
Teaching experience	Pre-service teachers	12	0 YEARS
	Beginning teachers	9	1-3 YEARS
	Mid-career teachers	12	4-10 YEARS
	Late career teachers	13	11-20 YEARS
	Veteran teachers	14	21+ YEARS

For a detailed description of the DIF analysis procedures using *Winsteps*, see Appendix 28. No DIF was detected for the first two person factors as was mentioned above. The remaining person factors, namely school type, level of chemistry content training, highest teaching qualification, and years' teaching experience, were also investigated as described in Appendix 28, and the items which showed potential bias are summarised in Table 5.2. The complete DIF tables can be found in Appendix 29 to Appendix 32.

Table 5.2 Summary of statistically significant DIF for all person factors

Item	Person factor	DIF size	T-value	Proba-bility	Class performance vs whole group
CK1.3 (two tier question on metallic bonding)	School type	-1.61	3.40	0.0114	Township teachers found the item easier
	School type	1.49	3.07	0.0181	Private school teachers found the item harder
	Content level	0.93	2.57	0.0221	Teachers with a major in chemistry found the item harder
CK4.2 (metallic bonding model)	Content level	-0.81	2.24	0.0419	Teachers with a major in chemistry found the item easier
CK4.3 (explaining physical properties of metals)	School type	0.86	2.40	0.0310	Teachers who were not currently teaching found the item harder
	Teaching experience	1.17	2.83	0.0178	Teachers with no teaching experience found the item harder
CK2.1 (what is a chemical bond)	School type	-0.70	2.12	0.0457	Ex-model C school teachers found the item easier
CK2.3 (why do atoms bond)	School type	-0.89	2.49	0.0261	Teachers who were not currently teaching found the item easier
CK2.4 (bonding dichotomy)	Teaching experience	-0.88	2.27	0.0424	Teachers with more than 21 years' teaching experience found the time easier
REP1 (strengths and weaknesses of representations)	Teaching experience	-0.94	2.17	0.0450	Teachers with no teaching experience found the item easier
REP3 (using a representation in teaching)	Education qualification	0.68	2.15	0.0448	Teachers with a PGCE or HDE found the item harder
CS1 (choosing and sequencing big ideas)	School type	-0.94	2.52	0.0245	Teachers who were not currently teaching found the item easier
	Teaching experience	-1.05	2.42	0.0359	Teachers with no teaching experience found the item easier
CTS2 (Conceptual teaching strategy)	School type	-1.47	2.86	0.0242	Private school teachers found the item easier

A DIF size >0.50, together with a t-value >2.0 and probability <0.05, indicate statistically significant DIF (Linacre, 2014). Positive DIF size values indicate that the item was more challenging than predicted, whereas negative DIF size values indicate items which were easier than predicted by the model. The CK items where DIF was identified were all the items on metallic bonding (CK1.3, CK4.2 and CK4.3), as well as all the items on the nature of a chemical bond (CK2.1, CK2.3 and CK2.4), with none of the other CK items showing any DIF. The presence of DIF is usually an indication of inadequate item formulation, however, since DIF was detected in very specific content questions, the possibility that other factors may be playing in role in the teachers' differences in performance, were considered.

All three items on the nature of a chemical bond were flagged for DIF, but only for some person factors. Teachers who were teaching at ex-model C schools found CK2.1 less challenging, while teachers who were not currently teaching found item CK2.3 less challenging. Most of these teachers (12 of the 16 teachers) were busy with their teacher certification programme (PGCE) and had no teaching experience. Lastly, teachers with the most teaching experience found CK2.4 on the bonding dichotomy less challenging than the other teachers. The metallic bonding items were also flagged for DIF for different teacher factors. Metallic bonding is known to be difficult and a topic that is not well understood (Taber, 2002), and the DIF results could be an indication of the non-uniform development of teachers' understanding of metallic bonding.

For the TSPCK items, teachers with no experience performed better in identifying strengths and weaknesses of representations (REP1), as well as choosing and sequencing big ideas (CS1). This was a very interesting finding since the expectation was that teachers with no teaching experience would not have high levels of TSPCK. Again it flagged the possibility that knowledge developed differently for some groups of teachers.

Teachers with a bachelor's degree and teaching qualification (PGCE or HDE) found describing how they would use representations in their teaching more challenging than expected, whereas private school teachers found the second conceptual teaching strategy question (CTS2) much easier than expected. All private school teachers had more than 10 years' teaching experience, except for T37 and T01, who had 9 and 10 years' experience respectively. This was an interesting finding as it shows that the CTS items perform differently for this group of teachers. It also highlights the influence that teaching experience and qualification may have on teachers' knowledge.

The DIF analysis identified a number of factors that may have played a role in the development of teacher knowledge. The factors are teaching experience, teachers' level of content training, teachers' education qualification, and the type of school where the teachers were teaching. In the next section a more detailed analysis of the teachers' performance on the test was done to shed light on the possibility of these factors playing a role in the teachers' topic specific knowledge for teaching chemical bonding.

5.4 General teacher performance on the test

The teachers' overall performance on the test represented a spread of competence levels. In light of the DIF analysis findings, the teachers' performance was investigated in more detail by looking at the trends in performance on individual test items.

5.4.1 Trends in teacher performance as revealed by the instrument responses

The person measures for individual items were investigated to determine trends in the teachers' overall performance on the items. The average performance for each item, as obtained from the statistical analysis, is shown in Figure 5.4. Item difficulty is plotted in log-odd units (logits) on the vertical axis and the items are listed on the horizontal axis. The mean of the entire test was set at zero. A high logit value indicates a more difficult item and a low logit value indicates an easier item. For example, CK2.1 was found the easiest of all the items, as it has the lowest measure. The teachers found the CK items, on average, more difficult than the TSPCK items. All the TSPCK item difficulties were below the mean, whilst most of the CK item difficulties were above the mean. This is in line with findings in the literature where experienced teachers often perform better at PCK items than CK items (Krauss, Baumert & Blum, 2008).

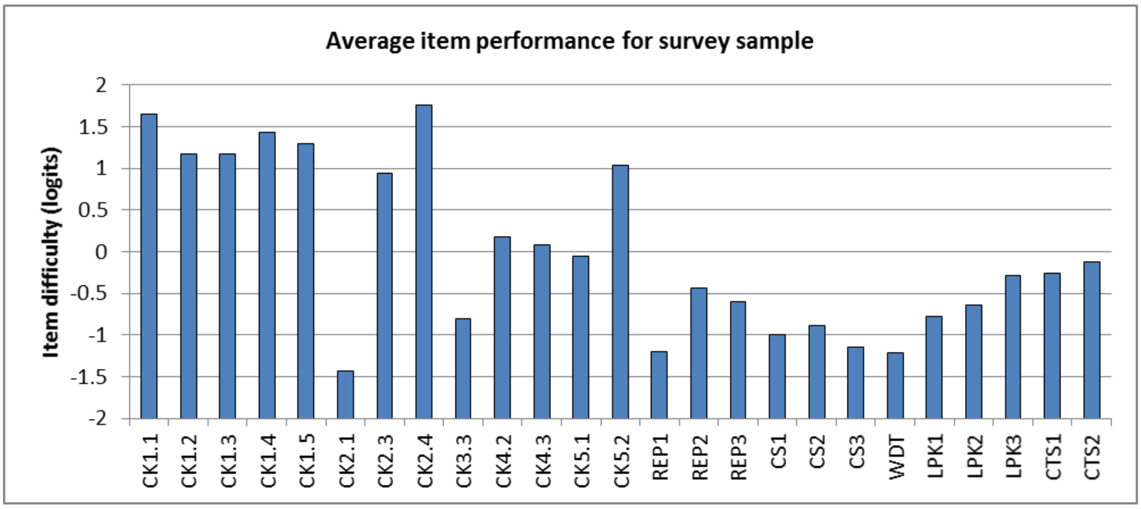


Figure 5.4 Average item performance for the survey sample

The questions on alternative conceptions (CK1.1 – CK1.5 and CK2.4) were the most challenging CK questions in the test. Item CK2.1 (what is a chemical bond) and the question probing covalent bonding (CK3.3), were the least challenging CK questions. From the TSPCK items, identifying strengths and weaknesses of representations for chemical bonding (REP1) and what is difficult to teach (WDT) were the least challenging. The conceptual teaching strategies questions (CTS1 and CTS2) were the most challenging for the teachers. It was anticipated that the representations would not be too challenging for the teachers as they included familiar diagrams often used in textbooks. It was also anticipated that the CTS items would be the most challenging since it required teachers to integrate all the other knowledge components and draw together all aspects of teaching the topic.

The teachers' responses on individual items were now investigated to gain further insight into the possible trends in teachers' performance. Since the study investigated teacher learning trajectories over the careers of teachers, the teaching experience categories were used for this analysis.

5.4.2 Teacher performance on the alternative conceptions items

The first set of CK questions probed some of the known alternative conceptions in chemical bonding as described in the literature review in Chapter 2. Figure 5.5 shows the teachers' performance (item difficulty) for the five CK1 items and CK2.4. Item difficulty is indicated on the y-axis and the various items on the x-axis. The teachers were grouped in the five teaching experience categories that were used in the DIF analysis.

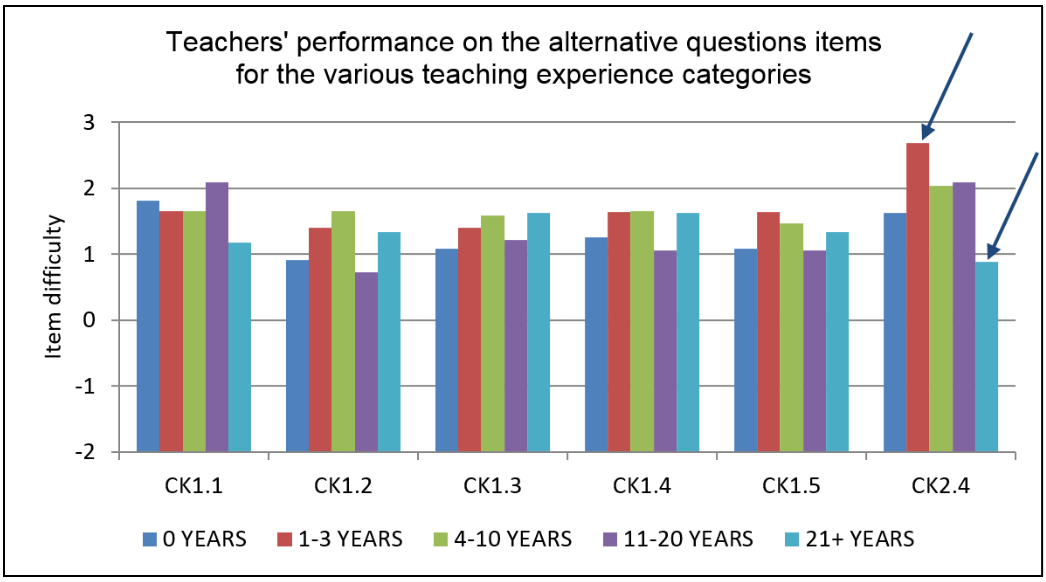


Figure 5.5 Teachers' performance for the items probing alternative conceptions

The CK1 items were two-tiered, with the first part of the question requiring a true or false answer, and the second part requiring a reason for the choice. CK2.4 was an open-ended question asking whether bonds can have both covalent and ionic character. A higher value for item difficulty (a taller bar) indicates that teachers in that experience group found the item more challenging than what was predicted by the Rasch measurement model. CK1.1 and CK2.4

were found to be a marginally more challenging than the other items (on average the bars are slightly taller). CK2.4, the open-ended question, provided a larger spread of difficulty levels. Here teachers had to come up with their own explanations and not choose one of the options provided. Beginning teachers (1-3 years' teaching experience) found this question the most challenging and veteran teachers (teachers with 21 or more years' experience) found these items the least challenging.

Overall there were no specific trends found for the CK1 items, with all the teachers finding it equally challenging. However, a closer look at the teachers' answers to specific items revealed some of the most prevalent alternative conceptions reported in the literature. Table 5.3 summarises all the teacher responses to CK1. The most appropriate answer is highlighted in each question. The number of teachers choosing each option, and the equivalent percentage that this number represents, are also indicated in the table.

Table 5.3 Number of teachers answering each option in CK1

CK1.1 NaCl molecule	Number of teachers	Percentage	CK1.2 Ionic covalent	Number of teachers	Percentage	CK1.3 Metallic properties	Number of teachers	Percentage	CK1.4 Graphite conduct	Number of teachers	Percentage	CK1.5 Ionic covalent	Number of teachers	Percentage
A1	3	5	A1	6	10	A1	0	0	A1	31	52	A1	3	5
A2	9	15	A2	0	0	A2	11	18	A2	5	8	A2	3	5
A3	6	10	A3	1	2	A3	27	45	A3	10	16	A3	3	5
A4	0	0	A4	42	70	A4	1	2	A4	6	10	A4	8	13
B1	0	0	B1	2	3	B1	6	10	B1	1	2	B1	1	2
B2	1	2	B2	2	3	B2	1	2	B2	3	5	B2	3	5
B3	37	62	B3	1	2	B3	10	16	B3	3	5	B3	35	58
B4	2	3	B4	3	5	B4	3	5	B4	0	0	B4	3	5
NR	2	3	NR	3	5	NR	1	2	NR	1	2	NR	1	2

NR: no response

Sodium chloride is a molecule (CK1.1)

The first two-tier multiple choice item investigated teachers' views on whether sodium chloride is a molecule or not. Sodium chloride is generally not considered a molecule as it exists as a network structure held together by electrostatic forces between positive sodium ions and negative electrons throughout the lattice. According to Taber (2002) this is one of the most common alternative conceptions amongst students, and stems from the belief that all atoms combine to form molecules. These molecules are then packed in solid structures to form compounds such as NaCl. It forms part of what Taber identifies as the *molecular framework for ionic bonding* or *octet alternative framework*.

The best answer was option B3 – sodium chloride is *not* a molecule as it exists as a lattice consisting of sodium and chloride ions. Thirty-seven teachers (62%) answered with this choice. Tan and Treagust (1999) found that 80 percent of Singaporean students in their study thought that sodium chloride *is* a molecule.

Eighteen teachers (31%) in this study indicated that the statement *NaCl is a molecule* is true. The most prevalent incorrect reason provided by the teachers was the statement that sodium donates an electron to chlorine to form a sodium chloride molecule. Ten teachers (17%) chose this option (nine chose A2 and one chose B2), well below the 46 percent that Tan and Treagust (1999) found. This view stems from the belief that an atom 'wants' to fill its octet structure, and does so by donating an electron to another atom to become stable. The two atoms then 'belong' together (Taber 1997) and act as a molecule, or an ion-pair. This ion-pair view was presented in option 1 – the sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule. Only three teachers (5%) chose this reason. Tan and Treagust (1999) found that 23 percent of students in their study thought this was the best reason for their choice. From the analysis of this question fewer teachers held this alternative conception than what was reported for students in Tan and Treagust's (1999) study. However, a fair number of teachers still held the alternative conception that sodium chloride forms molecules, a view that may impede further understanding.

Covalent or ionic bonding (CK1.2 and CK1.5)

The second and fifth CK1 questions probed the teachers' knowledge of ionic and covalent bonding. For CK1.2 teachers had to use electron configuration to decide whether a covalent or ionic bond is the better description for the interaction between two atoms, and for CK1.5 they had to use a Lewis representation for the same task. Teachers were better at using electron configuration than Lewis diagrams: 70 percent of teachers chose option A4 for CK1.2, and only 58 percent of teachers chose option B3 for CK1.5. Both these representations are part of the Grade 10 curriculum and should have been familiar to the teachers.

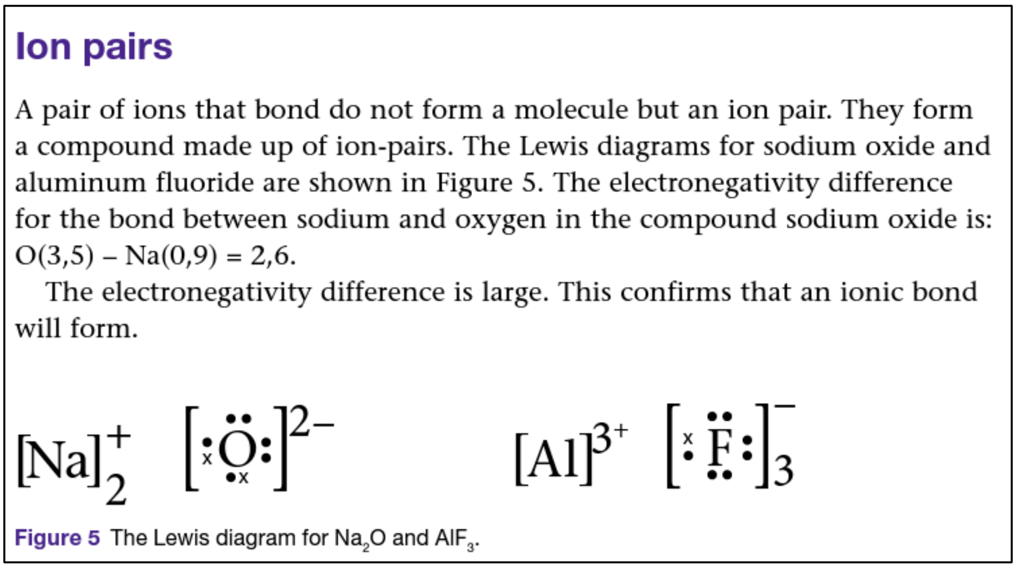
For CK1.5 eight teachers (13%) thought the compound was covalent and chose a representation that showed overlap and sharing of electrons, in line with their covalent choice for the bonding model. For CK1.2 six teachers (10%) correctly indicated that the compound CE_2 is ionic, yet they gave the reason 'the atom of C will share one pair of electrons with each atom of E to form a *covalent molecule* CE_2'. This revealed an alternative conception which

Taber (1994) identifies as the ion-pair molecule, a view that can limit further learning in chemistry. When ionic substances are viewed as molecules packed in lattice structures, it can inhibit understanding of, for example, the dissolution of ionic substances in aqueous media, forming molecules in solution instead of ions.

The CAPS curriculum describes ionic bonding as follows:

> When the electrons of atoms are transferred from one atom to another atom to form positive and negative ions, the ions bond with ionic bonds and the resulting solid is called an ionic substance (or salt or ionic compound) (DBE, 2011a, p. 33)

It is easy to incorrectly assume that the ions form pairs when an electron is transferred from one atom to another. This view could be (unintentionally) strengthened by textbook authors making the ion pairs explicit, for example in Figure 5.6. Ionic bonding is also taught after covalent bonding in Grade 10 (DBE, 2011a), and Lewis diagrams are used to represent the ionic bond. When ionic substances, like sodium oxide or aluminium fluoride in Figure 5.6, are shown as pairs and not in a network structure, it could support the development of alternative conceptions amongst students, and teachers.


Ion pairs

A pair of ions that bond do not form a molecule but an ion pair. They form a compound made up of ion-pairs. The Lewis diagrams for sodium oxide and aluminum fluoride are shown in Figure 5. The electronegativity difference for the bond between sodium and oxygen in the compound sodium oxide is: O(3,5) – Na(0,9) = 2,6.

The electronegativity difference is large. This confirms that an ionic bond will form.

Figure 5 The Lewis diagram for Na_2O and AlF_3.

Figure 5.6 Extract from a Grade 10 textbook (Broster, Horn, & James, 2011, p. 70)

Metallic bonding (CK1.3)

Item CK1.3 probed teachers’ knowledge of the metallic bonding model. This question had the lowest number (45%) of teachers choosing the most appropriate choice, namely A3. It was also one of the items that showed teacher performance statistically different from the expected performance, as was seen in the DIF analysis earlier in this chapter.

The focus in this question was not so much whether teachers were able to identify the statement as correct or not, but rather the reason they provided for their choice. The first reason stated was that bonding is not a force, and only six teachers (10%) chose this option. The second reason stated was that atoms provide the properties for the metal. A fifth of the teachers chose this option: 11 chose A2 and one teacher chose B2. The third reason correctly stated that delocalised valence electrons were responsible for the electrical conductivity in graphite. Just over 60 percent of teachers gave this as the reason (45 percent of teachers chose A3 and 17 percent chose B3). The fourth reason stated the fact that metal atoms slide over each other as the reason for hardness and strength. Only 4 teachers chose this reason.

The most popular incorrect choice (reason 2) was ascribing the metallic properties of hardness and strength to the metal atoms. This is a well-documented alternative conception, namely that students ascribe macroscopic properties to atoms and not the substance as a whole (Coll & Treagust, 2003b; Taber, 2003). Another common incorrect combination was choosing the right reason (reason 3), but stating that metals are not hard and strong (choice B). This may be due to the belief that ionic substances are considered to be hard (e.g. crystals) and because metals are malleable and ductile, they are not considered strong. Teachers may have been of the opinion that metals are soft because it can be cut or moulded.

The teachers' performance on this item was poor as the results show that 40 percent of the teachers still hold naïve conceptions about metallic bonding and properties. The teachers' lack of conceptual understanding could be a reason for the DIF findings on the metallic bonding items.

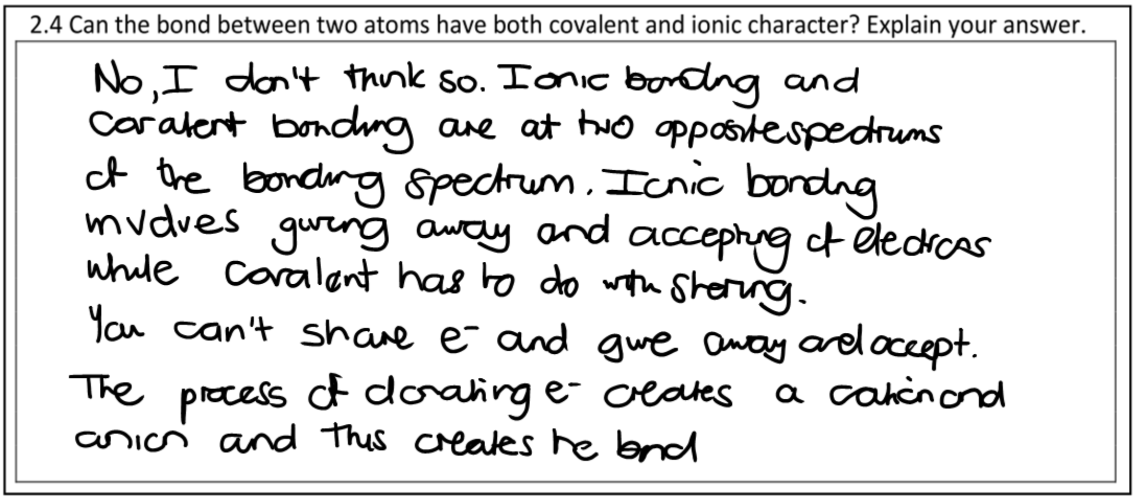
Graphite (CK1.4)

Item CK1.4 probed teachers' knowledge of whether graphite can conduct electricity. For this item 52 teachers chose the correct answer for true and false (87%) but their reasons varied considerably. Only 52 percent of teachers, who confirmed that the statement is true, could identify reason 1 (three electrons are involved in bonding and the fourth is delocalized) as the correct reason. A further 10 teachers (16%) chose the correct reason, but said that graphite does *not* conduct electricity. Six teachers (10%) thought graphite *atoms* are delocalized (option 4) and 8 percent of teachers thought electrons escape the covalent bonds in graphite to conduct electricity (option 2). Ten teachers thought electrical conductivity had to do with the graphite layers that can slip over each other (option 3). This reason is usually provided to explain why graphite is used in pencils. Teachers' confusion here may be ascribed to them recognizing the description, but not applying their knowledge to the correct situation.

Understanding the chemical bonds in graphite requires an understanding of the electron structure of carbon and knowing which electrons take part in bonding. Tan and Treagust (1999) reported that only 28 percent of the students in their study understood that only three of the four valence electrons in an atom of carbon are involved in bonding. In this study a much higher percentage of teachers grasped the concept, but still a large proportion of teachers had limited understanding of the bonding in graphite.

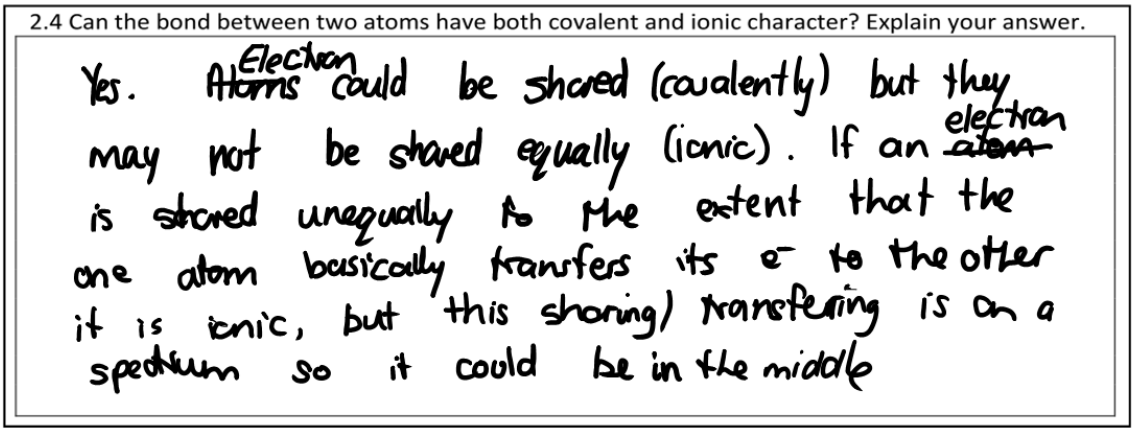
Bonding dichotomy (CK2.4)

The last alternative conception question (the bonding dichotomy) was investigated in an open-ended question by asking teachers whether a chemical bond can have both covalent and ionic character. Viewing chemical bonds as only covalent or ionic is a naïve conception which can limit further learning (Taber, 1998). When a chemical bond is seen as only covalent or ionic, explaining polar or metallic bonds are problematic as they do not fit the description of either a sharing or a transfer of electrons. Two teachers' responses (T52 and T54, respectively) are included in Figure 5.7 and Figure 5.8 to illustrate these two views. Both teachers have an honours level chemistry, were enrolled in a post graduate teacher certification programme and did not have any teaching experience.


2.4 Can the bond between two atoms have both covalent and ionic character? Explain your answer.

No, I don't think so. Ionic bonding and
covalent bonding are at two opposite spectrums
of the bonding spectrum. Ionic bonding
involves giving away and accepting of electrons
while covalent has to do with sharing.
You can't share e⁻ and give away and accept.
The process of donating e⁻ creates a cation and
anion and thus creates the bond

Figure 5.7 Teacher T52's response to item CK2.4


2.4 Can the bond between two atoms have both covalent and ionic character? Explain your answer.

Yes. Electron Atoms could be shared (covalently) but they may not be shared equally (ionic). If an electron ~~atom~~ is shared unequally to the extent that the one atom basically transfers its e^- to the other it is ionic, but this sharing/transfering is on a spectrum so it could be in the middle

Figure 5.8 Teacher T54's response to item CK2.4

Teacher T52 states that 'you can't share e^- [electrons] and give away and accept'. Although she mentioned a spectrum of bonding, she has a dichotomous view – either sharing or transfer, not both. Teacher T54, on the other hand, also mentions the bonding spectrum but sees ionic bonding as an extreme case of covalent bonding. Electrons are shared so unequally that 'the one atom basically transfers its e^- [electrons] to the other'. Bonds can therefore be classified as anywhere on the spectrum. Eighteen teachers in the study (30%) were of the view that bonds can only be ionic or covalent, similar to teacher T52, while 42 teachers (70%) were of the opinion that bonds lie on a spectrum and can therefore have both covalent and ionic character, similar to teacher T54.

When the teachers' performance on the CK2.4 item was compared across the experience categories it was found that the teachers with the most teaching experience found the item the easiest (see Figure 5.9). Teachers with more teaching experience therefore moved away from a dichotomous view of chemical bonding to viewing covalent and ionic bonding on a continuum (Levy Nahum et al., 2007). The pre-service teachers also found this item less challenging than most of the other teachers, although, as demonstrated above, not all pre-service teachers had a continuum view of covalent and ionic bonding.

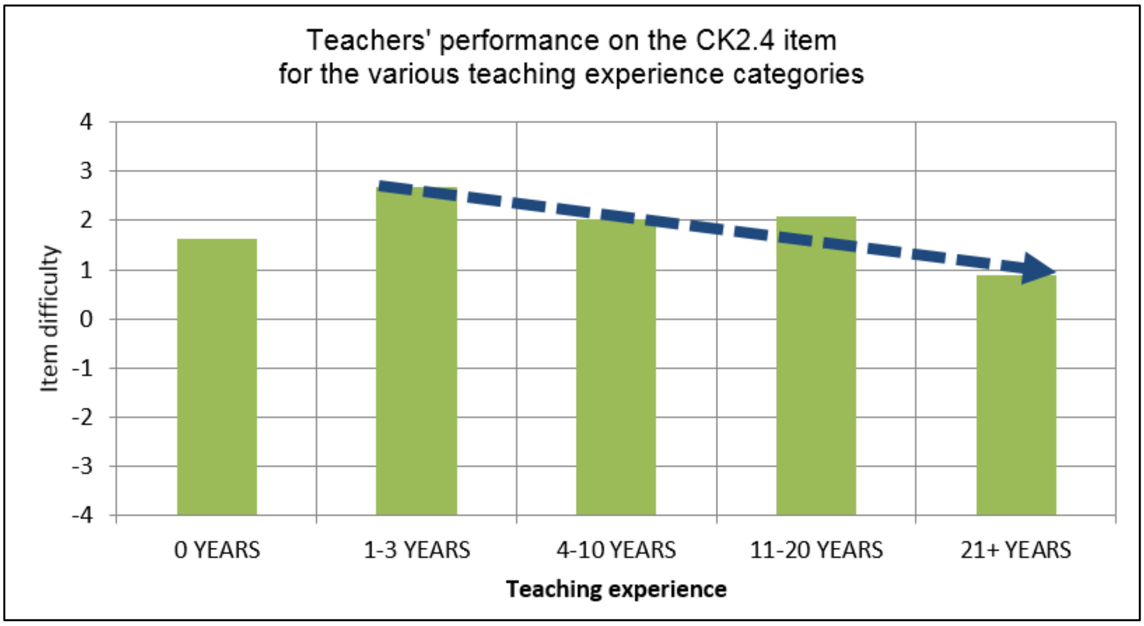


Figure 5.9 Teacher's performance on CK2.4

It is important that teachers do not hold alternative conceptions, but equally important that they are able to identify alternative conceptions in student answers and are able to use teaching strategies to help students develop more scientifically aligned views. The transformation of the content in these last two questions, CK1.3 and CK2.4 (the physical properties of graphite and the bonding dichotomy) was probed further in the conceptual teaching strategies questions (CTS1 and CTS2) (see page 128 for the discussion).

5.4.3 Teachers' views of bonding models

The teachers' views on three different bonding models were investigated. Item CK3.3 investigated polar bonds, CK4.2 and CK4.3 metallic bonding, and CK5.1 and CK5.2 ionic bonding. Items CK3.2 and CK3.4 were combined with CK3.3 in the design of the instrument (see Chapter 4), as it probed the same content knowledge, namely the bonding type found between hydrogen and nitrogen in ammonia. What is reported as CK3.3 is therefore a combination of responses from CK3.2, CK3.3 and CK3.4.

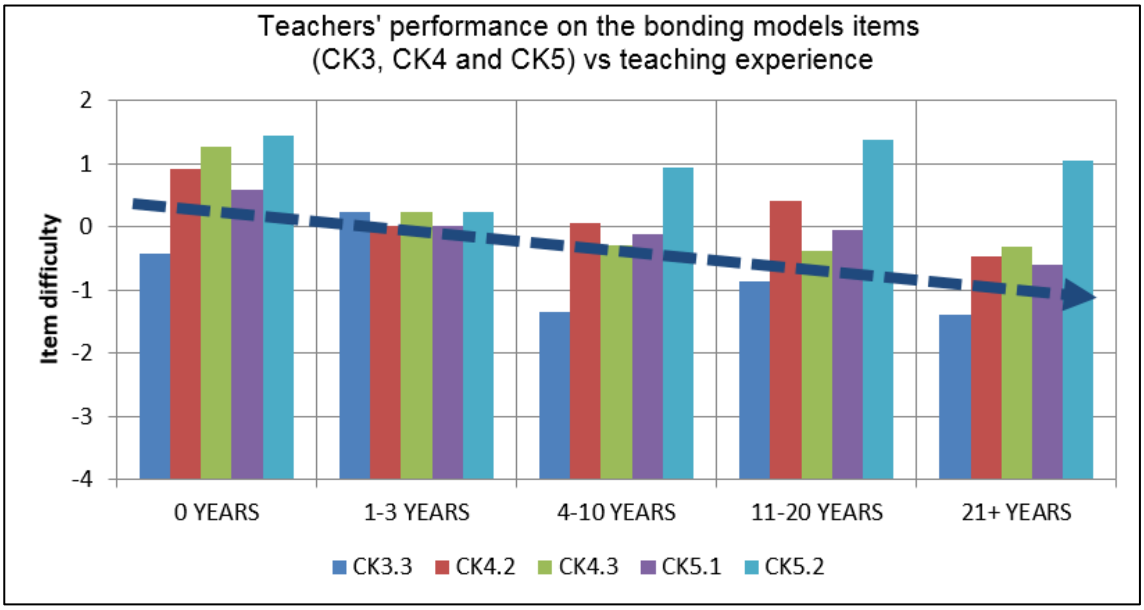


Figure 5.10 Teachers' performance on CK3, CK4 and CK5

The item difficulty for these five items was plotted for the different teaching experience levels (Figure 5.10). Teachers with no teaching experience found all the items challenging - the first set of bars (0 years) are on average higher than the other sets. Teachers with the most experience generally found the items less challenging than the other teachers. Beginning teachers (1-3 years' teaching experience) found all the items of similar difficulty level. This was different to the rest of the groups, where CK3.3 on covalent bonding was the least challenging (first bar is the shortest) and CK5.2 on ionic bonding the most challenging (last bar is the tallest). Beginning teachers made up the smallest group, which consisted of nine teachers, compared to 12-14 in all the other groups. The last item, CK5.2, was answered particularly poorly by most of the teachers. The item asked teachers to apply their knowledge of ionic bonding to explain why magnesium bromide has a high melting point. Ionic bonding is known to be a difficult concept to understand (Coll & Treagust, 2003a; Vladusic et al., 2016), and the teachers in this study were no exception.

In summary, teachers with more teaching experience had a better understanding of the models for chemical bonding, and found the items less challenging than teachers with less experience.

5.4.4 Teachers' conceptions of the nature of chemical bonding

The first two open ended questions elicited teachers' views on the nature of chemical bonding. Teachers were asked to define what a chemical bond is (CK2.1), and to explain why atoms bond (CK2.3).

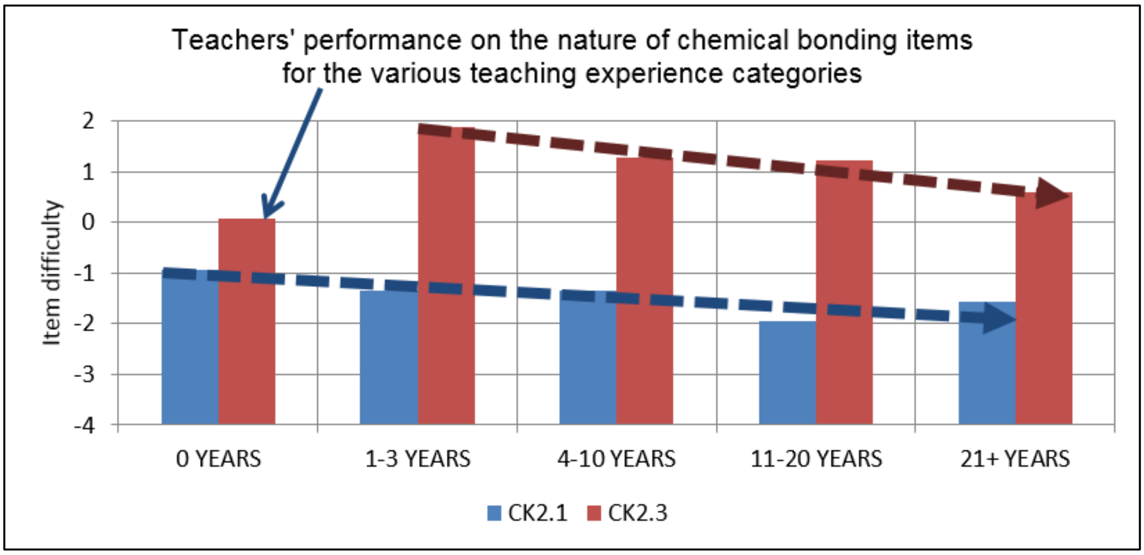


Figure 5.11 Teachers' performance on the CK2 items

When the teachers' performance on each of the items was compared for the different teaching experience categories, it was found that teachers with more teaching experience found the items less challenging (see Figure 5.11). Similar to the finding for CK2.4, the pre-service teachers found CK2.3 (why do atoms bond) less challenging than all the other groups. This question is fundamental to understanding chemical bonding and chemical systems. Pre-service teachers in this sample can be considered content specialists since all of them had recently completed their undergraduate training. It was therefore expected that they would answer this question drawing from recently gained content knowledge.

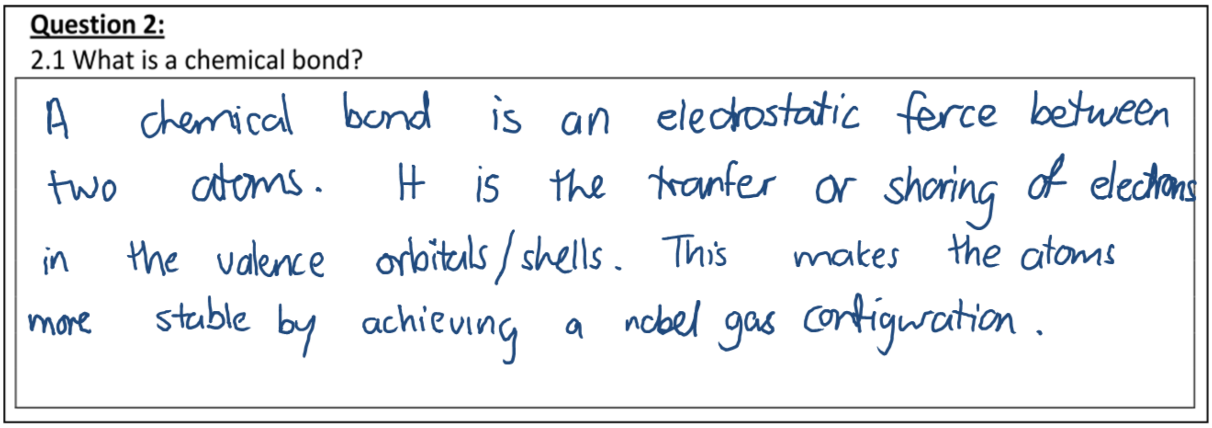
A qualitative analysis of teachers' answers revealed that teachers used five distinct approaches to explain what a chemical bond is, and why bonding takes place. Three of these views aligned with the explanatory principles which Taber (2002) identified, namely the octet, minimum energy, and electrostatic explanatory principles. Taber's orbital explanatory principal was not identified in the data, but an additional idea which centred on the atom was identified. This 'atomic ontology' was also identified by Taber (1998) in an earlier study and it was suggested that it originated from a view that atoms are the building blocks, or 'natural' units, of matter (Watts & Taber 1996). Eight of the teachers expressed the view that bonds are formed when atoms combine to form molecules or new substances. A further 16 teachers described a chemical bond as a force between atoms, therefore still using an atomic view, but starting to incorporate the notion that a bond is a force. Taber also noted this 'transitional state' in A-level chemistry students whom he studied in the United Kingdom (Taber 2001).

Table 5.4 summarises the explanatory principles that were identified for the CK2.1 item for the survey sample. Examples are included to illustrate each principle, and the number of teachers in each category is provided.

Table 5.4 Explanatory frameworks for conceptualising chemical bonding

Description of the framework	**Exemplar teacher responses for 'What is a chemical bond?'**	**Number of teachers**
Atomic ontology (bonding is combining of atoms to form molecules)	It is a bond that exists between atoms to form molecules. (T12) The reaction of elements to form a bond and compound which will behave as single unit chemically. (T23)	8
Atomic ontology (transitional - bonding is a force between atoms)	A force that keeps two or more atoms tightly together. (T05) A force that holds atoms together to form a single unit. (T44)	16
Octet principle (bonding is sharing or transfer of electrons)	Atoms coming together in the form of covalent bonding (sharing electrons) or ionic bonding (transfer-donate/accept). (T15) A chemical bond is either a sharing of electrons between two or more non-metal atoms, so that each atom has a full outermost energy level. (T40) A chemical bond is a bond between two atoms to satisfy their valence electron necessity and the octet rule. (T55)	11
Minimum energy principle (bonds are formed to create stability)	A type of bond that takes place in atoms of elements for stability. (T20)	10
Electrostatic principle (bonds are electrostatic forces between oppositely charged species)	A chemical bond is an electrostatic force of attraction between positively charged and negatively charged particles that hold atoms or ions together. (T26)	15

It was also noted that some teachers used multiple frameworks in their explanations, similar to what Taber (1997) found in his case study of A-level students in the UK. The response from teacher T54 illustrates this, as can be seen in Figure 5.12.


Question 2:
2.1 What is a chemical bond?

A chemical bond is an electrostatic force between two atoms. It is the tranfer or sharing of electrons in the valence orbitals/shells. This makes the atoms more stable by achieving a nobel gas configuration.

Figure 5.12 Teacher T54's response to CK2.1

The teacher acknowledged that a bond is an electrostatic force (electrostatic view), but she also defined it as a transfer or sharing of electrons with the purpose of achieving a noble gas configuration (octet view), thus creating stability (minimum energy view). This suggests that teachers, similar to students, hold multiple conceptions of a concept and draw from these conceptions in different ways when they reflect on their knowledge for teaching.

The preliminary findings here are based on teachers' responses to only two items, and may be a limited representation of their knowledge. The last section in this chapter investigates this further by doing a detailed explanatory framework analysis of more items (see page 131 for this analysis) for a more comprehensive view.

5.4.5 Teachers' topic specific pedagogical content knowledge

The item difficulty for the TSPCK items were also compared for the different teaching experience categories, similar to the analysis of the CK items. Overall the TSPCK items were found less challenging than the CK items, as mentioned earlier. The teachers' performance in each of the five TSPCK item categories is discussed below.

Representations

Three aspects of the representation of chemical bonding were included in the instrument. The first TSPCK item, REP1, required the identification of weaknesses and strengths of six representations, REP2 asked teachers to identify the best representation and provide reasons, and REP3 asked teachers to describe how they would use their choice of representation in teaching.

Figure 5.13 shows the comparison of the teachers' performance on the three items according to the different teaching experience categories. As the teachers gained teaching experience, it appears that the items became more difficult. Pre-service teachers (with no teaching experience) performed statistically better (see Table 5.2 on page 110) on identifying the strengths and weaknesses of representations (REP1) than the rest of the teachers (indicated with an arrow in Figure 5.13). REP1 was also overall marginally easier than the other two items.

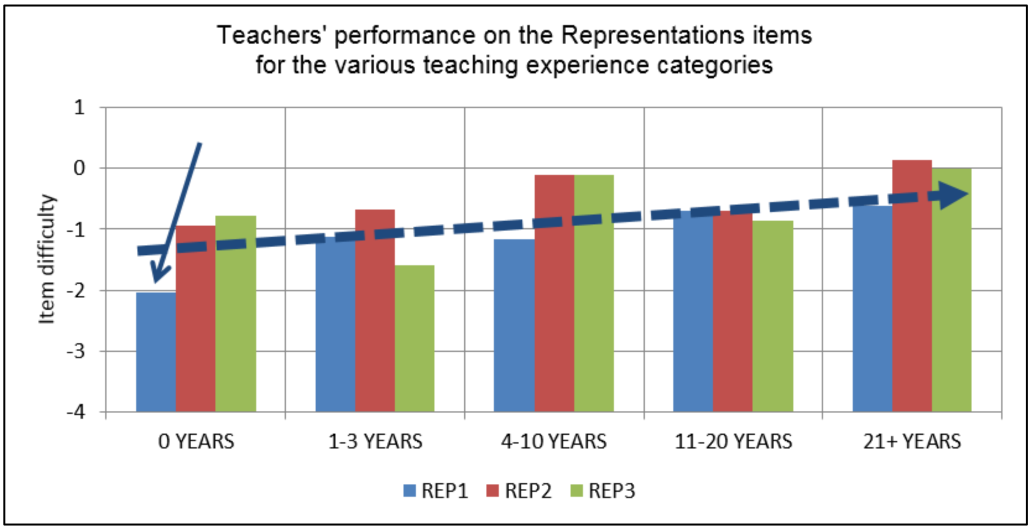


Figure 5.13 Teachers' performance on the representations items

Curricular saliency

The curricular saliency component included three items: CS1 asked teachers to identify and sequence the big ideas for teaching chemical bonding; CS2 asked them to describe (using a mind map) how these ideas were related; and for CS3 they had to explain why they thought chemical bonding is an important topic to teach. The teachers' performance on these three items was again compared for the various teaching experience categories, and the findings are presented in Figure 5.14.

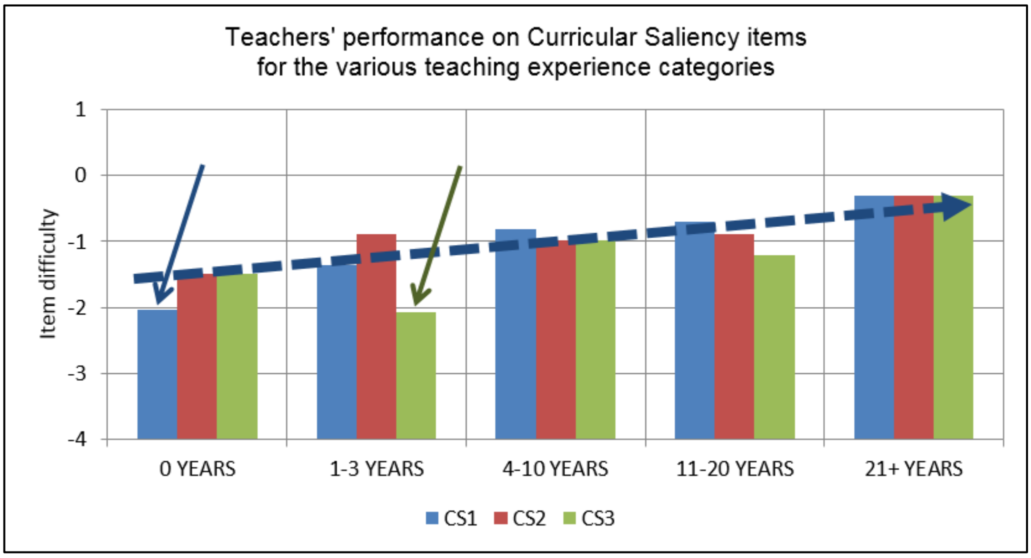


Figure 5.14 Teachers' performance on the curricular saliency items

Similar to the findings for the representations component, teachers with more teaching experience appear to find the curricular saliency items more challenging. Pre-service teachers found it less challenging than other teachers to identify the big ideas for teaching chemical bonding (CS1) (indicated with a blue arrow). This result was statistically significant as per the DIF analysis in Table 5.2 on page 110. Beginning teachers found CS3 less challenging than the rest of the teachers (see the green arrow). Although this was not statistically significant, it was an unexpected result. Teachers in this category have all only taught during the first three years since the introduction of the latest curriculum in South Africa. It may be that due to the introduction of the new curriculum and the fact that they were beginning teachers, they were more alert to the importance of a topic, and were therefore more able to articulate their knowledge.

What is difficult to teach

The instrument included only one item for the 'what is difficult to teach' component, but it required teachers to reflect on at least three different chemical bonding concepts that may be considered to be difficult to teach. Teachers had to provide reasons why they thought the concepts are difficult to teach. As with the previous two components, teachers with more teaching experience found this item more challenging to answer. However, in contrast to the previous two components, the pre-service teachers found this item the most challenging. The findings are shown in Figure 5.15. It was interesting that pre-service teachers found this item very difficult, whereas beginning teachers found it the easiest. De Jong et al. (2005) described a similar finding in a study with pre-service teachers in the Netherlands. The pre-service teachers had limited knowledge of the difficulties their students had with relating the properties of substances to characteristics of the constituent particles. However, the pre-service teachers quickly gained knowledge about these difficulties from teaching the content for the first time. This finding may indicate that this is the component of TSKFT that teachers learn about early in their careers.

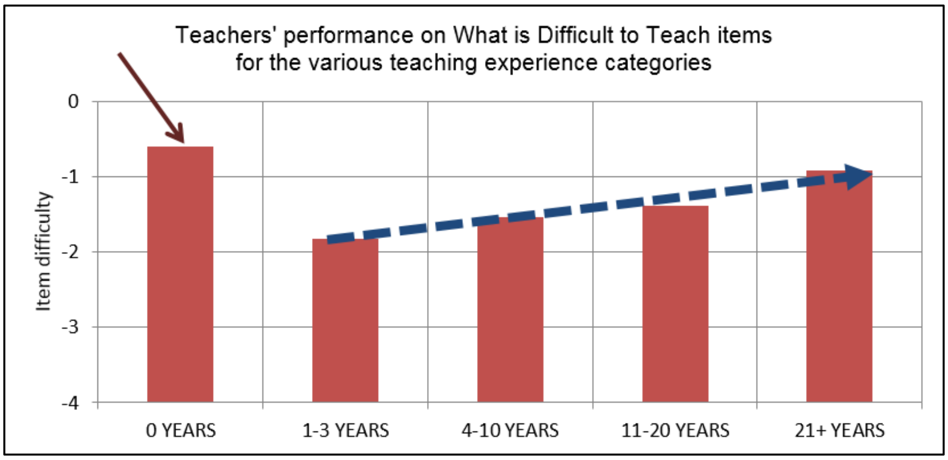


Figure 5.15 Teachers' performance on the what is difficult to teach item

Student Prior Knowledge

The first item in the 'student prior knowledge' section (LPK1) asked teachers to choose the most important concept from the section on the periodic table which they consider essential knowledge their students need to have in place before learning about chemical bonding. For the second item (LPK2), they had to explain how this concept relates to their teaching of bonding. LPK3 was a question on recognising and explaining alternative conceptions in student answers.

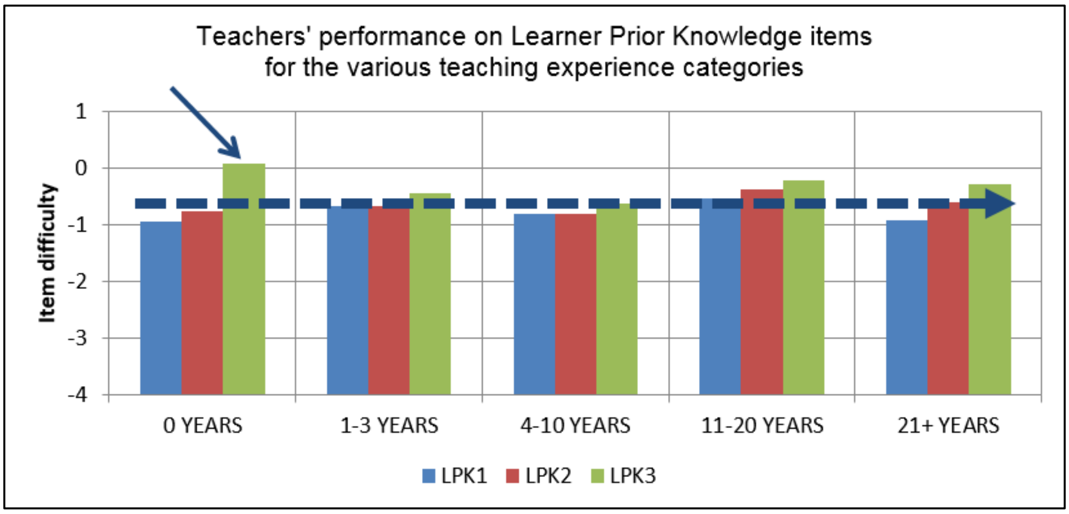
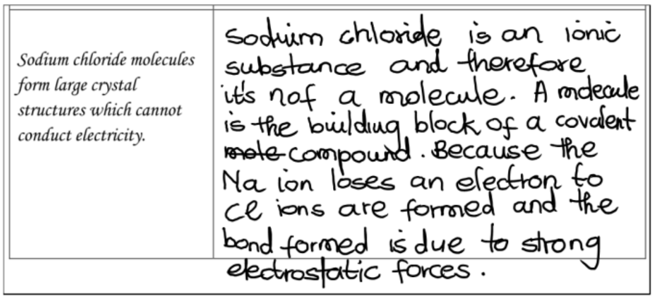


Figure 5.16 Teachers' performance on the student prior knowledge items

The performance of teachers on these items was compared, and the graph is included in Figure 5.16. The performance of the teachers across the experience groups were similar and no specific trend was found. The third LPK item was found to be slightly more challenging than the first two (the green bars are slightly taller than the other two bars for each of the teaching experience groups). Three student statements, each representing a different aspect on the octet explanatory framework (molecular, full shell and ion-pair views) were provided for LPK3 and teachers were asked to identify and elaborate on the problem with each statement. Pre-service teachers found this question more challenging than the rest of the teachers, possibly because it required reflection on student responses, something of which they did not have any prior experience. A closer look at the other teachers' answers, however, revealed that their knowledge was also limited. Despite their ability to identify *that* there was a problem (i.e. an incorrect factual statement), very few teachers were able to identify *why* it was a problem. For example, some teachers knew that it was incorrect to classify sodium chloride as a molecule, as was already found in CK1.1, but almost none of these teachers mentioned that this revealed a view which could limit further understanding. Most teachers just stated the fact, for example: 'NaCl does not form a molecule but an ionic crystal' (T37). Some teachers offered an explanation, but this was strongly linked to the definition from the CAPS document that ‘Molecules (molecular substances) are due to covalent bonding. Ionic substances are due to ionic bonding.’ (DBE, 2011a, p. 32). To illustrate this, the response from teacher T30 is included in Figure 5.17 below:



Sodium chloride molecules form large crystal structures which cannot conduct electricity.	Sodium chloride is an ionic substance and therefore it's not a molecule. A molecule is the building block of a covalent ~~mole~~ compound. Because the Na ion loses an electron to Cl ions are formed and the bond formed is due to strong electrostatic forces.

Figure 5.17 Teacher T30’s response to one of the LPK3 items

This raised the question about teachers’ knowledge of alternative conceptions as tools to gain insight into student learning, and the role of the curriculum in shaping teachers’ understanding of concepts. These aspects were further investigated through interviewing selected participants, as reported in the next chapter.

Conceptual teaching strategies

The conceptual teaching strategy items were the last two TSPCK items. They required teachers to integrate their knowledge of the other components to describe teaching strategies. Two content areas were chosen for this section. CTS1 was designed around the bonding continuum, and CTS2 asked teachers to explain a physical property of graphite from a bonding perspective. Both items were based on classroom scenarios, since to answer this question teachers needed to apply their knowledge for the purpose of teaching.

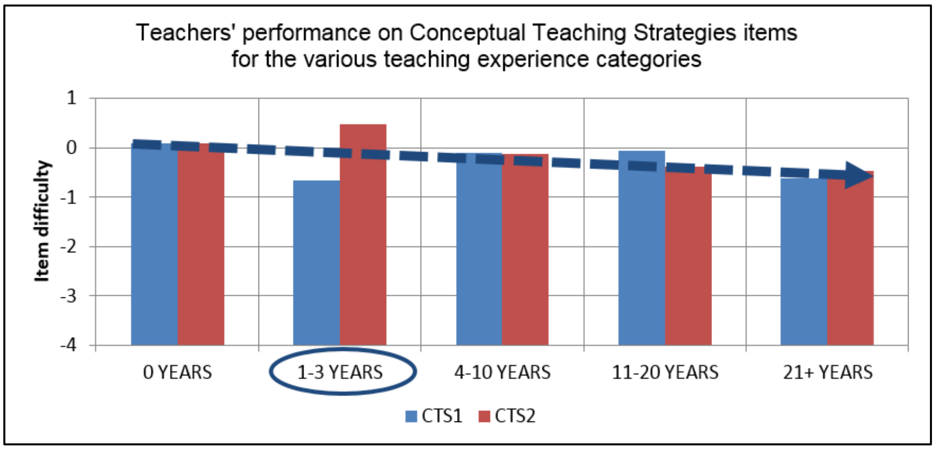


Figure 5.18 Teachers’ performance on the conceptual teaching strategy items

Figure 5.18 plots the teachers' performance against the different teaching experience categories. The CTS items were found to be less challenging for teachers with more teaching experience. As expected, veteran teachers (with 21 or more years' teaching experience) found these items the least challenging. Beginning teachers found CTS1 less challenging, but CTS2 slightly more challenging than expected.

The teachers' performance on these two items was further investigated by comparing the item difficulty to three other person factors. The results are shown in Figure 5.19 to Figure 5.21 on page 130. When the teachers' highest level of teaching qualification was compared, teachers with a master's degree in education found the items much less challenging than the other teachers (see Figure 5.19). The teachers with a master's degree qualification were spread across the experience levels and as no clear reason for their performance could be obtained from the data. This was further investigated in follow up interviews (see Chapter 6).

When the teachers' performance was compared against their highest level of chemistry content training, two different trends for the two items were observed (see Figure 5.20). The first CTS item probing the bonding dichotomy was found less challenging as the teachers had a higher levels of content training, whereas they found the second CTS item more challenging. This was particularly prominent in the chemistry honours group. Four of the five teachers in this group had no teaching experience and the fifth teacher had only one year teaching experience. A possible explanation for the variance in performance can be ascribed to their advanced level chemistry content knowledge. Their content preparation ensured a solid base which they could draw from in reflecting on how they would teach about covalent and ionic bonds (CTS1). However, they performed poorly in the question on bonding in graphite, which meant that their content preparation did not have the same impact in this case. The section on graphite is very specific to the school curriculum, and a possible explanation for their poor performance could be a lack of teaching experience, rather than their advanced content preparation. When the item difficulty was compared across teachers from different types of school (see Figure 5.21), teachers from private schools found the items much easier than the rest of the teachers. This finding was statistically significant, as was shown in Table 5.2 on page 110. It was found that the teaching experience of the teachers in this category varied between 9 and 28 years, with an average of 17.5 years (SD=6.3). This finding mirrors the teaching experience finding that teachers found the CTS items less challenging as they gained more classroom experience. The private school teachers were therefore a sub-set of teachers with much experience. Teachers from other types of school performed similarly on these two items.

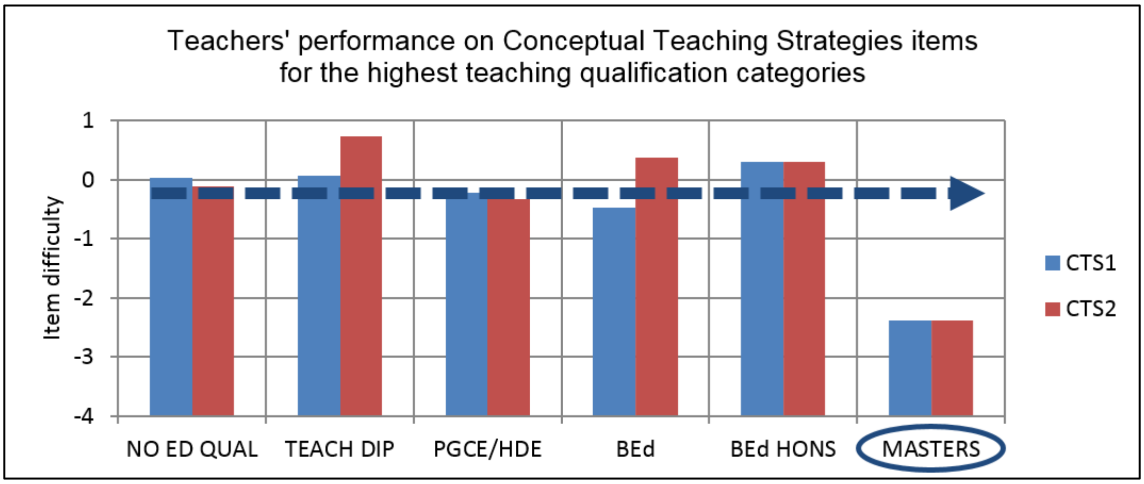


Figure 5.19 Teachers' performance on the CTS items according to teaching qualification

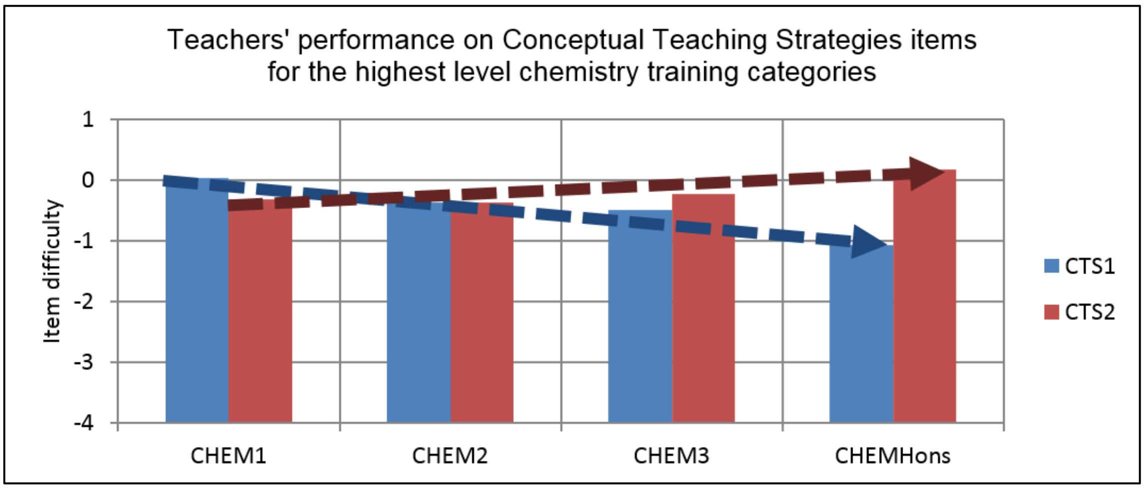


Figure 5.20 Teachers' performance on the CTS items according to chemistry level

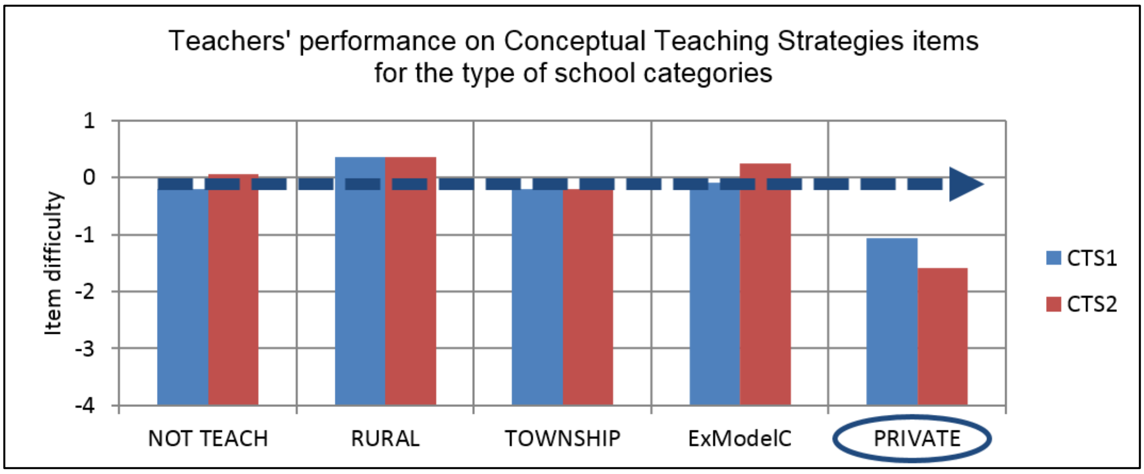


Figure 5.21 Teachers' performance on the CTS items according to the type of school

5.5 Teachers' use of explanatory frameworks as revealed by their instrument responses

Taber (1997, 1998, 2000b, 2001) identified four explanatory principles for chemical bonding, namely the full shell or octet principle, the minimum energy principle, the electrostatic principle, and an orbital or quantum view. He also noted that as individuals develop their understanding of concepts, they can hold multiple conceptions, and will draw from the view that seems most appropriate for the situation (Taber 2000).

In an initial analysis of two of the CK items three of the explanatory principles were prominent, and one additional view and one transitional view were identified (see pages 121-125). To investigate this further a qualitative analysis on more items was performed to form a comprehensive picture of the explanatory frameworks used by the 60 teachers in this study.

Keeping in mind that teachers may hold various views on the nature of chemical bonds (Taber 2000), and the fact that teachers find it difficult to articulate what they know (Loughran, 2012), an analysis of a bigger range of items was needed. All the items in the instrument were examined and the eight best items for eliciting explanatory views were chosen (see Table 5.5 for the list of items). Not all the items were considered equally suitable - for example, the two-tier multiple choice items were not included as they did not allow teachers to freely *choose* a principle and then use it to *explain* the phenomena. The 'what is difficult to teach' items were also not very effective in eliciting principles, because they focussed on identifying a concept and describing what is difficult to teach about the concept. The final list contained eight items, four from each of the CK and TSPCK sections.

Table 5.5 List of items used for an explanatory framework analysis

Item code	**Description**
CK2.1	What is a chemical bond
CK3.3	Description of the polar bonding model
CK4.2	Description of the metallic bonding model
CK5.1	Description of the ionic bonding model
REP2	Choosing a representation and describing its use in teaching
CS1	Choosing the big ideas for teaching and providing reasons for sequencing them
LPK3	Identifying alternative conceptions and explaining the problem
CTS1	Describing a teaching strategy for teaching about the bonding dichotomy

The five explanatory principles which guided this analysis were discussed in the literature review (see pages 36-38), and only their main characteristics are repeated here for ease of reference.

The atomic ontology

This includes the view that the atom is 'the basic building block of matter, and therefore molecules are combinations of atoms, and ions are altered atoms and not entities in their own right' (Taber & Watts, 1996, p. 560). Chemical bonding takes place when atoms combine to form molecules or new substances, therefore building up the structures of matter. In this view a chemical bond can be defined as an interaction between atoms.

The octet rule explanatory principle

This principle is based on the octet rule, which includes a view that atoms actively seek to fill their outer shells. Atoms are viewed as unstable, and will form bonds in order to have a full outer shell, or noble gas configuration, so that it can 'think' it has the right number of electrons and be stable (Taber, 2000).

This view includes explanations where bonding type is viewed as a dichotomy – either covalent or ionic. Covalent bonds are formed by sharing electrons and ionic bonds are formed by transferring electrons, in each case to obtain full octet structures. When electrons are transferred from one atom to another, the atoms belong together and form an ion-pair, or ionic molecule. These are held together in a lattice structure by forces, and not by 'real' bonds. The number of ionic bonds in the lattice is therefore dependent on the valency of the atom (for example sodium can form only one bond), and not the coordination number of the ion. Metallic bonding is often difficult to describe, and may be referred to as 'not a real bond'. It can also be viewed as positively charged ions in a sea of delocalised electrons, where each metal ion has enough electrons around it to have a full shell and therefore be stable.

The minimum energy explanatory principle

According to Taber (2000b), this principle is closely linked to an electrostatic view, but used as a distinctly separate principle in school science. Here physical systems evolve towards lower energy configurations which are more stable than higher energy configurations. Chemical bonding takes place for systems to become stable, or reside at lower energy. The impression may be given that there is an external driving force that causes the system to move towards a lower energy or higher stability.

The electrostatic or Coulombic forces explanatory principle

This view is based on electrostatics principles where opposite charges attract and like charges repel. Atomic structures are formed as a result of the balance of electrostatic attraction and repulsion between positives and negatives. Chemical bonding is viewed as the net electrostatic force between two or more atoms, as a result of forces of attraction between nuclei (protons) and electrons, forces of repulsion between nuclei, and forces of repulsion between electrons.

The orbital or quantum view

This view is based on molecular orbital theory and includes explaining chemical bonding in terms of the existence of atomic orbitals. Chemical bonding involves the overlapping of atomic orbitals to form molecular orbitals with bonding and anti-bonding electrons at different energies.

Analysing responses

The teachers' written responses to the eight items were qualitatively analysed to identify which of these views were displayed in each case. Each teacher was therefore allocated eight codes to produce a total of 480 codes for the 60 teachers. All responses were coded once, after which a coding guideline and examples for each category were compiled. The guideline document is included in Appendix 33. In 24 cases (5%) the teachers gave either no response, or a response that was not relevant. These data points were coded as 'NR', and not included in further analysis. The coding process was repeated, using the guideline document, to ensure consistent application of the coding scheme. Coding was then moderated by one of the members of the reference group (RG4). The various explanatory principles were discussed first, and one questionnaire (T41) was coded together. The moderator then coded three further questionnaires (T16, T27 and T59) in her own time. An inter-rater reliability measure was obtained using *ReCal* (Freelon, 2010). Cohen's kappa value was found to be excellent (κ = 0.818) (McHugh, 2012), and the average percentage agreement was 87.5 percent.

A table with all the findings can be found in Figure 5.22. The teachers' responses are ordered according to the total person measures as obtained from the Rasch analysis described earlier in the chapter. Teachers who obtained the highest scores are ranked at the top of the table, and teachers with the lowest scores are found at the bottom of the table. All person factors are also included in the table. The mean for the test was set at zero, and is indicated by the bold horizontal line.

Teacher code	Teaching experience	Teaching qualification	Content training	School type	Pro-vince	CK 2.1	CK 3.3	CK 4.2	CK 5.1	REP	CS	LPK	CTS	Person measure	Ranking
T28	4-10 YEARS	PGCE / HDE	CHEM2	EXMODELC	WC	EL	OR	EL	EL	OR	EL	ME	EL	2.64	1
T27	21+ YEARS	PGCE / HDE	CHEM3	PRIVATE	WC	EL	OR	OR	EL	EL	ME	EL	EL	2.54	2
T26	11-20 YEARS	MASTERS	CHEM2	EXMODELC	GP	EL	OR	OC	EL	EL	ME	EL	EL	2.44	3
T58	11-20 YEARS	BEd Hons	CHEM3	EXMODELC	GP	EL	OR	EL	EL	OR	ME	EL	EL	1.98	4
T40	21+ YEARS	MASTERS	CHEM3	PRIVATE	WC	OC	EL	EL	EL	OR	OC	EL	EL	1.89	5
T01	4-10 YEARS	MASTERS	CHEM1	PRIVATE	WC	AT	OC	EL	EL	OC	ME	EL	EL	1.71	6
T09	21+ YEARS	PGCE / HDE	CHEM3	NOT TEACHING	GP	ME	OR	EL	EL	OR	ME	EL	OR	1.71	7
T44	21+ YEARS	BEd Hons	CHEM1	PRIVATE	GP	AT	OR	OC	EL	OR	ME	EL	EL	1.71	8
T30	11-20 YEARS	BEd Hons	CHEM1	EXMODELC	GP	OC	OC	OR	EL	OR	ME	EL	OC	1.63	9
T54	0 YEARS	NO ED QUAL	CHEMHons	NOT TEACHING	WC	ME	OC	EL	EL	OC	ME	EL	EL	1.63	10
T57	0 YEARS	NO ED QUAL	CHEM1	NOT TEACHING	WC	AT	OC	EL	EL	ME	ME	EL	NR	1.63	11
T32	21+ YEARS	BEd	CHEM3	EXMODELC	WC	AT	OR	OC	OC	OR	OC	EL	EL	1.46	12
T38	11-20 YEARS	PGCE / HDE	CHEM3	PRIVATE	WC	ME	ME	EL	EL	ME	OC	OC	EL	1.46	13
T29	11-20 YEARS	BEd	CHEM1	EXMODELC	WC	AT	OC	EL	OC	OR	EL	EL	EL	1.37	14
T41	11-20 YEARS	PGCE / HDE	CHEM3	PRIVATE	WC	EL	OC	EL	OC	OC	OC	OC	EL	1.37	15
T36	1-3 YEARS	PGCE / HDE	CHEM3	EXMODELC	WC	AT	OR	EL	EL	ME	ME	EL	EL	1.20	16
T59	21+ YEARS	TEACH DIP	CHEM1	EXMODELC	WC	EL	AT	EL	OC	OR	EL	EL	EL	1.20	17
T03	4-10 YEARS	BEd	UNKNOWN	TOWNSHIP	GP	AT	OC	EL	EL	OC	ME	EL	EL	1.12	18
T33	21+ YEARS	PGCE / HDE	CHEM3	EXMODELC	WC	EL	OR	OR	EL	OR	ME	EL	EL	1.12	19
T37	4-10 YEARS	PGCE / HDE	CHEM1	PRIVATE	WC	EL	OC	OR	OC	OC	ME	OC	EL	1.12	20
T43	4-10 YEARS	MASTERS	CHEM1	EXMODELC	WC	AT	OC	OC	EL	OC	OC	EL	EL	1.04	21
T02	1-3 YEARS	BEd	CHEM1	EXMODELC	GP	AT	OC	OC	EL	OR	OC	EL	EL	0.71	22
T39	21+ YEARS	PGCE / HDE	CHEM3	EXMODELC	WC	AT	OC	EL	EL	OC	OC	EL	OC	0.71	23
T11	21+ YEARS	NO ED QUAL	CHEM1	RURAL	GP	AT	OC	EL	EL	AT	ME	OC	OC	0.63	24
T45	4-10 YEARS	BEd Hons	CHEM1	EXMODELC	GP	EL	EL	OC	OC	EL	EL	OC	EL	0.63	25
T04	4-10 YEARS	BEd	CHEM1	EXMODELC	GP	ME	OC	EL	EL	ME	OC	EL	OC	0.55	26
T34	21+ YEARS	BEd	CHEM3	EXMODELC	WC	EL	OC	EL	OC	OC	ME	EL	EL	0.55	27
T46	0 YEARS	NO ED QUAL	CHEMHons	NOT TEACHING	WC	OC	OC	OR	OC	OC	ME	EL	OC	0.55	28
T10	1-3 YEARS	PGCE / HDE	CHEM3	EXMODELC	GP	AT	OC	OC	OC	OC	OC	OC	OC	0.30	29
T31	21+ YEARS	PGCE / HDE	CHEM2	PRIVATE	WC	OC	EL	OC	EL	OC	ME	EL	EL	0.30	30
T35	21+ YEARS	PGCE / HDE	CHEM3	EXMODELC	WC	EL	OR	EL	OC	OC	ME	EL	EL	0.30	31
T05	1-3 YEARS	PGCE / HDE	CHEM3	EXMODELC	GP	AT	OC	OC	OC	ME	AT	EL	OC	0.22	32
T22	21+ YEARS	BEd	CHEM1	NOT TEACHING	GP	ME	OC	OC	OC	OR	OC	OC	OC	0.14	33
T52	1-3 YEARS	NO ED QUAL	CHEMHons	NOT TEACHING	WC	ME	NR	OC	OC	ME	ME	OC	EL	0.14	34
T60	1-3 YEARS	NO ED QUAL	CHEM2	EXMODELC	WC	ME	OC	OC	EL	ME	ME	EL	EL	0.06	35
T07	11-20 YEARS	PGCE / HDE	CHEM1	NOT TEACHING	GP	AT	NR	OC	OC	OR	NR	EL	EL	-0.18	36
T42	11-20 YEARS	PGCE / HDE	CHEM2	EXMODELC	WC	EL	OR	OC	EL	OC	AT	OC	OC	-0.18	37
T48	0 YEARS	NO ED QUAL	CHEMHons	NOT TEACHING	WC	OC	EL	OC	OC	OC	OC	OC	OC	-0.18	38
T23	21+ YEARS	PGCE / HDE	CHEM1	TOWNSHIP	GP	AT	EL	EL	OC	OR	ME	OC	EL	-0.35	39
T06	4-10 YEARS	BEd	UNKNOWN	TOWNSHIP	GP	AT	OC	OC	OC	OC	ME	OC	EL	-0.43	40
T49	0 YEARS	NO ED QUAL	CHEM3	NOT TEACHING	WC	ME	OC	OR	OC	OC	OC	OC	NR	-0.43	41
T16	11-20 YEARS	BEd Hons	UNKNOWN	TOWNSHIP	GP	AT	OC	OC	NR	OC	OC	OC	EL	-0.51	42
T55	0 YEARS	NO ED QUAL	UNKNOWN	NOT TEACHING	WC	OC	OC	NR	OC	OC	ME	OC	NR	-0.51	43
T12	4-10 YEARS	PGCE / HDE	CHEM1	EXMODELC	GP	AT	OC	OC	EL	OC	OC	OC	EL	-0.59	44
T18	11-20 YEARS	NO ED QUAL	CHEM1	PRIVATE	GP	EL	OC	OC	OC	OC	NR	OC	EL	-0.92	45
T47	0 YEARS	NO ED QUAL	CHEM1	NOT TEACHING	WC	OC	OC	OC	OC	OC	ME	OC	OC	-1.01	46
T51	0 YEARS	NO ED QUAL	CHEM1	NOT TEACHING	WC	NR	OC	NR	OC	OC	OC	OC	NR	-1.01	47
T08	4-10 YEARS	BEd	CHEM1	TOWNSHIP	GP	OC	OC	NR	OC	AT	ME	OC	NR	-1.09	48
T20	0 YEARS	BEd	UNKNOWN	NOT TEACHING	GP	ME	AT	AT	OC	ME	ME	OC	EL	-1.09	49
T21	11-20 YEARS	PGCE / HDE	UNKNOWN	EXMODELC	GP	ME	OR	NR	OC	OC	ME	OC	OC	-1.25	50
T17	1-3 YEARS	BEd	UNKNOWN	TOWNSHIP	GP	AT	NR	AT	OC	OC	OC	OC	AT	-1.42	51
T50	1-3 YEARS	NO ED QUAL	CHEMHons	TOWNSHIP	WC	AT	AT	AT	OC	OC	ME	OC	OC	-1.42	52
T56	0 YEARS	NO ED QUAL	UNKNOWN	NOT TEACHING	WC	AT	NR	NR	NR	ME	OC	OC	NR	-1.42	53
T25	11-20 YEARS	TEACH DIP	CHEM1	EXMODELC	GP	OC	OC	OC	EL	OC	OC	OC	OC	-1.51	54
T19	4-10 YEARS	TEACH DIP	UNKNOWN	TOWNSHIP	GP	EL	AT	OC	EL	OC	ME	OC	EL	-1.59	55
T24	0 YEARS	BEd	CHEM1	NOT TEACHING	GP	AT	OC	AT	OC	AT	OC	OC	EL	-1.76	56
T15	1-3 YEARS	PGCE / HDE	CHEM3	RURAL	GP	OC	OC	OC	OC	OC	OC	OC	OC	-1.93	57
T53	0 YEARS	NO ED QUAL	UNKNOWN	NOT TEACHING	WC	EL	OC	OC	OC	OC	ME	OC	EL	-1.93	58
T13	4-10 YEARS	PGCE / HDE	CHEM1	TOWNSHIP	GP	OC	AT	OC	OC	OC	ME	NR	NR	-2.56	59
T14	11-20 YEARS	PGCE / HDE	UNKNOWN	EXMODELC	GP	AT	AT	AT	OC	OC	OC	OC	EL	-2.66	60

Key: **AT**: Atomic ontology **OC**: Octet explanatory principle **OR**: Orbital view
ME: Minimum energy explanatory principle **EL**: Electrostatic explanatory principle
NR: No response

Figure 5.22 Explanatory framework analysis results

The most prevalent view was the octet explanatory principle (Figure 5.23). Teachers used it 43 percent of the time (196 cases), followed by the electrostatic view at 29 percent (132 cases) of the time. Teachers used the atomic (9%) and orbital (7%) views less frequently. The minimum energy principle was used 12 percent (55 cases) of the time.

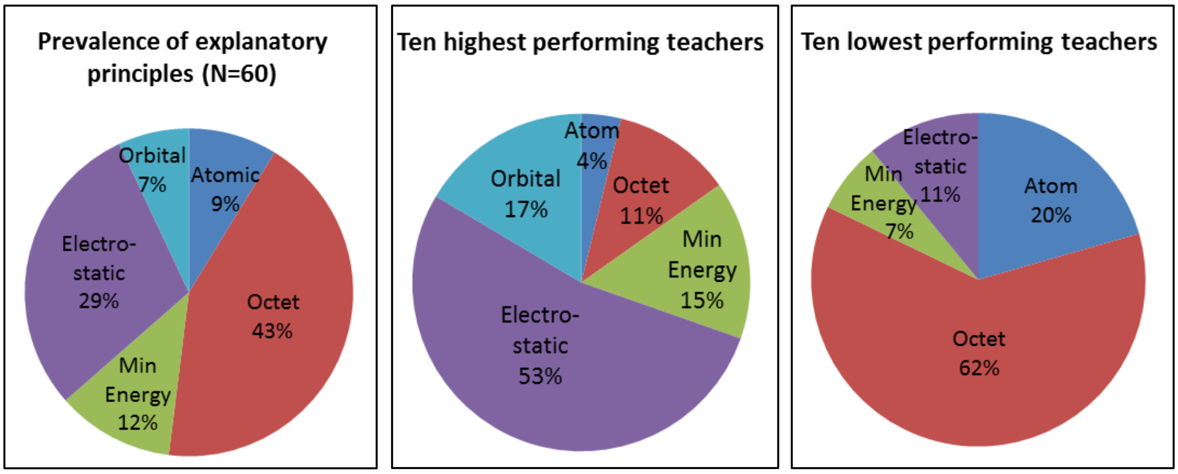


Figure 5.23 Prevalence of explanatory principles

The results from the ten highest performing teachers were compared to the ten lowest performing teachers (see Figure 5.23). High performing teachers used an electrostatic view in more than half (242) the cases, and an atomic and octet view only 15 percent of time (68 cases). The low performing teachers used an atomic or octet view 82 percent of the time (374 cases). High levels of TSKFT is therefore linked to more frequent use of a more sophisticated understanding of chemical bonding, such as orbital or electrostatic views. The finding was not unexpected as a conceptual teaching approach underpins TSKFT. The electrostatic view is more sophisticated than an atomic or octet view, and the higher performing teachers were expected to use it more often.

The focus for the study, however, was not to identify explanatory principles, but rather to use it as a tool to map potential learning trajectories for teachers. For this purpose the prevalence of explanatory principles was compared across the different teaching experience categories and other person factors identified by the DIF analysis.

The data obtained from the explanatory framework analysis was used to quantify how often each of the teacher subgroups used each of the principles. Figure 5.24 on page 136 summarises the prevalence of the five explanatory principles according to teaching experience, highest teaching qualification, highest level of chemistry content training, and the type of school a teacher was teaching at.

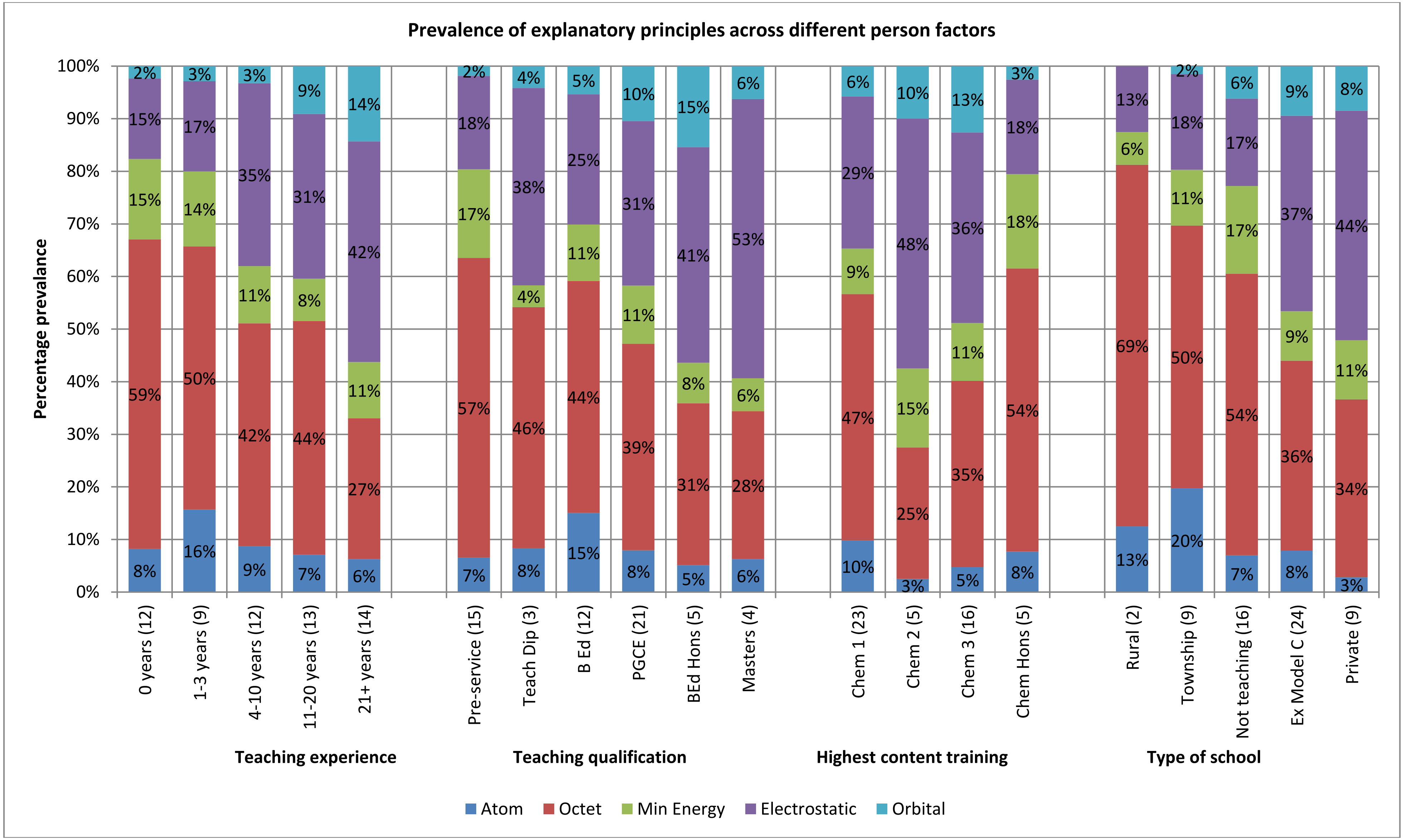


Figure 5.24 Prevalence of explanatory principles for four person factors

The percentage prevalence is indicated on the vertical axis, and the various person factor categories on the horizontal axis. The number of teachers in each category is placed in brackets after the category code.

The most naïve view, the atomic view, is indicated in darker blue at the bottom of each bar graph, with the octet principle above it. As one moves towards the top of the bar graphs, the explanatory principles become more sophisticated, and closer to the currently accepted scientific view.

The teachers in each of the categories made use of all the frameworks at some point. There was only one exception, namely teachers from rural schools. This group had only two teachers and did not use the orbital view in any of their answers.

Teachers with more teaching experience used the orbital and electrostatic views more often, and the atomic and octet view less frequently. Teachers with higher levels of teaching qualifications also used the orbital and electrostatic views more often, and the atomic and octet views less frequently.

There were no specific trends within the chemistry content training categories. The chemistry honours group performed weaker than expected, but as explained earlier, this group had very little teaching experience. The chemistry third year level group used the electrostatic view more often, and the octet view less frequently, than the chemistry first year group. From the results shown here, it appears that teaching experience and teaching qualification seem to play a more important role than the teachers' level of chemistry training.

When the teachers were grouped into the type of school they were teaching at, teachers from ex-model C schools and private schools used the electrostatic and orbital view much more frequently than teachers from township schools and teachers who were not yet teaching.

The minimum energy principle was used almost equally across all the categories (between 6 and 18 percent) and no specific trends were observed. The orbital view was not used by many teachers, or on many occasions. This was somewhat expected as the school curriculum does not require an orbital view of chemical bonding. Teachers, even if they understand chemical bonding in terms of atomic orbital overlap, may therefore choose not to use this line of explanation since it was not required by the curriculum.

5.6 Conclusion

The second research sub-question required the identification of factors which influenced the quality of teachers' topic specific knowledge for teaching chemical bonding. From the DIF analysis, and further in-depth quantitative and qualitative analysis of the teachers' answers to the questionnaire, the following factors have been identified:

- Teaching experience
- The level of the teachers' chemistry content training
- The level of the teachers' teaching qualification

The type of school, and more specifically teaching at a private school, was also identified as a possible factor, but from the analysis in this chapter, it was found that the private school teachers are a sub-set of teachers with many years' teaching experience. The type of school was therefore not considered a separate factor.

The quantitative and qualitative analysis of the teachers' responses to the instrument further highlighted the following trends in teachers performance, and shed light on how these factors influenced the quality of the teachers' topic specific knowledge.

Trends for the TSPCK items show that teachers with more **teaching experience** found the representations, curricular saliency and what is difficult to teach items more difficult, the student prior knowledge items more or less the same, and the conceptual teaching strategies items less challenging.

Pre-service teachers and beginning teachers had different performance profiles: **pre-service teachers** found identifying strengths and weaknesses for representations and choosing the big ideas for the topic less challenging than the other teachers, whilst what is difficult to teach, student prior knowledge and conceptual teaching strategies items, were found to be more challenging. **Beginning teachers** had mixed performance patterns. They found some items easy (identifying why it is important to teach about chemical bonding and what is difficult to teach), and some items much more challenging than expected (one of the conceptual teaching strategies questions). It seems that teachers develop different aspects of topic specific knowledge for teaching at different stages of their careers. Teachers with a **master's degree in education** were more likely to find the conceptual teaching strategy questions easy. It seems that teaching experience and the level of teachers' teaching qualification played a more influential role than the type of school where the teacher was teaching.

Teachers performed **better at the TSPCK items than the content knowledge items.** This was somewhat expected since the survey sample were mostly experienced teachers. Teachers showed an increase in their knowledge of chemical bonding models over time. Covalent bonding was the least challenging, with ionic and especially metallic bonding much more challenging. Teachers found applying their knowledge of chemical bonding to explain physical properties of substances particularly challenging; on the content itself (CK5.2), as well as transforming the content for the purpose of teaching it (CTS2).

Teachers were found to **hold alternative conceptions** in a number of areas of chemical bonding. The CK1 items were the most challenging, and teachers found it particularly difficult to identify possible learning impediments in student answers (LPK3). Similar findings were reported in other countries, for example in Sweden (Bergqvist et al., 2016). This is an area of concern as it limits teachers' ability to recognise alternative conceptions in their students' work, and consequently limits their ability to support student learning in the classroom.

Teachers also held **multiple conceptual frameworks,** and may choose to use a less complex framework to explain the content whilst their own understanding included a more sophisticated framework. This can be interpreted as teachers showing curricular saliency – choosing a particular line of explanation because they have contextualised their teaching to suit the specific group of students. However, some teachers did not have a more sophisticated understanding of the content than an octet framework, and were therefore not able to use a more complex framework, such as an electrostatic framework, to use in their explanations.

This chapter presented the qualitative and quantitative analysis of the survey teachers' responses to the questionnaire. Three prominent teacher factors were identified and possible trends in the teachers' performance were described, using an explanatory framework analysis. Some findings, for example the performance of teachers with master's degrees in education, the inability of teachers to identify the alternative conceptions as a tool to support further learning, and the weaker performance on the conceptual strategies questions, could not be fully explained. The next chapter will investigate this further by looking more closely at the experiences of ten selected teachers to identify significant events, and how the events have influenced the quality of the teachers' topic specific knowledge for teaching chemical bonding.

Chapter 6 Interview analysis and findings

Chapter 5 reported on the analysis of teachers' instrument responses to identify teacher factors which may have played a role in the teachers' performance on the test for topic specific knowledge for teaching. This chapter will now look more closely at ten selected teachers to identify how these factors, and other significant events, played a role in their perceived shifts in topic specific knowledge for teaching over time, by analyzing the teachers' story-line interview data.

6.1 Introduction

Teaching can be seen as an activity which involves lifelong learning (Feiman-Nemser, 2001). Learning can be viewed as change and has a trajectory (Duschl & Hamilton, 2011) and to understand the trajectory of learning one must investigate the route and process of how change took place, and the factors and events which influenced the change.

Teachers experience a variety of events, or opportunities for learning, over their careers, some which play a role in their teaching and others which don't. Some events and their influence on teaching are significant enough for teachers to remember long after the event took place. In this study, a selected group of ten teachers were interviewed to capture some of these significant events, and to understand how the events played a role in their learning to teach. The story-line method (Beijaard et al., 1999; Berry & Van Driel, 2013; Nilsson & Van Driel, 2011) was used to support teachers in remembering events and identifying their influence on specific aspects of their teaching.

The story-line method was adapted to enable teachers to reflect on the six components of TSKFT, as was described in Chapter 3. Since the teachers completed a diagnostic instrument probing the same aspects of teaching chemical bonding, they were also asked to elaborate on their answers in the questionnaire, specifically on the two items on conceptual teaching strategies.

The interview transcripts and the teachers' story-line graphs were analysed using a grounded approach to identify emerging themes for significant events. PCK episodes (Park & Chen, 2012), were identified for each of the teachers and further qualitatively analysed to describe how the events have influenced the quality of the teachers topic specific knowledge for teaching chemical bonding.

A summary of the participants was provided in Chapter 3, but is included in Table 6.1 below for ease of reference.

Table 6.1 Interview participants

Teacher code	Teacher pseudo-nym	Pro-vince	Gen-der	School type	Highest chemistry level	Highest teaching qualification	Years' teaching experience	Overall ranking
T28	Adrian	WC	M	Ex-model C	Chem2	PGCE/HDE	4	1
T26	Simon	GP	M	Ex-model C	Chem2	Masters	12	3
T58	Doreen	GP	F	Ex-model C	Chem3	Honours	16	4
T40	Alicia	WC	F	Private	Chem3	Masters	24	5
T44	Glenda	GP	F	Private	Chem1	Honours	22	6
T01	Natalie	WC	F	Private	Chem1	Masters	10	7
T41	Stephanie	WC	F	Private	Chem3	PGCE/HDE	14	14
T59	Desmond	WC	M	Ex-model C	Chem1	Teach Dip	30	17
T43	Jonathan	WC	M	Ex-model C	Chem1	Masters	5	21
T45	Vuyo	GP	M	Ex-model C	Chem1	Honours	5	25

6.2 Identifying significant events

The story-line interview transcripts were analysed using a grounded approach to identify the most significant events for each of teachers, as was described in Chapter 3 and Appendix 8. Events were considered significant if teachers were able to recall the event and describe its significance in terms of specific aspects of teaching chemical bonding. The grounded analysis of the interview transcripts, story-line graphs and questionnaire responses, revealed five salient themes, namely: curriculum change, furthering their education, teaching experience, the role of colleagues, and the role of students. Sub-themes were also identified and are listed in Figure 6.1.

Instances of explicit PCK, also referred to as PCK episodes (Park & Chen, 2012), were then identified for each of the teachers and qualitatively analysed to identify how the events contributed to the perceived growth in the teachers' topic specific knowledge for teaching chemical bonding. The PCK episode analysis procedures are described in Appendix 10.

Significant events

Name	Sources	References	Created On	Created By
Curriculum change	9	86	2015/07/29 07:40 A	RT
Designing curriculum materials	7	34	2015/02/18 04:00 P	RT
Introducing a new curriculum	8	44	2015/02/18 12:28 P	RT
Working with curriculum documents	4	8	2015/02/18 04:04 P	RT
Furthering their education	9	64	2015/07/29 07:47 A	RT
Additional courses and workshops	2	6	2015/09/21 04:41 P	RT
Content training	8	27	2015/02/18 04:29 P	RT
Post-graduate studies in education	6	31	2015/02/18 12:28 P	RT
Teaching experience	10	66	2015/07/29 07:46 A	RT
Teaching the topic for the first time	8	22	2015/02/19 02:09 P	RT
Teaching the topic multiple times	8	25	2015/02/18 02:10 P	RT
Teaching the topic to multiple grade	6	19	2015/02/18 12:29 P	RT
The role of colleagues	8	53	2015/07/29 08:14 A	RT
The role of students	9	47	2015/02/18 12:28 P	RT

Figure 6.1 Themes for significant events for 10 teachers

6.3 Findings

The findings from each of the main themes are briefly summarised to provide an overview, and then discussed in more detail by presenting selected events from each of the teachers.

Curriculum change

South Africa experienced three curriculum changes in the past 15 years (see page 6 for a diagrammatic representation of the curriculum changes in South Africa). The NATED curriculum was in place until 2005 for Grade 10, when it was replaced with the Revised National Curriculum Statement (RNCS) from 2006 to 2011, and the Continuous Assessment Policy Statement (CAPS) from 2012 onwards. Teachers with 11 or more consecutive years' teaching experience therefore taught all three these curricula, and teachers with four or more years taught at least two curricula. Most teachers in the sample therefore experienced at least one change in the national curriculum.

Nine of the ten teachers mentioned that the changes in the curriculum played a role in shifting their knowledge of teaching chemical bonding. The only teacher who did not mention anything about curriculum change was Glenda. She has only taught in private schools and mostly the same curriculum. At the time of most of the national curriculum changes she was the Deputy Head at her school and involved in a process of obtaining international accreditation for the school, and therefore distanced from the local changes taking place.

Eight of the ten teachers noted that **the introduction of a new curriculum** brought changes in terms of new content and assessment requirements. Although a change in a curriculum could be an unsettling experience for many teachers (Rogan, 2007), the teachers in this study perceived the change as having had a positive effect on their teaching. They felt it pushed them to expand their content knowledge and think differently about how they taught.

Seven teachers mentioned that the new curriculum brought the need for **new curriculum materials** like textbooks, worksheets or other teaching resources. The creation of these materials challenged the teachers' content knowledge and made them reflect on how they would sequence and teach the content.

The NATED curriculum documents were not as accessible as the later curriculum documents, and teachers generally used textbooks as a proxy for NATED. With the introduction of the NCS and CAPS the curriculum documents became freely available. The education department arranged many training workshops and distributed the curriculum documents at these workshops. The availability of the documents also improved with the shift towards electronic communication at many schools at the time. Four teachers mentioned that **working with the actual documents** to make sense of the changes as important, because it gave them general knowledge about how curricula worked, and knowledge about the sequencing of concepts.

Furthering their education

Nine of the ten teachers mentioned aspects of furthering their education as significant. Some of the events were linked to **content training** where the teachers reflected on how their undergraduate chemistry and physics coursework provided the foundation for teaching about bonding. All the teachers who completed **post-graduate courses in education** mentioned one or more aspects of the coursework as significant, such as learning about how students learn, knowledge about alternative conceptions, assessment, and teaching strategies. Two of the teachers mentioned that **the additional courses or workshops** they attended were significant in providing them with knowledge about assessment strategies, or made them reflect on the teaching sequence prescribed by the curriculum.

Teaching experience

All ten teachers identified one or more aspects of teaching experience as important. For some teachers the fact that it was the **first time that they were teaching the topic** was important, especially because it challenged their content knowledge. Over time, as the teachers **taught the topic multiple times**, they became more familiar with the content and developed a better appreciation for what their students found difficult. Six teachers mentioned that the responsibility of **teaching the topic in multiple grades** gave them an overall view of the curriculum and helped them sequence concepts.

The role of colleagues

Eight of the ten teachers mentioned the role of colleagues as significant. This included colleagues at the same school, in their department or from another department, at another school through online forums or electronic mailing lists, or from a district office. Teachers most often reflected on the content support they received from their colleagues, but also mentioned that observing someone else teach gave them alternative teaching strategies or new ideas for teaching.

The role of students

Nine of the ten teachers reflected on the role that their students played in their teaching. This included the questions students asked in class which challenged their content knowledge or teaching strategies, or the comments from students which gave them insight into student prior knowledge. Many teachers felt that they became more student-focussed over time, therefore paying more attention to their students, what they know, don’t know, or found challenging.

Overall, single events sometimes played a role, but more often it was a combination of events that teachers felt that shifted their perceived knowledge for teaching chemical bonding. The teachers’ experiences were integrated and each of the cases involved events across the themes and events that influenced more than one aspect of their knowledge. Selected events from each of the teachers is presented below to provide more detail about the events and show how the events influenced the teachers’ knowledge.

6.3.1 Natalie

Natalie is a biology major and did not have any content training beyond first year chemistry. Like many South African teachers she started her career teaching up to a Grade 10 level, and over time she was given the senior grades to teach. When she had to teach Grade 11 for the first time, she was confronted with new content that she had not come across before. A new curriculum, the National Curriculum Statement (NCS) (DBE, 2003), had recently been implemented and ‘bond energy and length’ was a new section in the Grade 11 curriculum. Students were required to interpret a potential energy diagram which explains the link between bond energy and inter-atomic distance. (DBE, 2006, p.72).

In the interview, seven years later, Natalie remembers quite clearly how she was challenged by this graph: ‘I had to sit with that graph for days before I understood what was going on and it probably took me another three years to explain what was going on’ (Natalie’s interview, lines 186-187). In the measuring instrument this graph was included under the representations section (REP1), and teachers were asked to comment on the strengths and weaknesses of using each representation to teach about chemical bonding. Figure 6.2 shows Natalie’s comments on the use of this representation in the questionnaire. She writes the following under weaknesses: ‘This graph is very challenging for them to understand and only older students generally get it. The negative energy is the part that confuses them’. The fact that Natalie found it difficult to understand the content, gave her a better understanding for her students’ challenges.

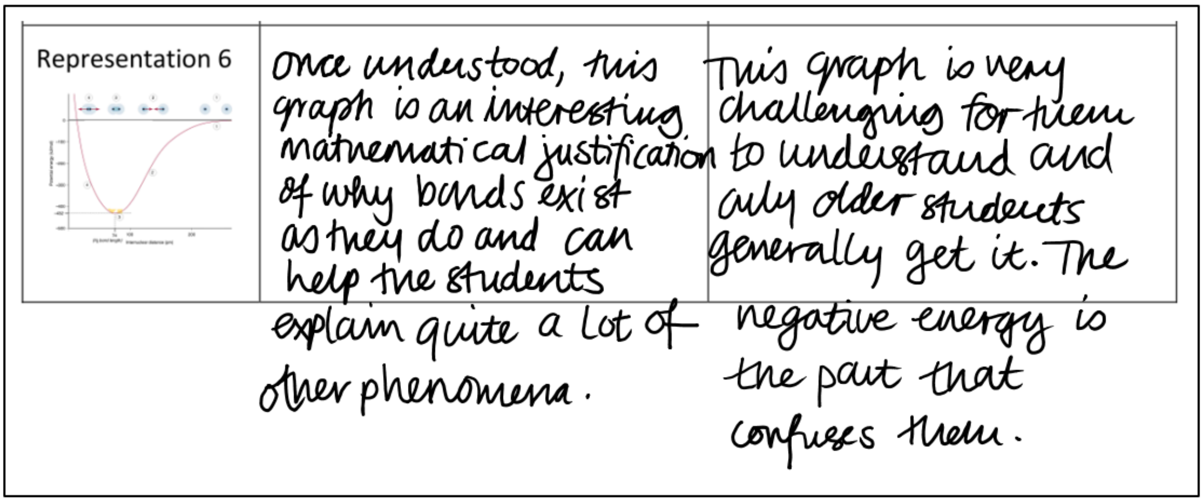


Figure 6.2 Natalie’s response to representation 6 in the instrument (REP1)

When Natalie reflected on how her knowledge of representing chemical bonding had changed over time, this event stood out. In her story-line (see Figure 6.3) she showed an increase in her perceived knowledge of content representations over a period of three years and when reflecting on how this had changed her teaching strategy, she explained: ‘I am not doing the ‘oh just learn this’ any more, … now I can actually have a conversation about it. (Natalie’s interview, lines 188-189).

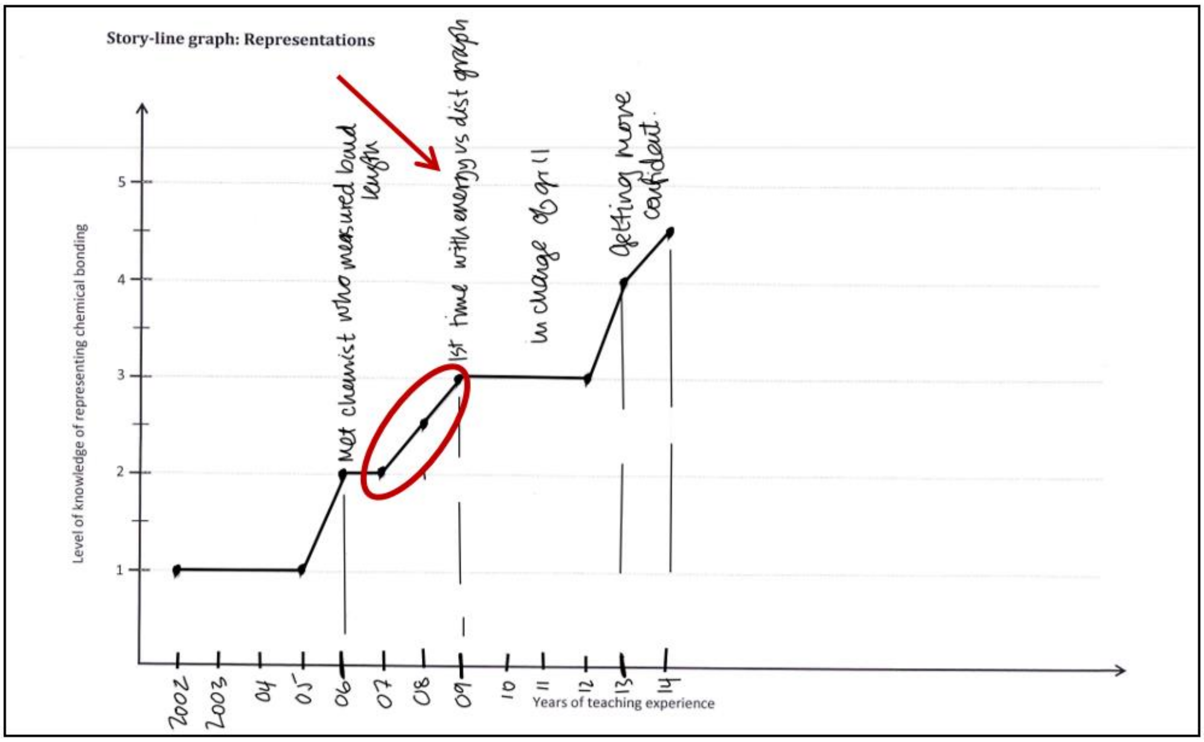


Figure 6.3 Natalie's story-line of her perceived knowledge of content representations

The introduction of new content as part of the new curriculum, and the fact that Natalie had to teach this content for the first time, made her realise that she lacked content knowledge in this topic. She increased her knowledge of chemical bonding by finding information in textbooks and on the internet. She was also fortunate that she had a knowledgeable colleague whom she could ask for help. She explains that her colleague 'was actually very good, she would actually just sit down and explain … just like she would teach the kids, she would be teaching me.' (Natalie's interview, lines 196-197)

Through these events, Natalie gained knowledge about representing chemical bonding, as well as what her students found difficult. Over time she gained confidence in teaching a new topic, and also changed the way she taught this section, shifting to a more conceptual approach, and not just telling her student to learn the content.

6.3.2 Alicia

Alicia has 24 years' teaching experience, a bachelor's degree in chemistry, and a master's degree in education. In her first teaching post she taught students who failed Grade 12 and had enrolled in a one-year programme to repeat Grade 11 and 12. As part of her job she had to design a teaching sequence[5] for the programme. Alicia worked with curriculum documents in various ways over her career, in writing textbooks, piloting material for adult education (ABET), and implementing the various new curricula in South Africa, but it was this first experience that stood out the most. Twenty years later she identified this experience as significant in three of her story-lines. Figure 6.4 shows the story-lines for curricular saliency where she referred to the experience as 'design curriculum for failed set Gr 12s'. Alicia remembered that she had to work with the curriculum documents to put together a condensed curriculum for the programme, which included chemical bonding.

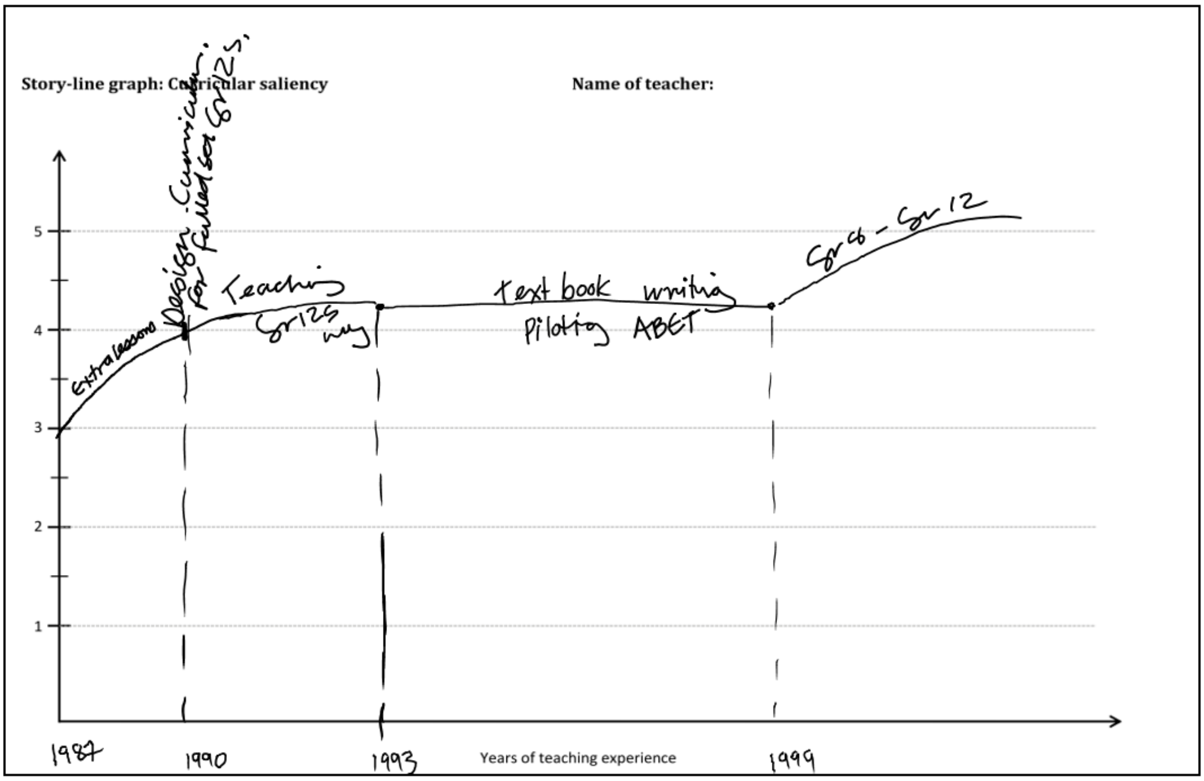


Figure 6.4 Alicia's story-line for curricular saliency

This experience influenced her general curricular knowledge as well as her ability to sequence concepts for teaching. She reflected on her experience as follows: 'I had to design curriculum there, so I had to say what is the order in which to teach this, what are the most important things, what comes before what' (Alicia's interview, lines 403-405). When Alicia was asked how she taught chemical bonding, she was adamant about the order: teach covalent bonding first, then ionic bonding, and only then metallic bonding. She explains her thinking as follows:

[5] Teaching sequence here, and in the rest of the thesis, refers to the order in which topics are taught.

‘never, never, never [teach metallic bonding] before ionic bonding, because they need to get an understanding of what an ion is first’ (Alicia’s interview, lines 372-373). The teaching order she proposed was determined by the prior knowledge that had to be in place to ensure further understanding.

Alicia completed a master’s degree in education before starting her career as a teacher. She remembered the variety of teaching strategies she learned about during this course. Although these were not aimed at a specific topic, it increased her general pedagogical knowledge which she could draw from later in her career. She says the following about her perceived growth in pedagogical knowledge: ‘I mean not particularly with bonding but I was exposed to many teaching strategies when I did my master’s degree and that was really helpful’ (Alicia’s interview, lines 555-556)

In the questionnaire, Alicia identified metallic bonding as difficult to teach (see Figure 6.5). She is aware that students found it difficult to make sense of the presence of delocalised electrons amongst positive ions in a metallic solid, and suggested that the topic should perhaps be taught in a later grade.

	Reasons why I think this is difficult to teach:
Concept 1: Metallic bonding	They are taught that metallic bonding is a form of bonding and yet it is also an intermolecular force and that is very confusing. You don't have a fixed molecule like with covalent, or a unit like with ionic bonding. You have the negative delocalized electrons and positive kernels so you can't look at that like a unit. Students get confused. I think it should be taught in grade 11 and not in grade 10 because they don't need it this early.

Figure 6.5 Alicia’s response to ‘what is difficult to teach’

When Alicia was asked how she would teach about metallic bonding, she explains how she uses a demonstration with Vaseline (petroleum jelly) and ball bearings or marbles to help students conceptualise a metallic bond:

> I used to take Vaseline, and put ball bearings in the Vaseline, or marbles. … They can see with the marbles that there are no bonds in fixed directions, and it can move around in the Vaseline, which of course is a metaphor for delocalized electrons, so they can see the total difference between an ionic bond, on the one hand, … and then on the other hand a metallic bond, with no bonds in fixed directions and which you can flatten, it’s malleable, it’s ductile, it’s flexible. (Alicia’s interview, lines 364-370)

Alicia has very good content knowledge and obtained the fifth highest overall score. She ascribed this to her chemistry training:

> 'we had an outstanding chemistry teacher, her major was chemistry ... I absolute totally adored hybridization, sp^3, pi, sigma bonds, loved the whole thing of bond angles of ammonia and methane and all that kind of stuff, knew it off by heart, absolutely loved it.' (Alicia's interview, lines 267-272)

She drew from this content knowledge to choose a representation and teaching strategy for metallic bonding that will help her students visualise the concept of a metallic bond.

Alicia's involvement in creating curriculum materials and designing curricula not only increased her general curriculum knowledge, but also expanded her knowledge of sequencing topics, and concepts within a topic (curricular saliency). This influenced the order in which she taught the chemical bonding models, keeping student prior knowledge in mind. Her post-graduate studies in education provided her with a repertoire of teaching strategies which she could choose from later in her career. When teaching about metallic bonding she chose a representation (Vaseline and marbles) and accompanying teaching strategy (demonstration) that would ensure conceptual understanding, and drew from her content knowledge to explain the analogy she chose for teaching the concept.

6.3.3 Jonathan

Jonathan has five years' teaching experience. He has an honours degree in physics, and chemistry only at a first year level. He completed the coursework for a Master in physics education before he started his career as a teacher. Jonathan viewed his teaching as student-focussed and said: 'I feel like I am very relational in how I teach, so I do make an effort to get to know them [the students]' (Jonathan's interview, lines 112-113). He used many metaphors and analogies, often involving individual students in his examples. He prides himself in finding better analogies and metaphors: 'One of my favourite things in teaching is coming up with a really good metaphor, that's got as little extra baggage and gets to the heart of what the issue is' (Jonathan's interview, lines 92-93). For example, in the first conceptual teaching strategy question (CTS1), he suggested a metaphor for teaching about the bonding spectrum and making sense of the 'cut-off value' for electronegativity difference by using height as a metaphor (see Figure 6.6). He wrote: 'Imagine that we have to classify people as short or tall'. He then related this to the idea that covalent and ionic bonding lies on a continuum and that the cut-off value is arbitrary.

Section 5: Conceptual teaching strategies

5.1 During a lesson, a learner asks the following question:

He read on the internet that beryllium bromide ($BeBr_2$) forms an ionic bond because it is a bond between a metal and a non-metal. However, the Periodic Table shows the electronegativity difference between the atoms as 1.3, which makes the bond a covalent bond, according to the rule they have learned in class: 1,3 is less than 1,7, the 'cut-off value' for ionic bonds. Which type of bond is formed in beryllium bromide?

H 2.1									He
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.[illegible]	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.[illegible]	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6

How would you teach about this in a lesson? Consider the following in your response: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

I think its important to stress that then "non-metal/metal is ionic" is a rule of thumb.

I find it useful to get the kids to think of a physical attribute that spans a spectrum

E.g. "Imagine that we have to classify people as short or tall. What is good cut-off height?" Gets them to see that although we set a cutoff, you might have two people that are almost the same height. The 1,7 mark isn't a sharp divide, but rather a reference value from which we can say a bond is "more covalent" or "more ionic".

Figure 6.6 Jonathan's response to item CTS1

During his master's degree Jonathan was introduced to various theories on how students learn, and now views learning as a process of organising bits of knowledge in a logical way. When he was asked when he developed this way of thinking he said: 'I think that is because of my masters, I mean it dealt a lot with … a unitary view of ideas or things, versus a spontaneous knowledge in pieces type of approach, and I think that I have reflected on this more in the last few years' (Jonathan's interview, lines 304-306). Jonathan further explained that he believed students find it difficult to logically put these bits of knowledge together. In his view teachers need to provide scaffolding for students to help them organise information and in the process learn better. Jonathan's increased knowledge about how students learn has impacted his teaching strategies, shifting from initially being textbook bound, to now focussing more on constructing good metaphors to help his students learn. He said the following when he reflected on how his teaching strategies had changed over time: 'I am less bound by the textbook … I have become more competent in my ability to construct a good metaphor on the fly … and to be able to say this is where this metaphor breaks down' (Jonathan's interview, lines 423-426).

As Jonathan became more comfortable in teaching the same content year after year, he was able to focus less on how to teach the content, and more on his students. He says: 'I can focus more subconsciously to get to know students 'cause I don't have to think about teaching' (Jonathan's interview, lines 146-147). Jonathan taught with two very experienced colleagues. As part of their school policy he visited their classrooms and observed their teaching on a regular basis. This gave him ideas for teaching strategies:

> I think one of the things that is quite unique to [my school] is an expectation of professional development by watching other teachers. So a lot of the things that have helped were the things I saw [my colleague] doing when I sat in the back of his class. (Jonathan's interview, lines 526-529)

Over time Jonathan has become more student-focussed, adjusting his teaching strategies to ensure that his students learn: 'I will often see that the kids are not getting it, and then I adjust for that' (Jonathan's interview, lines 464-465). The introduction of more formative assessment in class gave him insight into whether his students are learning effectively. He identified the use of more formative assessment strategies as one of the main reasons why his knowledge of what is difficult to teach shifted (see his story-line in Figure 6.7). He explained it in the interview as follows:

> It probably took a while to realise that this stuff was hard, and partly this is also my own teaching, as my teaching got better I've been able to get more feedback from learners to what they don't understand. My teaching style incorporates far more forms of assessment now than it ever did, and that is the biggest change in the last year. (Jonathan's interview, lines 216-219)

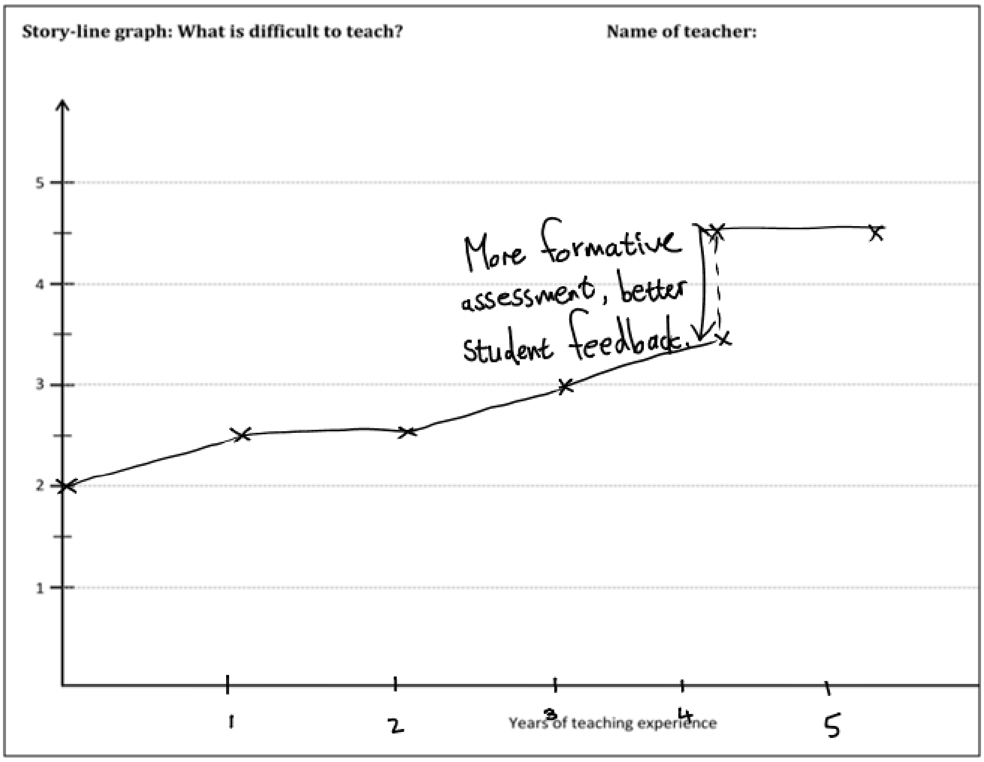


Figure 6.7 Jonathan's story-line on what is difficult to teach

For Jonathan post-graduate studies in education increased his general knowledge of how students learn, which impacted his choice of representations (metaphors and analogies) for chemical bonding. Jonathan also incorporated more student feedback after a few years, which gave him insight into what his students don't understand and made him shift away from being textbook bound towards a more student-focussed approach. Lastly, he had the opportunity to watch his colleagues teach and this expanded his repertoire of teaching strategies.

6.3.4 Glenda

Glenda has 22 years' teaching experience and a bachelor's degree in geography, but only has chemistry at first year level. Like Natalie she completed her teaching certification only later in her career, and then continued doing further post-graduate studies. She obtained a bachelor of education honours degree in curriculum studies, and at the time of the interview was finishing her dissertation for a master's degree in science education. Glenda never really wanted to become a teacher, but ended up in the profession 'by default'. She taught a variety of subjects in the beginning of her career, but soon settled on physical sciences. Over time she became the head of the department and later the vice principal of the school. When she reflected on her career she realised the effect that this leadership role had on her teaching:

> You know the thing that came with the vice, was actually what killed my teaching, even if I was okay at both of them, it killed it, and I crisis taught science for about 10 years. (Glenda's interview, lines 111-113)

After teaching at her first school for 16 years, she resigned and started teaching at a much smaller school where the students came from very diverse and challenging backgrounds, and with many of them experiencing learning problems. This made her realise that she actually enjoyed teaching:

> It was just a fill-in, but what [the school] did for me, those kids … I just loved those kids, and the process of teaching is what I enjoy, and not the admin. (Glenda's interview, lines 107-109)

This experience brought a major shift in Glenda's thinking about student learning, and made her realise her identity as a science teacher and that she needed to develop expertise in that. She said:

> I made peace with the fact that I am actually a science teacher and I am actually pretty good at it, and I actually need to develop my skills in that. (Glenda's interview, lines 115-116)

She ascribes this shift to two major events, apart from her experience at the school described above. Glenda completed a short course on assessment, and a few years later she did post-graduate studies in education. She reflected on the short course as follows:

> The assessors' course just helped link for me the assessment as part of teaching, and how important that was, it was the means to an end, and it made a shift in my thinking. (Glenda's interview, lines 655-658)

Assessment now plays a central role in her teaching. She explained how she now thinks differently about tests, and why questions are put in a test:

> When you set a test you sat with the book and asked a question, there was no thought in it, there was no 'what do you actually want to know that they know', and that changed, so I think I began to become a professional after that assessors course, it wasn't a default career. (Glenda's interview, lines 662-665)

In reflecting on how her teaching strategies had changed, Glenda said: '[I am] significantly more student-focussed than what I was 10 years ago (Glenda's interview, line 690). She provided an example of where she used Lego® building blocks, something her students were very familiar with, to link molecular shape to structure:

> I use Lego a lot, because, Lego, you've got the same building block, but a different structure every time …but because of the square-ness you are never going to get a round shape, you are always going to have an edge so the shape of the molecule does have an influence on what the thing looks like. (Glenda's interview, lines 623-626)

She also used this teaching tool to explain how the properties of graphite are linked to its structure in her answer to CTS2. Figure 6.8 gives her response to how she would teach this section:

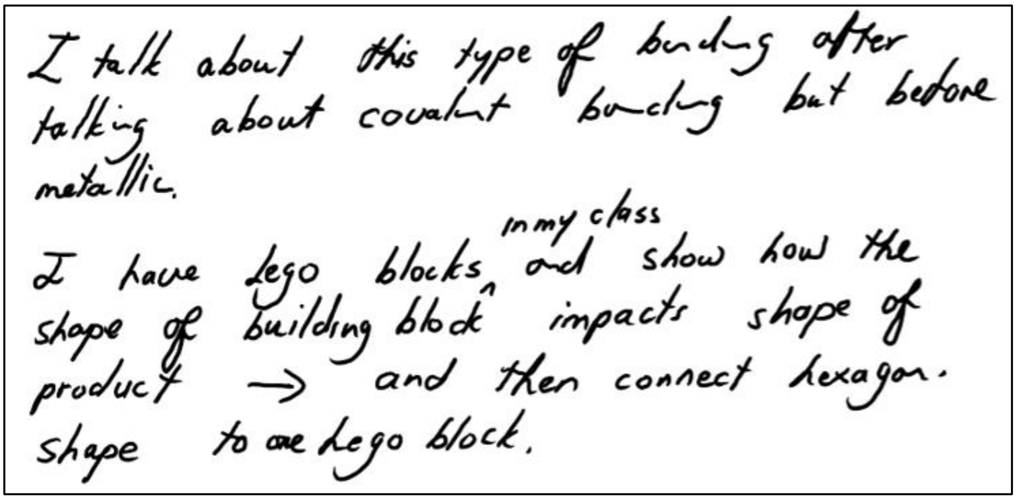

I talk about this type of bonding after talking about covalent bonding but before metallic.
I have lego blocks in my class and show how the shape of building block impacts shape of product → and then connect hexagon. shape to one Lego block.

Figure 6.8 Glenda's responses to CTS2

The course on assessment which Glenda attended set the scene, but it was the master's coursework that consolidated her shift in thinking:

> It was short, hey, it was only a week's course, it really just shifted my thinking ... and then the masters took it to the next level … I think what the master did, first of all it gave me language, and a model, a way of thinking … and maybe to another level it made me more conscious of what I actually did on a day to day basis. (Glenda's interview, lines 667-673)

The master's degree coursework gave her the language to articulate what she already knew. It also introduced her to how students learn and the existence of alternative conceptions:

> And then what are, in words, the big misconceptions … where are the kids going to stuff up most, basically, and to put that in the actual words, I find that the most useful thing in my teaching …just having a word for that concept, so I could pick it up, so I could go, ok this kid is doing this, so then I could speak, not correct the answer, but correct what he is thinking, like knowing what he thinks. (Glenda's interview, lines 170-178)

Glenda's thinking about teaching shifted dramatically after a series of events. She realised her identity as a professional and her love for her students when she taught at a different school. She also learned about alternative conceptions and the importance of assessment through a short course and formal post-graduate studies. All of this made her much more student-focussed and reflective of what she does when she is teaching.

6.3.5 Adrian

Adrian had four years' teaching experience, a bachelor's degree in physics and astrophysics, and a sub-major in chemistry. In his first year of teaching he taught only one Grade 10 class while he was studying towards his teaching certification (PGCE). From his second year he was responsible for teaching one class in each of the Grades 8 to 12.

In his second year of teaching he felt much more comfortable teaching Grade 10, as he could draw from the previous year's teaching experience. He said: 'So teaching Grade 10s I had a much better idea of what they knew, because I had taught a Grade 10 class the previous year' (Adrian's interview, lines 412-413).

A new curriculum (CAPS) was introduced in his second year of teaching. He was given the responsibility of planning the new Grade 10 teaching sequence for their department. This involved examining the new curriculum documents, comparing it to the previous curriculum, deciding on what was most important to teach, and the order in which the topics should be taught. It also involved looking at what was taught in the previous grade (Grade 9) and the following one (Grade 11). As a result of the new curriculum and accompanying changes in the order of teaching, he found himself teaching chemical bonding to three different grades at the same time. He reflected on this as follows:

> Then in my second year of teaching it was the first time teaching bonding to Grade 9s and Grade 10s and Grade 11s, because in my first year I just had my Grade 10 class, whereas now it's my first time of teaching bonding across different grades, and there was this very strange overlap where I was actually teaching it at the same time, and working out which representations are better for Grade 9s, and which are okay for Grade 10s, and what ones you need by the time you get to Grade 11. (Adrian's interview, lines 124-128)

He further explained that he thought Lewis diagrams were appropriate to use in Grade 10 teaching, but were not suitable for Grade 9, as valence electrons had not been covered at this point yet. He therefore decided that Bohr diagrams should rather be used in Grade 9. On his story-line he annotated this perceived growth at the end of his first year as 'differentiating the grade approach' (see Figure 6.9). A year later, after reviewing his use of Bohr diagrams, he changed the Grade 9 content. On the story-line he indicated another increase in his knowledge and annotated this as 'changed grade approach'. In explaining this he said: 'we teach less of the theory behind bonding in Grade 9, so what we are doing now is just getting them to practice the skill of writing chemical formulae in Grade 9' (Adrian's interview, lines 146-148). His experience of teaching the content to the Grade 9s in his second year convinced Adrian that his choice of representation (Bohr diagrams) was probably not ideal, and that students should rather use this time to master the skill of writing chemical formulae.

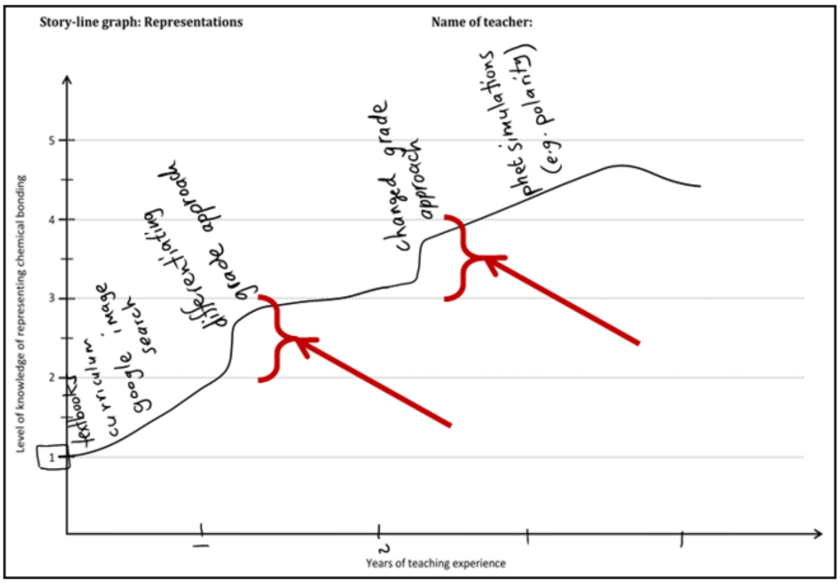


Figure 6.9 Adrian's story-line for representations

Furthermore, the experience of planning across different grades gave Adrian an expanded insight into why ionic bonding is difficult to teach. In reflecting on this, he drew from his content knowledge of ionic bonding and his knowledge of the curriculum, as well as the pre-concepts that were required, for example electronegativity (see his questionnaire response in Figure 6.10). He explains that in Grade 10 ionic bonding is easy to teach since the 'metal-non-metal' approach can be used, but because a more complex understanding involving electronegativity and ionization energy is needed in Grade 11, it then becomes more difficult to teach.

Concept 2: Ionic bonding	'easy' to teach in grade 10 and earlier as you have the old metal- non-metal stand by. but it is actually quite difficult if you are anticipating the fuzziness introduced with EN cutoffs in Grade 11. also can be tricky to match up with ionisation energ where it costs energy to lose an e^-...

Figure 6.10 Adrian's answer to what is difficult to teach about ionic bonding

Adrian has sound content knowledge. He is able to draw from this content knowledge (including metals and non-metals, which is taught before bonding), as well as his knowledge of the curriculum requirements for the various grades. All these factors played a role in shaping his view that ionic bonding is easy to teach at one level, but difficult to teach at another level.

A feature of the South African curriculum is content progression across the grades. The same topic is revisited a number of times, each time expanding on the scope and depth of the topic being covered. Adrian was able to identify this progression for ionic bonding, as was seen in Figure 6.10. The fact that Adrian was teaching Grades 9, 10 and 11 gave him an overview of the spiral nature of the curriculum. The responsibility of having to plan for teaching a specific topic made him think carefully about what students in each grade should learn, what prior knowledge was needed, and which representations were appropriate for which grades. Teaching the topic multiple times helped him revise his initial choice of representation, adapting it for the next year, while keeping in mind how content in one grade should act as prior knowledge for the next grade.

6.3.6 Doreen

Doreen had 16 years' teaching experience. She graduated with a bachelors' degree in botany and zoology, with chemistry and physics as sub-majors. She obtained a teaching post at the school where she matriculated, and started her career directly after graduating. Fourteen years later she obtained a teaching qualification when she completed a BSc honours degree in science education.

When Doreen started teaching she was very strongly guided by the textbook. She believed that she had to repeat every word that was in the textbook to the students in her class. She was also scared that if she didn't do this, her students would fail. She reflected on this as follows:

> I gave out what the textbook gave ... I was a scared teacher because I didn't want to skip a word. I was scared that if I missed a word from the textbook, they would fail. So I would try to memorize the textbook for the lesson before and then I would repeat it verbally for them to take home to read. (Doreen's interview, lines 151-155)

She was encouraged in her thinking by some of her school colleagues, who made her believe that the students were blank slates who knew nothing from previous teaching, and that teachers had the responsibility to make sure that they are filled with information:

> ... and our teachers who were teaching at that time, but not in my subject, were saying 'look you've got to teach them as if they know nothing', so we were told that they are blank slates. Whatever they have learned before, they don't know it, pretend they know nothing.

> In our school there was very little emphasis on prior knowledge. So you would have to just start pumping them full of information. (Doreen's interview, lines 155-158)

It took Doreen a few years to get used to the students and gain confidence in her ability to teach the content. She said the following when reflecting on the shifts in her teaching practice over time:

> I was more comfortable with the syllabus as well, so I wasn't scared of it anymore … and then you also start getting used to the children and you are not scared of them anymore. (Doreen's interview, lines 190-195)

Over time, as Doreen taught the same content again and again, she became more confident in her teaching, and was able to focus more of her attention on her students. She started attending to the questions they asked and the answers they provided in class. This happened relatively early in her career, but more than 10 years later she still remembered it. In her reflection on how her knowledge about students' prior knowledge had increased over time, Doreen indicated the influence of her interpreting her students' answers (see Doreen's story-line in Figure 6.11).

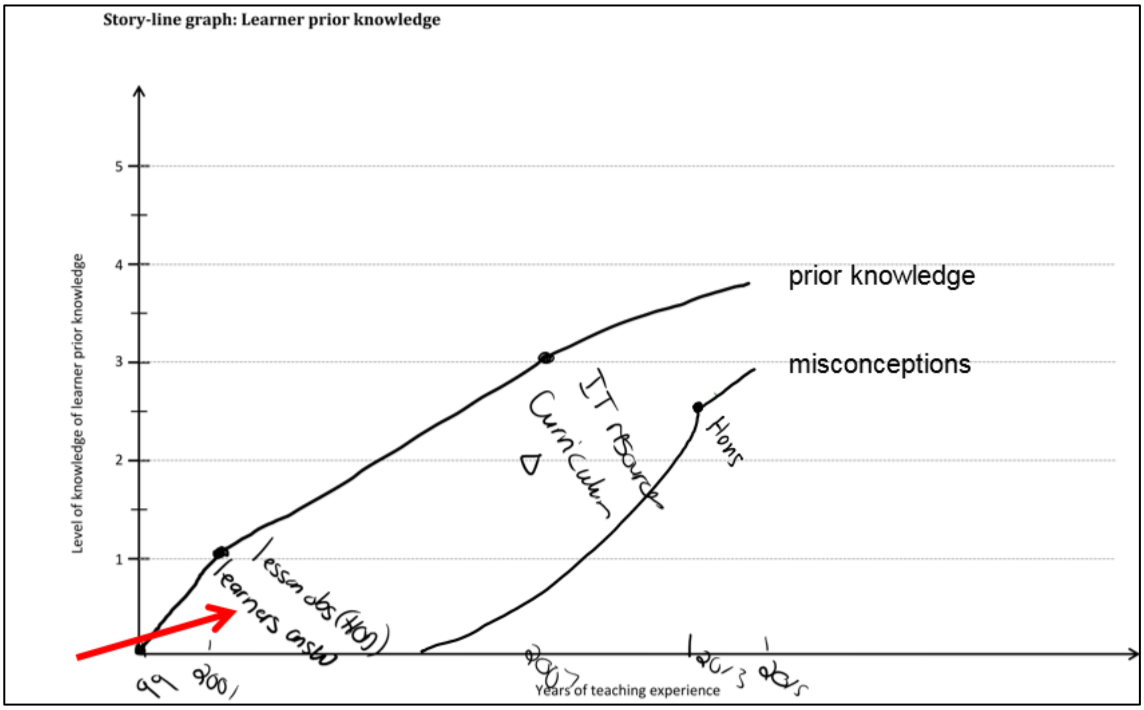


Figure 6.11 Doreen's story-line for student prior knowledge

Although Doreen started to pay more attention to the (correct) answers her students gave early on, it was only after she had completed post-graduate studies in education that she was able to decipher their incorrect answers:

> And only recently I know that an answer is not just correct or incorrect. If it is incorrect, there is a reason why it is not there …there is something causing that reasoning of the child to think that he is right. (Doreen's interview, lines 623-625)

In her story-line her knowledge of misconceptions is placed at zero for a number of years, before it increases. Doreen also placed herself at a current level '3' on the graph, indicating that she was still learning about alternative conceptions and that there was room for future improvement. Her increased knowledge about alternative conceptions had also influenced her teaching strategies. She said the following: 'now what I am doing is that every time I teach a section, I go and look up what everybody else says about learner misconceptions, things that I have never done before' (Doreen's interview, lines 614-615).

With the introduction of each new curriculum, the South African Department of Education arranged a series of training workshops, mainly to inform teachers about the changes in the new curriculum, the content allocation across grades, and any newly included content. Doreen attended these workshops and started to reflect on the prescribed teaching order, and how she would teach the content if she had a 'blank slate'. This had a positive effect on her curricular saliency, and sparked an important shift in her thinking from delivering a curriculum, towards designing her own teaching sequence:

> And also with the curriculum changes … it made me reflect. During our workshops they would say, this is what we took out, and this is now in Grade 11 … and then I had to think about why are they doing that? Why did they think a Grade 11 could handle it, whereas in the last 20 years they didn't think a Grade 11 could handle it, so it *made me reflect on why they think this, and if I think the same thing?* And then *eventually I would say, well, what do I think*? If I had a blank slate, and I had to teach only chemical bonding, where would I start and what would make sense to me? And then I started merging that with what they were saying. (Doreen's interview, lines 353-361, emphasis added)

As a result of this experience, Doreen started to move away from the textbook, and started to teach the topics in a sequence that *she* thought made sense. As she reflected on how her teaching approach had changed over time she said:

> Because I knew the content, and I was confident that, you know, I don't have to be bound by the textbook … I don't teach from the textbook at all anymore. I am teaching a section that I know I am supposed to be teaching for the day, and I teach it with a structure that I consciously planned to teach in a certain format to make sense. So I know where the beginning is, and I know where it is leading towards (Doreen's interview, lines 374-379)

The changes in the curriculum and the fact that Doreen attended a district workshop, made her reflect on the teaching sequence for a topic and supported her in shifting from delivering a curriculum to designing a curriculum.

Early in her career Doreen gained confidence in what she knew about the subject by teaching the same content year after year. She could then shift her attention to her students, realising that they had prior knowledge which could give her insight into how they understood the content.

Later in her career, post-graduate studies in education gave her knowledge about how students learn and the alternative conceptions they may have. She was then able to incorporate this new knowledge into her teaching, shifting her teaching strategies to become much more student-focussed, and interpreting her students' 'incorrect' answers as tools to guide her teaching, and help her students understand better.

6.3.7 Vuyo

Vuyo had five years' teaching experience and a BSc honours degree in science education. His first teaching post was at a very small school where he had fewer than ten students in a class. One of the events that stood out for Vuyo was the bigger diversity of students he encountered when he moved to a much larger school and taught classes of 25 or more. On the question on what played the most significant role in his teaching, he commented as follows:

> Changing schools, moving to the school I am in, because at my previous school, I had five kids, ten kids, now you are getting to a class where you have twenty five kids, three of them are in the top twenty, so that forces you to understand beyond reasonable doubt, because those kids are so smart, that when they come to class they will outsmart you, so I think that for me it said that I can't take any chances. (Vuyo's interview, lines 647-651)

The 'smart kids' challenged Vuyo's content knowledge and motivated him to prepare well for his lessons. He knew he had to know the content well, and welcomed the challenge. He recalls a situation where he was teaching about the periodic table when one of the students asked him why bonding takes place. Part of the conversation is included below:

> Vuyo: You see I have the interactive periodic table, my aim was to show them the periodic table, but then one learner actually said, but sir, how does bonding take place, and I knew in my mind it was when orbitals overlap, and I remember they told us, and I was happy that I understood it.
>
> René: Was that during your BEd?

> Vuyo: Yes, second or third year, when he told us that bonding happens because of the overlapping of the orbitals ... and that periodic table showed my kids why bonding takes place. (Vuyo's interview, lines 522-528)

Vuyo did not prepare to teach about bonding in this lesson, but when the student asked the question about bonding he knew that he had the required content knowledge, gained during his undergraduate training. He was therefore able to explain on the spot: 'one [atom] has an unoccupied orbital which means it can allow some electrons to come in' (Vuyo's interview line 532). After this event, he started using the interactive periodic table to explain bonding.

Students played an important role in Vuyo's teaching. The questions from students, especially the ones who challenged his content knowledge, made him draw from content knowledge gained during undergraduate studies, and helped him discover a new teaching strategy for chemical bonding.

During the story-line interviews the teachers were also asked to expand on their answers to the questions in the instrument. This was done to give them opportunity to articulate more of their knowledge, in addition to what they wrote in the questionnaire.

The first conceptual teaching strategies item (CTS1) asked teachers to reflect on how they would teach about the chemical bonds in beryllium bromide. Jonathan's response to this item, where he suggested a height analogy, was discussed on page 149. Unlike Jonathan, Vuyo did not write anything for this question. When he was asked about this in the interview, he said the following:

> You know I thought about that: In sodium chloride … it is ionic, you know, and I thought about the electronegativity, you see sodium is 0.9 and chlorine is 3.0, ok … now this one, shoo! This one, how would you do this? The fact that now you say it is ionic, but the electronegativity shows that it is covalent, eh, uhm. (Vuyo's interview, lines 576-579)

Vuyo did not know how to answer this question. However, when he was probed to take a guess, he fell back on what he knew: a metal and a non-metal forms an ionic bond. He said: 'I would probably choose to stick to the fact that it is a metal and a non-metal'. However, in the subsequent conversation it was clear that he had the prior knowledge about electronegativity, polar bonding, and even overlapping electron clouds, but that he had just not been able to apply his knowledge to come up with a teaching strategy for this question. He still viewed bonding as a dichotomy, which limited his teaching of so-called 'exceptions to the rule'. According to Vuyo, bonding could either be explained as covalent or ionic, but not 'something in between': 'Ionic bonds in my mind is not that embedded as covalent, so I think I will choose the covalent route for explaining' (Vuyo's instrument, page 10). Vuyo mentioned another factor that played a role in his lack of familiarity with the content, despite it being in the Grade 10 and 11 curricula he had been teaching for five years. He said that not much time was spent teaching about ionic and metallic bonding, since the Grade 12 examination only required knowledge of covalent bonding:

> I would have gone to the extent to say I am not interested in ionic and metallic because you are not going to use it in Grade 11 and 12. They do talk about it, but it is not something that the examiner is going to ask because also it is a very problematic, but covalent bond is going to be asked almost every time. (Vuyo's interview, lines 430-433)

> What is being asked in the exams, when you teach … we all say ionic is this and metallic is this, and then let's run to covalent bonding, because it is a huge section and thirty percent of the exam is around that. (Vuyo's interview, lines 613-616)

Completing a content based undergraduate course provided Vuyo with the content knowledge which gave him confidence to teach, even if he didn't prepare the exact content for the lesson. In addition, he discovered a new teaching strategy through the influence of his students. However, just having the content knowledge does not necessarily mean that he was able to apply it for the purpose of teaching. Teaching the content over and over again would have helped Vuyo in this process, but since the focus was strongly on what was examined in Grade 12, some aspects of the Grade 10 and 11 content was not taught in any detail. Here the context in which Vuyo was teaching played a role in limiting the development of his topic specific knowledge for teaching.

6.3.8 Simon

At the time of interviewing Simon had 12 years' teaching experience and, like Natalie and Doreen, was a biology major. He obtained a bachelor's degree in zoology and botany, and only completed a post-graduate teaching qualification (at honours and master's degree level) much later in his career.

He was appointed to teach both life sciences and physical sciences. He realised that he did not have any formal physics training and chemistry only to first year level, and he therefore completed additional university courses in physics and chemistry while teaching. During his interview many years later, he remembered specific content related to chemical bonding. He recalled learning about the Van Arkel-Ketelaar Triangles of Bonding (McCaw & Thompson, 2009) which show different compounds in differing degrees of ionic, metallic and covalent bonding. This experience was significant for him, and he included it on two of his story-lines.

Figure 6.12 shows his story-line for representations. He explained the ‘triangle’ in the interview as follows:

> And then when I did the inorganic chemistry, that was when I learned about the triangle, and that it is not just electronegativity difference, that it is the mean electronegativity difference, and they fit on this kind of scale that can range from covalent, to ionic, to metallic. (Simon’s interview, lines 236-238)

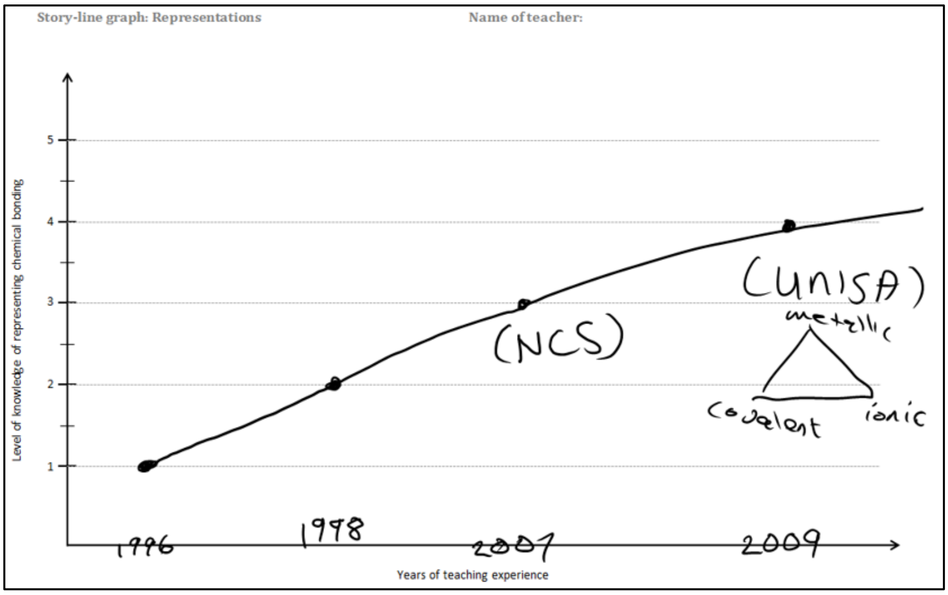


Figure 6.12 Simon’s story-line for representations

However, he chose not to use this concept in his teaching at school level, and only used it for his own understanding. In elaborating on his answer to the first conceptual teaching strategy question (CTS1) on the bonding in beryllium bromide, he said the following:

> ... and when I explain, I say, cause I don’t use that triangle, but I let them know that it is not as straightforward as the textbook says, you need to look at other things … (Simon’s interview lines 487-495)

Simon’s questionnaire response to this item is included in Figure 6.13 on the next page. He was able to draw from this content knowledge to explain a bonding continuum, and his explanations focussed on using electronegativity rather than the ‘cut-off’ rule (see shaded areas in the figure).

Section 5: Conceptual teaching strategies

5.1 During a lesson, a learner asks the following question:

He read on the internet that beryllium bromide ($BeBr_2$) forms an ionic bond because it is a bond between a metal and a non-metal. However, the Periodic Table shows the electronegativity difference between the atoms as 1.3, which makes the bond a covalent bond, according to the rule they have learned in class: 1,3 is less than 1,7, the 'cut-off value' for ionic bonds. Which type of bond is formed in beryllium bromide?

H 2.1									He
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.3	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.2	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6

How would you teach about this in a lesson? Consider the following in your response: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

It would be important to begin this lesson by highlighting the idea chemical bonds form to create stability.
The type of bond that forms will depend on the electronegativity difference which is 2.1 for an ionic bond. It is important for learners to realize that there is a spectrum of bonding (for covalent). Although beryllium is a metal with two valence electrons, and these are closer to the nucleus and the force of attraction between the nucleus and valence electrons is stronger, hence the higher its electronegativity. When teaching this it would be important to confront what they learner has read but bring the explanation to electronegativity. It is also always important to make learners aware that scientists look for trends or patterns and generally substances follow these trends and that there are always exceptions (such as boiling point difference between HF, HCl, HBr, HI, or that Xenon can form compounds even though it is a nobel gas, or that some metals and non-metals from covalent compounds) Throwing these exceptions in means that you can make learners aware that scientists need to look for other factors to explain these exceptions).
It would be important to reinforce that metals usually form ionic compounds but that there are exceptions and that beryllium halides are covalent compounds that form a polymeric chain this idea however, I would not explain to learners). When teaching a lesson the following concepts, and the order in which I'd introduce them would be:
(1) What is a chemical bond; (2) what is the different types of chemical bonds (3) there is a spectrum of bonds based on electronegativity difference.
I would get learners to draw models of these atoms with energy levels, so that they are aware of how close/far electrons are from nucleus. Then I would use the electronegativity table and get learners to work out electronegativity difference. I would hand out a table that classifies the bonds so that they can see Group II metals with some halides form covalent bonds. Learners will probably struggle to move away from (metal=non-metal forms ionic bond but I would reemphasize exceptions and scientists explaining these exceptions using the electronegativity difference.

Figure 6.13 Simon's response to CTS1

Simon was aware that his students still found these concepts challenging, and attributed it to the fact that chemistry is abstract: ‘because we are dealing with things that no one has ever seen, and it is abstract, and you have to use examples that the kids understand’ (Simon’s interview, lines 499-500). He suggested a variety of teaching models to help his students visualise what these bonds may look like:

> … I like to use the ball and stick models, and then I get the kids to do Lewis diagrams, and I also show them how orbitals overlap. You know, those kind of polystyrene models that show you what orbitals look like, and I always start with the ball and stick model, let them see, and then draw diagrams - energy level diagrams - because I like them to see why the bonds form. (Simon’s interview, lines 487-495)

Simon also mentioned the introduction of a new curriculum in his story-line (see ‘NCS’ in Figure 6.12). The Grade 11 NCS curriculum at the time required a stronger focus on the role that electronegativity plays in bonding, and it was the first time Simon had to teach bonding in this way. This created the necessity to move away from discussing bonding in three distinct categories to instead using an electrostatic approach. Here Simon was able to use his physics knowledge of electrostatics to explain what a chemical bond is. He said:

> you realise that is actually what a chemical bond is - it is an electrostatic force, and that is key for the kids to understand … so I use those examples, even when I taught electrostatics, so I say, let’s look at these real examples in terms of atoms. (Simon’s interview, lines 255-258)

Simon’s entire questionnaire is underpinned by an electrostatic view of bonding. Figure 6.14 shows only one such example, with more examples included in Appendix 37.

Concept 4: Bond energy	Bond energy is difficult to grasp since learners do not have a good understanding of chemical bonds as an electrostatic force between charged particles. In physics it is far easier to understand that when a force is exerted over a distance work is done, or that a mass due to its position has potential energy. Also, in CAPS fields are only covered at a basic level at Grade 9 and only dealt with after chemical bonding. It would be easier to explain using the graph (Representation 6) if learners understand that far away electrostatic forces are weak, stronger closer together. As atoms approach potential energy increases until that point is reached where forces are balanced. The define bond energy with the graph.

Figure 6.14 Simon’s questionnaire response to why bond energy is difficult to teach

He explained why he thought bond energy is difficult to teach, and ascribed this to the students struggling to understand that a bond is an electrostatic force. He further elaborated on the connection between physics and chemistry, stating that knowledge of electrostatics and fields were both required to understand chemical bonding.

Simon completed additional content courses midway through his career. This broadened his knowledge of chemistry and physics, which he could then integrate and apply to the teaching of chemical bonding. It provided him with an electrostatic view of a bond and underpinned his thinking about teaching this topic. He was able to draw from this topic content knowledge in his choice of content representations and teaching strategy to teach about the bonding in beryllium bromide.

6.3.9 Desmond

Desmond had 30 years' teaching experience, and obtained a four-year teaching diploma in the 1980s. He did not do any further studies, but fulfilled many leadership roles as head of department, deputy principal and principal. He started his career as a high school biology teacher, but soon started teaching physical sciences as well.

Desmond was very student-focussed and expected his students to actively participate in class. He wanted them to be independent learners by the time they left school. He was able to develop this view amongst his students because he taught the same students year after year. Over time he shifted his teaching from just focussing on the content, to making his students collaborators. He said the following:

> How do I get the learners to master that content? That was my primary focus before. In the beginning you think you have all the knowledge, when you start teaching, and you want to share your knowledge with them ... then there was a time where I switched my thinking, after reflection, and I said no, if they want 80 percent, they must work 80 percent of the time in the class, and therefore they must become co-collaborators with me. (Desmond's interview, lines 761-764)

He indicated this shift in thinking about his teaching strategies on his story-line (see Figure 6.15). His story-line shows a low level of perceived knowledge until around 2009, at which point on he wrote: 'reflection on my part'. After this he perceived his knowledge to increase continuously.

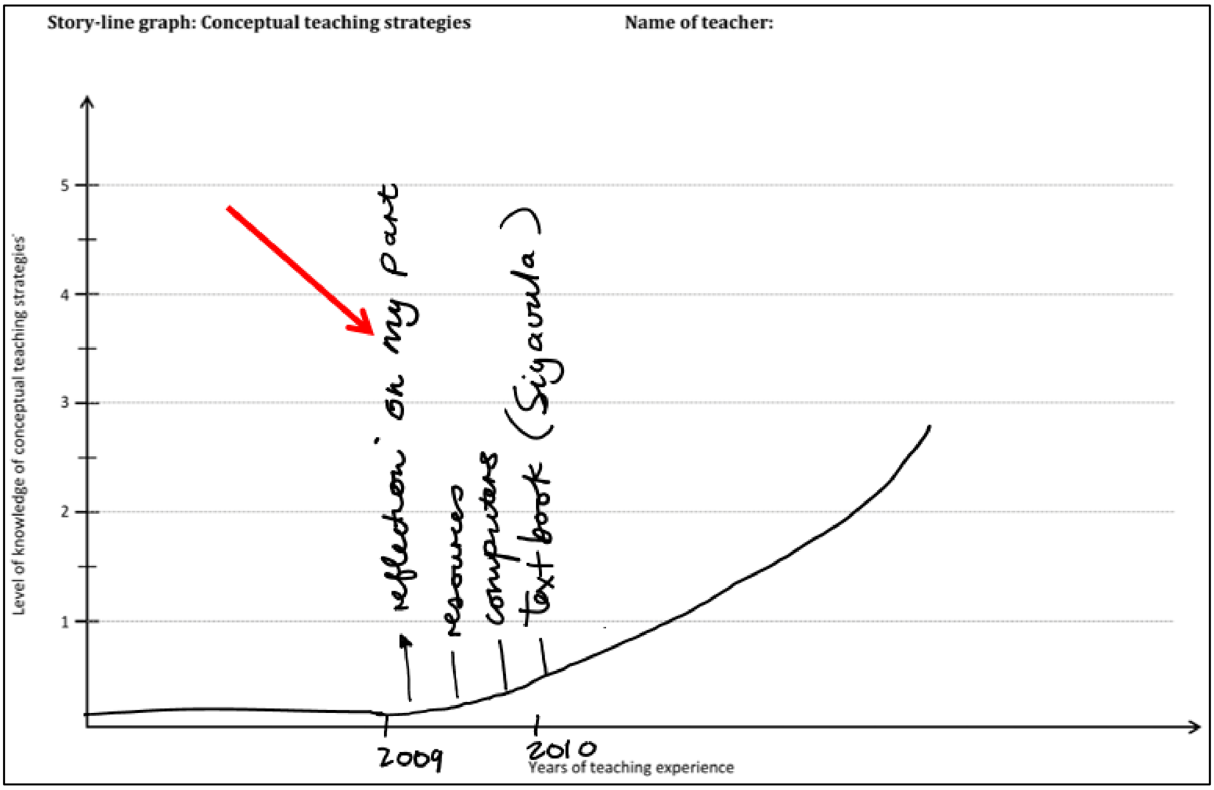


Figure 6.15 Desmond's story-line for conceptual teaching strategies

Desmond valued student feedback - both from current and past students - because it informed his teaching. He said:

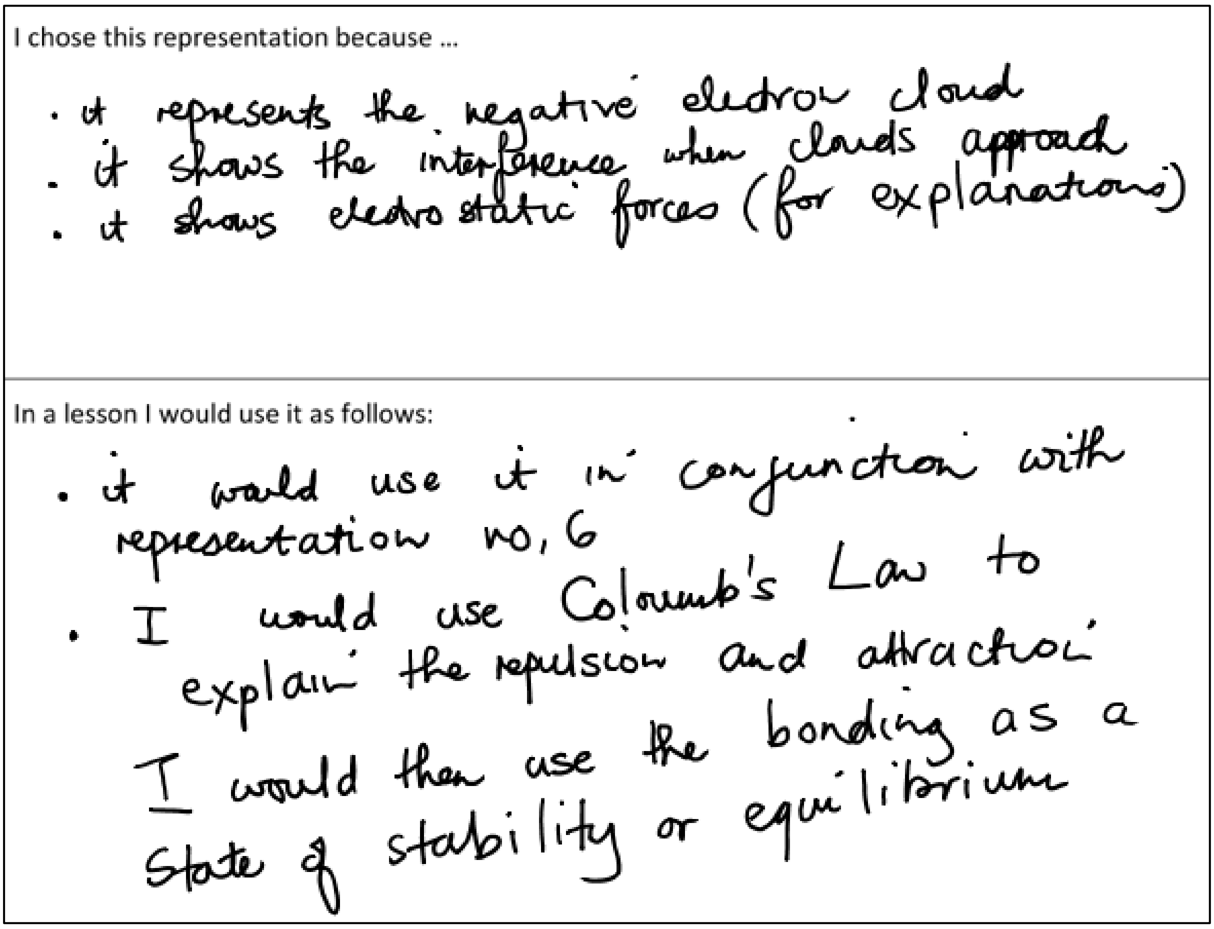
> I would keep in contact with two or three learners, ex-pupils. I ask them what topic are you doing, and how do you find it, and all of them are coming here like in their second and first year, and say: 'Sir, we don't get this, would you mind going through the basics again?', which means my learners inform my teaching in this sense (Desmond's interview, lines 445-448)

He recalled one such occasion where a group of ex-students, who were studying towards a bachelor's degree in science, came to him to ask for help on an issue about chemical bonding. Desmond said:

> Let me put it to you this way: if you listen to a learner coming back and he asks you a question for help and we did not, for instance, I did not pay very much special attention to the atomic orbitals previously, because I could just not see why a learner has to do that, but when a learner comes and that's the first thing they start with and they come back and they say: 'Sir, maybe you must explain to us why it's got this shape, and why does it spin that way, and why is it opposite spins', and so forth … so I would take that concept back to the class (Desmond's interview, lines 473-479)

Desmond now teach about atomic orbital overlap at school level. In the questionnaire, when he was asked to choose a representation for chemical bonding, he chose the representation which showed orbital overlap (number 3) because it 'represents the negative electron cloud' (an orbital view). His response to this item (REP2), is included in Figure 6.16.

When he explained how he would use the representation in his teaching, he drew from his knowledge of what students already knew (for example Coulomb's law) to explain bonds as electrostatic forces.


I chose this representation because ...

- it represents the negative electron cloud
- it shows the interference when clouds approach
- it shows electro static forces (for explanations)

In a lesson I would use it as follows:

- it would use it in conjunction with representation no, 6
- I would use Coloumb's Law to explain the repulsion and attraction

I would then use the bonding as a State of stability or equilibrium

Figure 6.16 Desmond's response to why he chose representation 3

Desmond not only gets feedback from past pupils, he insists on feedback from his current students as well. He starts his lessons by asking individual students questions:

> I would vary it, they would know that Mondays ... I would simply go through the class row by row, so nobody escapes ... and they also know where I am going to start on a Monday, this Monday I start at the front, next Monday I start at the back, so they could prepare themselves for that. (Desmond's interview, lines 657-661)

Desmond had knowledge of a wide range of bonding models, and chose the orbital model to explain bonding at school level. He was aware that this was beyond what was required by the curriculum, but did not limit the extent of the content he taught to what was prescribed by the curriculum. He wanted to prepare his students for further studies, and therefore included a more sophisticated explanatory framework to better achieve this goal.

Over time Desmond teaching approach shifted from delivering knowledge to focussing on student learning to prepare his students for tertiary education. He invited feedback from students, and used this feedback to inform his choices of representing the content. He also drew from his knowledge of what his students already knew, namely electrostatics, to explain how bonding takes place.

6.3.10 Stephanie

Stephanie had 14 years' teaching experience. She obtained a bachelor's degree in chemistry and applied chemistry, and completed a one year post-graduate diploma in education before she started her career as a physical sciences teacher.

Similar to Desmond, Stephanie's students were important to her, and she invested a substantial amount of time into getting to know them better. She taught multiple grades and the same students in consecutive years. She said the following about her students:

> I think it is relationships, you know the kids, you get to know where they come from … you know what they struggle with … they tell me 'I struggle with chemistry' and then I know that when we start with chemistry, I can help this learner specifically because I know she doesn't like it, or she finds it difficult, and that is only because she told me in the first year and now it is year three, so I think there is real value in that. (Stephanie's interview, lines 708-712)

Stephanie had good content knowledge and a conceptual approach to understanding chemical bonding. She was able to reason from a range of explanatory principles as was shown in the explanatory framework analysis in Chapter 5 (see also the analysis of Stephanie questionnaire responses in Appendix 36 on page 315). When she was asked to identify strengths and weaknesses of various representations, she wrote that she didn't like the first representation (the Lewis diagram) because it didn't show orbitals. However, she also liked it because it clearly showed the number of electrons involved in the bonding process. When she was asked to choose a representation to teach about bonding, this was the one she preferred because of its clarity (see Figure 6.17).

	What I **like** and **why** (Strengths of the representation)	What I **don't like** and **why** (Weaknesses of the representation)
Representation 1 	Clearly shows the number of electrons involved in the bonding process.	(No representation of the orbitals given)

Figure 6.17 Stephanie's response to identifying strengths and weaknesses of representations

I chose this representation because ... learners can determine the number of valence electrons from the group number on the Periodic Table. This Lewis structure representation then allows them to clearly see the number of electrons that are shared in the bonding process.
In a lesson I would use it as follows: - remind the class of valency rules learnt previously by refering to the Periodic Table - get students to draw the Lewis structure for Hydrogen - remind them that Hydrogen only needs two electrons to fill its outer shell, by making reference to Aufbau diagrams done previously show how two Hydrogen atoms come close to each other to form a covalent bond, with electrons shared between the Hydrogens.

Figure 6.18 Stephanie's response to the items on representations

Stephanie's choice of representation is underpinned by the octet explanatory principle. When she was asked whether she thought other representations, like the bond-energy graph, were important to teach, she said: 'no, I don't think this is very important and I think my children really struggle to understand this' (Stephanie's interview, lines 449-450). However, when the curriculum required this graph, she had the content knowledge to include it in her teaching:

> 'so this energy diagram, of how energy changes between two atoms, this pops up and it disappears again throughout my teaching career, so this was in 2003 and we definitely had to teach about how energy changes, but there was a time where I don't remember doing this with my classes, and now it has popped up again'. (Stephanie's interview, lines 442-445)

Ensuring that the content is delivered in the simplest and most understandable way was important to Stephanie. Although she was strongly guided by the requirements of the curriculum, she was not completely constrained by it. It was more important for her to make sure that the content was simple and easily understood by her students. When she was required to teach more complex content than what she thought was necessary, she would leave it out. This is illustrated in the following conversation:

René: So your thinking has shifted?

Stephanie: Yes definitely, it has become much simpler.

René: Can you think of a reason why?

Stephanie: I think it is just experience, you know you see how children struggle, or you see that this is like a multistep process and you could make it simpler, and this is also where I mentioned, you know, the curriculum now expects us to have group 1 to 18. Why on earth must we do that, because it messes up how we teach this? It is so much better if it is from 1 to 8, because then you can say that ok, group 7 needs one electron to get to 8, whereas group 17 it is much more confusing.

René: So, what do you do?

Stephanie: I teach 8, but I say, well, there are 18 and the books have it as 18, but fortunately no one asks what group this thing is in, otherwise we will get ourselves in a pickle. (Stephanie's interview, lines 573-576)

Both Stephanie and Desmond valued the input from their students and wanted their students to be successful. For Desmond it meant expanding his content to include concepts beyond the curriculum, whereas for Stephanie, it meant reducing and simplifying the content to ensure basic understanding amongst her students. In both cases their students played an important role.

6.4 Discussion

Seven of the ten teachers interviewed completed post-graduate studies in education. Alicia, Natalie, Jonathan and Simon completed a master's degree in education, Glenda was busy with a master's degree, while Vuyo and Doreen had completed a BSc honours degree in science education. For Jonathan the master's coursework provided knowledge about how students learn, and this directed his choice of content representations (analogies and metaphors), and influenced the teaching strategies he employed in the classroom. As he incorporated more student feedback, he learned which concepts were difficult to teach and used the feedback to determine whether his choice of metaphor was effective in promoting student learning. Being able to observe other, more experienced, teachers teach, expanded his knowledge of conceptual teaching strategies.

Alicia learned about a variety of teaching strategies during her master's degree, which she used later in her career when she, for example, chose to use a Vaseline and marbles demonstration to teach about metallic bonding. She was also involved in designing a teaching sequence and numerous curriculum materials, which expanded her curricular knowledge, as well as her ability to reason about the order in which to teach chemical bonding concepts.

Glenda realised the importance of assessment in teaching whilst doing a short course on assessment, but it was during her master's degree coursework that she really started to incorporate assessment strategies in her teaching. She also learned about alternative conceptions during her master's degree, and this gave her the vocabulary to articulate some of the tacit aspects of her teaching.

The Model for Teacher Professional Knowledge and Skill (Gess-Newsome, 2015) provides a useful conceptualisation of the interactions between the various knowledge bases for teaching, classroom practice and student outcomes. The model was adapted for this study as was discussed in Chapter 2. When the influences of the events for Jonathan, Alicia and Glenda are mapped on the adapted model, the interactions between the knowledge bases can be seen as shown in Figure 6.19 – Figure 6.21.

The significant events are indicated in the colour-coded boxes at the top of each diagram. The direction of the arrows shows the direction of the influence, or the flow of knowledge. For example, post-graduate studies (green box) influenced Jonathan's knowledge of students, which in turn influenced his knowledge of representations. He also drew knowledge from his students' comments, which are indicated by an arrow from the 'students' box to the 'representations' box.

For Jonathan, Alicia and Glenda, significant events sparked growth at a general Teacher Professional Knowledge Base (TPKB) level, and this then influenced their knowledge at the Topic Specific Knowledge for Teaching (TSKFT) level.

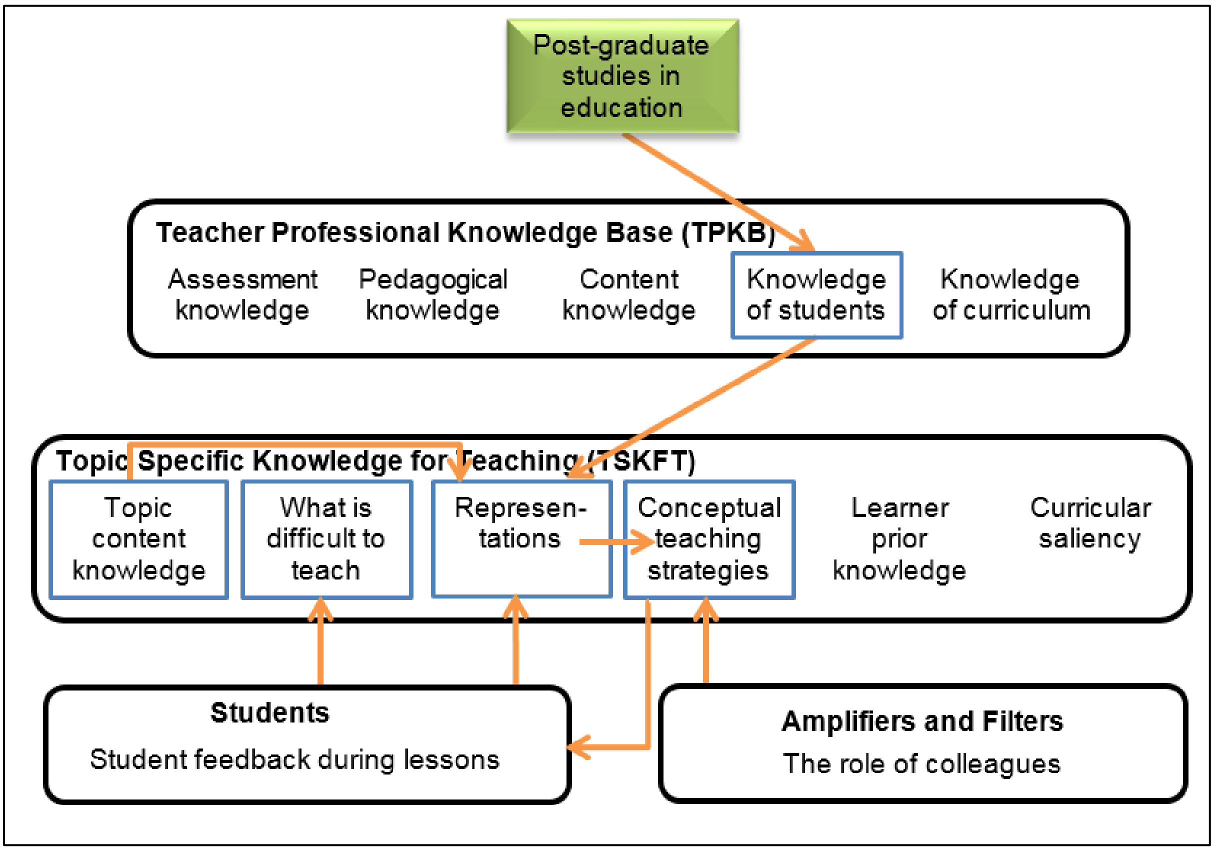


Figure 6.19 Mapping the influence of significant events for Jonathan

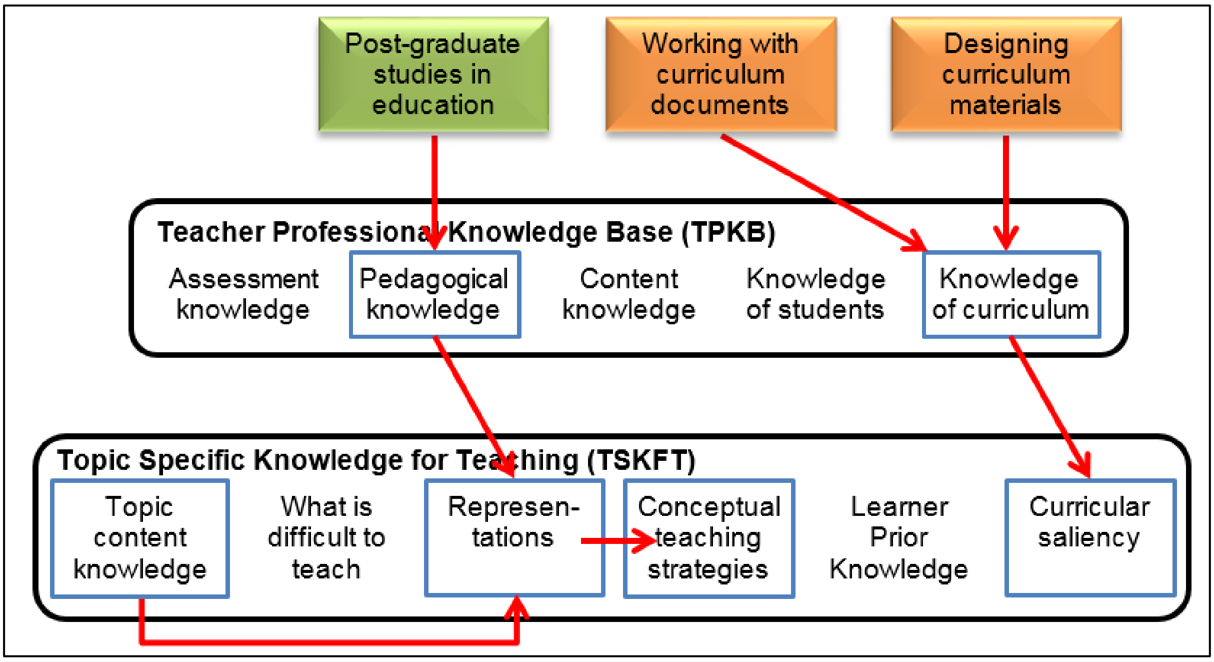


Figure 6.20 Mapping the influence of significant events for Alicia

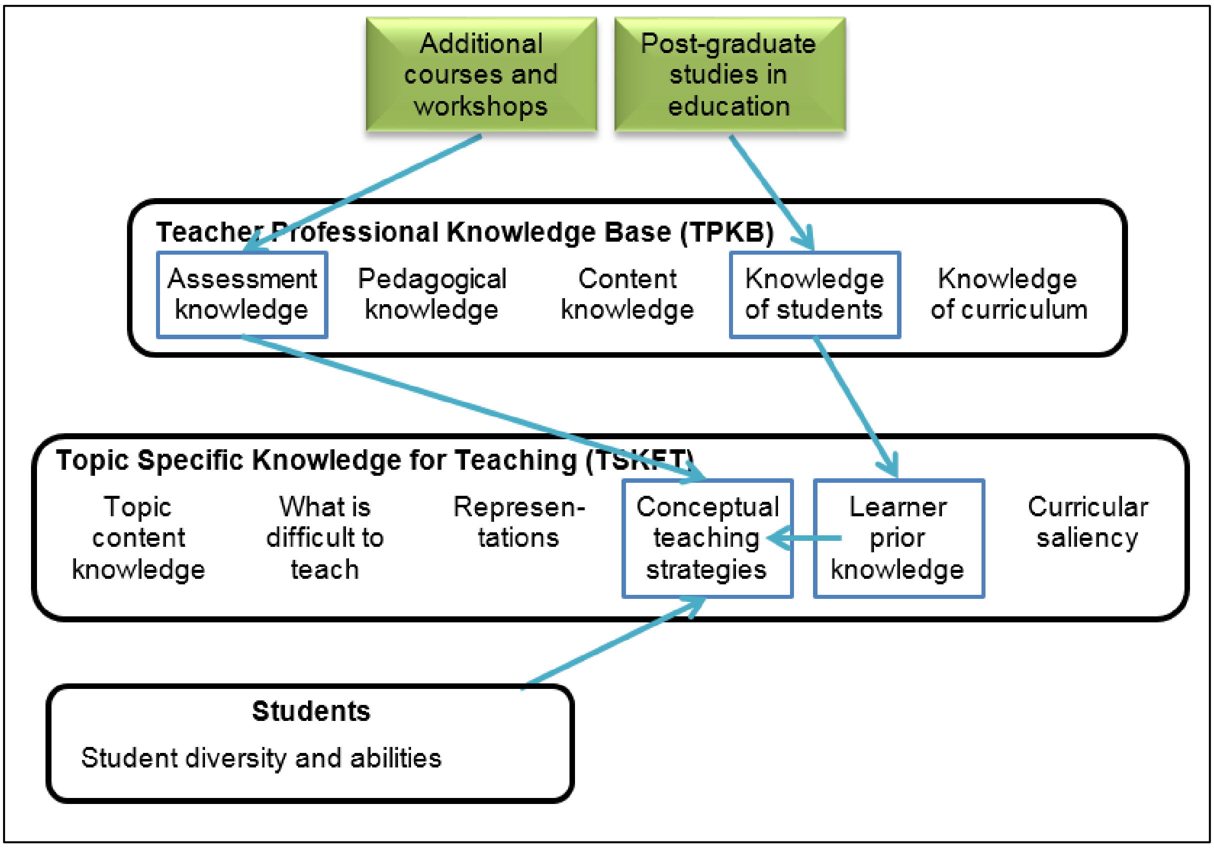


Figure 6.21 Mapping the influence of significant events for Glenda

Like many South African physical sciences teachers, Natalie is a biology major who, over time, started teaching more physical sciences classes. The introduction of a new curriculum, combined with the fact that Natalie had to teach the content for the first time, made her realise that she lacked content knowledge. She grappled with the content until she mastered it, increasing her topic content knowledge. This led to increased knowledge of content representations which, in turn, gave her insight into what her students found challenging. This shifted her reported teaching strategy towards a more conceptual approach. A combination of events initiated growth of one of the components at a topic specific level, which, in turn, shifted her knowledge of the other components. In addition, the context in which she was teaching acted as an amplifier. The presence of a willing and knowledgeable colleague further supported the development of topic specific knowledge for teaching. The influence of these significant events is shown in Figure 6.22.

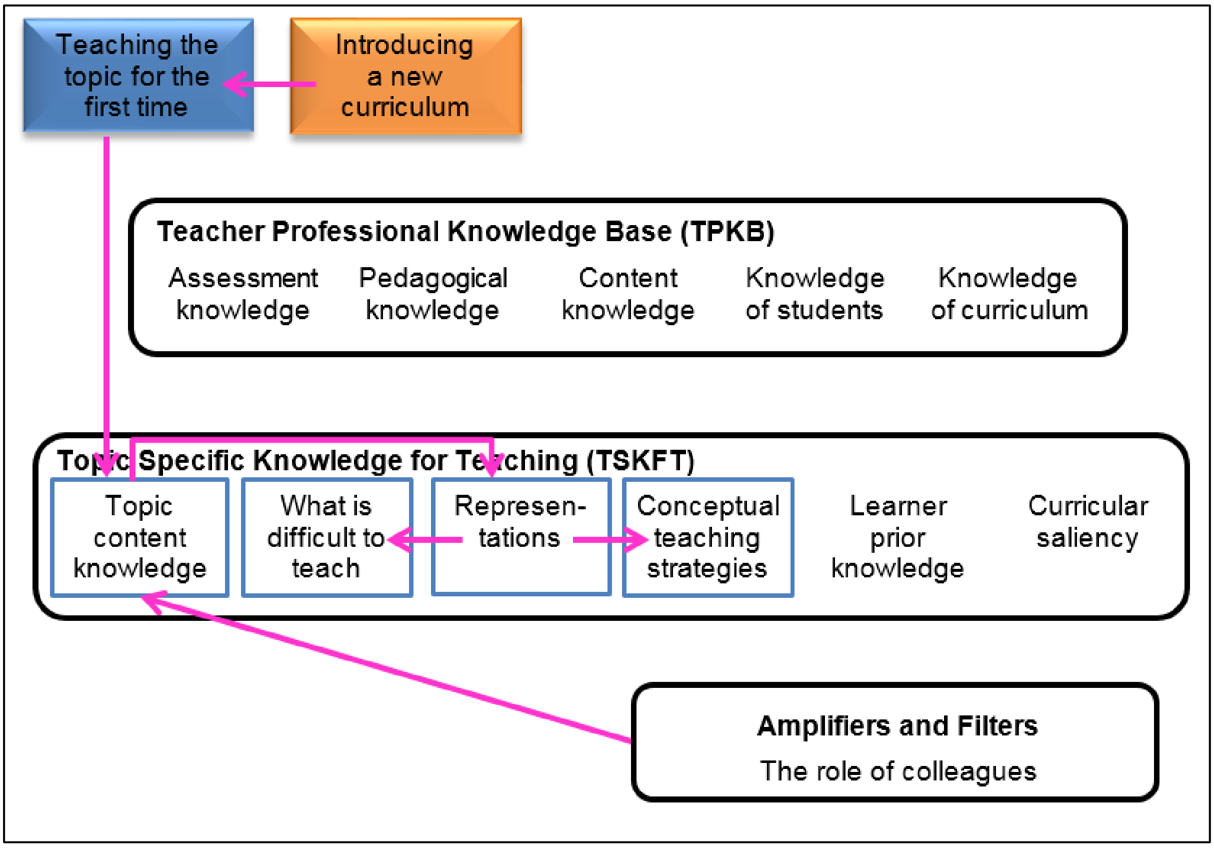


Figure 6.22 Mapping the influence of significant events for Natalie

Adrian had the responsibility of teaching multiple grades. When a new curriculum was introduced he had to plan the teaching sequence for his department. He had to work with the curriculum documents at a detailed level, and this gave him a better understanding of curricula in general. He then drew from his knowledge of the curriculum, his topic specific content knowledge, and his knowledge of what students have learned in previous grades (gained from teaching multiple grades), to decide what bonding concepts were needed for each grade, which order to teach it in, and which representations were best for teaching these concepts at the different grade levels. Once he taught the content, he had a better understanding of what was difficult for his students, and which representations were effective for which grades. He was then able to adjust his planning for the next year. The interaction between and within the knowledge bases for Adrian is shown in Figure 6.23.

Adrian was able to draw from a large number of knowledge bases as he reflected on his teaching of chemical bonding over time. There were also multiple interactions between the different components of TSKFT, and he was able to integrate his knowledge very well. Adrian obtained the top score on the measuring instrument. It appears that high levels of knowledge for teaching are linked to high levels of interaction between knowledge components, and the ability to integrate one's knowledge when planning to teach.

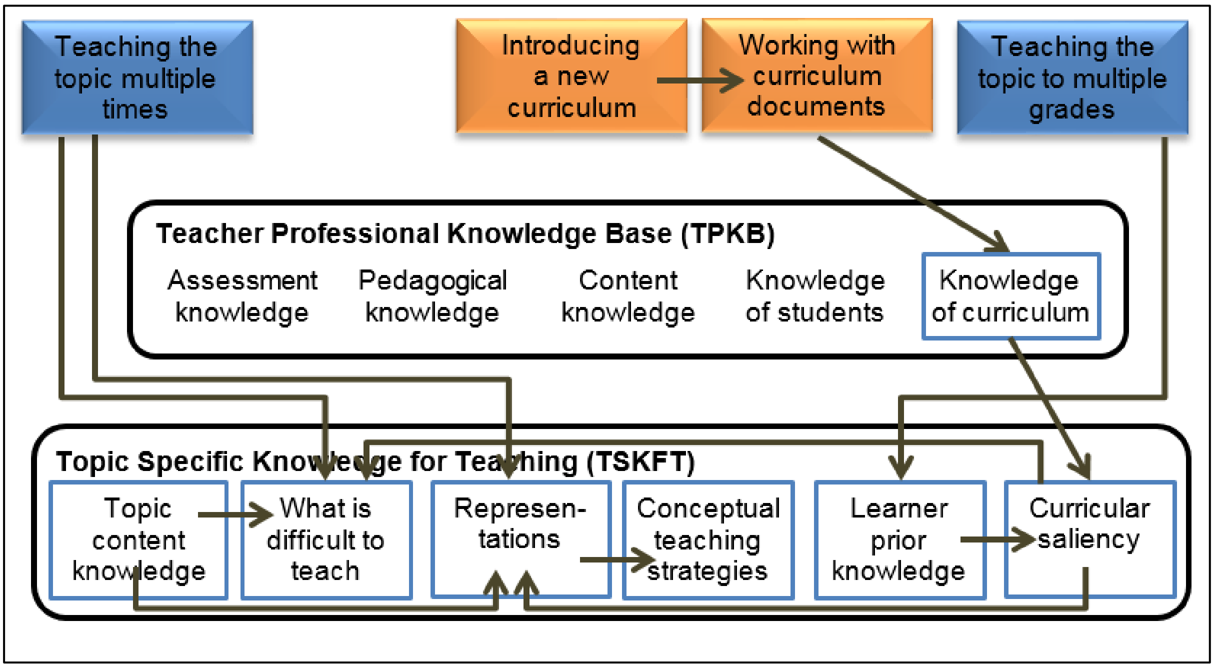


Figure 6.23 Mapping the influence of significant events for Adrian

Doreen's teaching strategy at the beginning of her career was influenced by the opinions of her more experienced colleagues at the school, and was strongly textbook bound. Over time, as she taught the content multiple times, she gained confidence in her content knowledge and got used to the students. She was then able to shift her attention to what her students were saying. This increased her knowledge of student prior knowledge, which she could incorporate into her teaching strategies by moving away from the textbook, and becoming more student-focussed. Later in her career, her post-graduate studies increased her general knowledge about how students learn, and provided her with topic specific tools to interpret her students' 'incorrect' answers, and further modify her teaching strategies to help her students learn better.

As a result of the frequent curriculum changes in South Africa, Doreen had the opportunity to attend curriculum training workshops. The workshops challenged her knowledge of curricula and her curricular saliency and supported the move away from textbooks to developing her own teaching sequence. The influence of the various events for Doreen is shown in Figure 6.24.

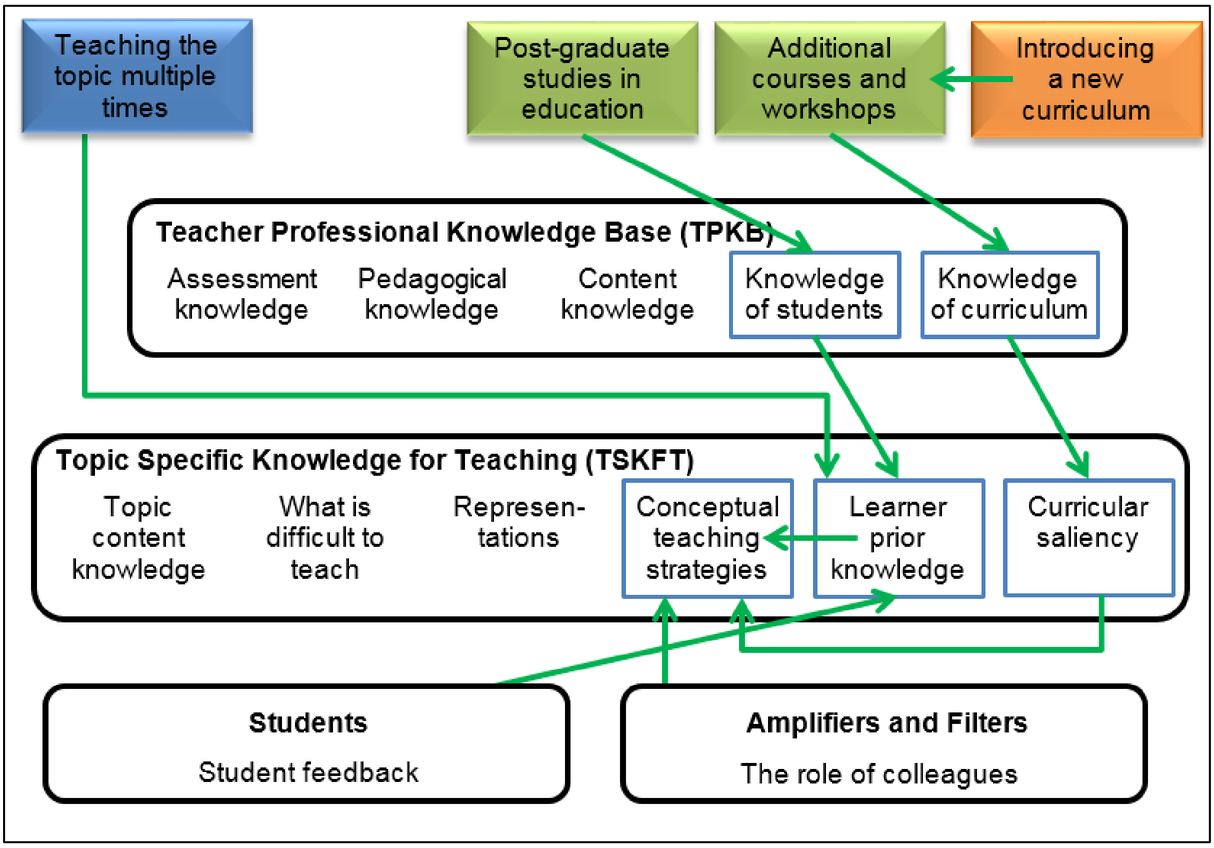


Figure 6.24 Mapping the influence of significant events for Doreen

A combination of events, over an extended period of time, played a role in Doreen's perceived shifts in her curricular saliency, and what she knew about her students' prior knowledge. Similar to some of the other teachers, events played a role at the TPKB level, which initiated growth at a topic specific level. Shifts in knowledge in one component at a topic specific level also sparked growth in other components at this level.

Furthermore, students played an important role in Doreen's teaching. The same was true for Jonathan, Stephanie and Desmond. Jonathan realised what his students found challenging when he started listening to them, and he used this feedback to improve his choice of analogies and metaphors. Doreen realised that her students were not 'empty vessels', and that they did know some content. Stephanie, as a result of student feedback, simplified the content she was teaching to ensure that her students understood, while Desmond expanded his approach into teaching more sophisticated chemical bonding models to ensure his students' success in tertiary studies.

A big shift in Desmond's teaching came after personal reflection, which made him shift his focus towards his students and their learning. He now used regular student feedback to adapt his teaching strategies to support student learning. When his past students identified a content area that they were not taught at school level, he changed his planned teaching content to include a representation that would better prepare his student for tertiary education. In reflecting on how he would use the representation in teaching, he drew from his content knowledge of the topic (molecular orbital theory), and his knowledge of what the students already know (electrostatics), to come up with a conceptual teaching strategy that would help them understand. The influence of these events on Desmond's TSKFT is mapped in Figure 6.25 below.

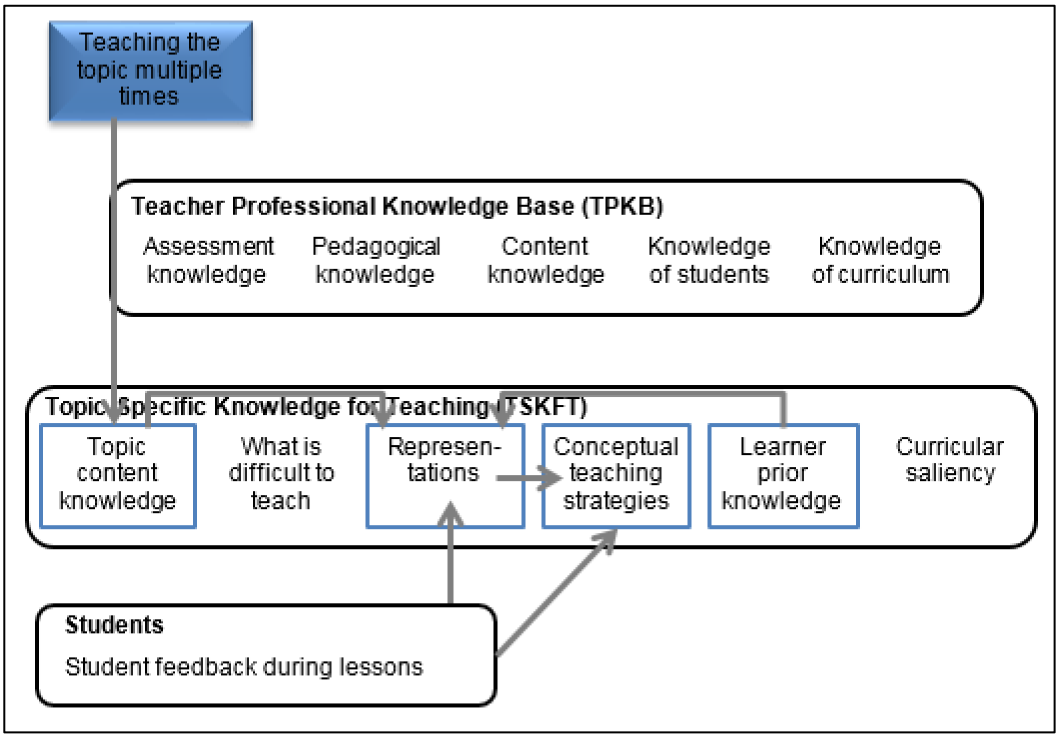


Figure 6.25 Mapping the influence of significant events for Desmond

Students, and the feedback they provide, played an important role in many of the teachers' teaching, and are therefore an important factor to consider as an influence on teachers' TSKFT.

Chapter 5 included an explanatory framework analysis of the larger group of teachers' responses to some of the items in the instrument. The findings for Stephanie and Desmond are compared in Table 6.2.

Table 6.2 Comparing explanatory principles for Stephanie and Desmond

Teacher	Teaching experience	Teaching qualification	Content training	School type	CK 2.1	CK 3.3	CK 4.2	CK 5.1	REP	CS	LPK	CTS
Stephanie	11-20 YEARS	PGCE / HDE	CHEM3	PRIVATE	EL	OC	EL	OC	OC	OC	OC	EL
Desmond	21+ YEARS	TEACH DIP	CHEM1	EX MODEL C	EL	AT	EL	OC	OR	EL	EL	EL

Desmond and Stephanie have a similar range of explanatory principles to choose from. When their explanatory frameworks for the CK items are compared, it becomes apparent that they used the same principles, with the exception of CK3.3, where Desmond used an atomic view, and Stephanie an octet view. However, when their use of explanatory frameworks for the TSPCK items are compared, Stephanie chose an octet principle for all except one item, whereas Desmond did not use an octet principle at all, but rather chose an electrostatic principle or orbital view. When teachers transform their topic specific content knowledge for the purpose of teaching, they make decisions on which representations to use, what student prior knowledge is required, and which teaching strategies are best. These decisions are influenced by the students they teach, and what they believe is best for their students, as we have seen with Desmond and Stephanie above.

Teachers have more knowledge than what may be revealed by pen-and-paper tests. Thus, Stephanie chose a predominantly octet framework when she transformed her content knowledge for teaching, which was not a reflection of the extent of her knowledge of chemical bonding models.

Simon and Vuyo both identified that further studies, especially the new content knowledge that they had gained, supported their knowledge of chemical bonding, but more importantly, it helped them formulate a view of their own about what a chemical bond is. Both teachers had the prior knowledge required, but Simon, since he had been teaching much longer, was able to structure and apply his understanding so that he could explain the bonding in beryllium bromide. Vuyo, with only five years' teaching experience and almost no experience of teaching ionic and metallic bonding, was unable to do this. Topic specific content knowledge was therefore a pre-requisite for designing a teaching strategy that would help students learn, but if the topic is not taught, teachers do not get the opportunity to expand and integrate their knowledge. Figure 6.26 and Figure 6.27 maps the significant events for Vuyo and Simon. In both cases an increase in their knowledge of chemistry and/or physics in general provided the base from which they could choose and integrate - in Simon's case - their knowledge of chemical bonding.

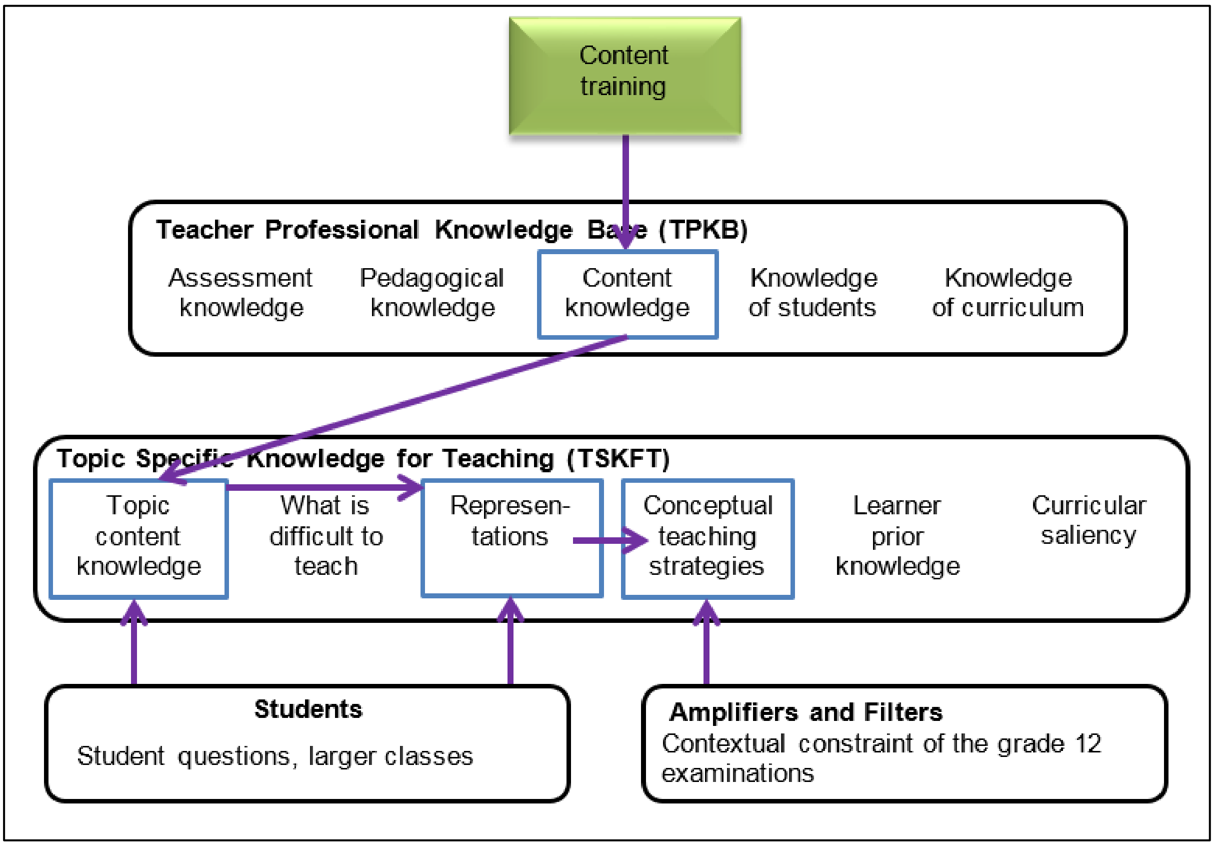


Figure 6.26 Mapping the influence of significant events for Vuyo

Simon realised that he lacked content knowledge and completed additional coursework to increase his content knowledge. During one of the courses he learned about chemical bonding and encountered a useful representation to assist with the understanding of the link between ionic, metallic and covalent bonds. This gave him a foundation to teach from, and when he was asked to elaborate on teaching a difficult concept (the bonding continuum), he was able to draw from this knowledge to explain that bonds are not dichotomous, but exist on a continuum. He made use of a variety of representations to help his student understand and overcome the 'abstract' nature of chemical bonding.

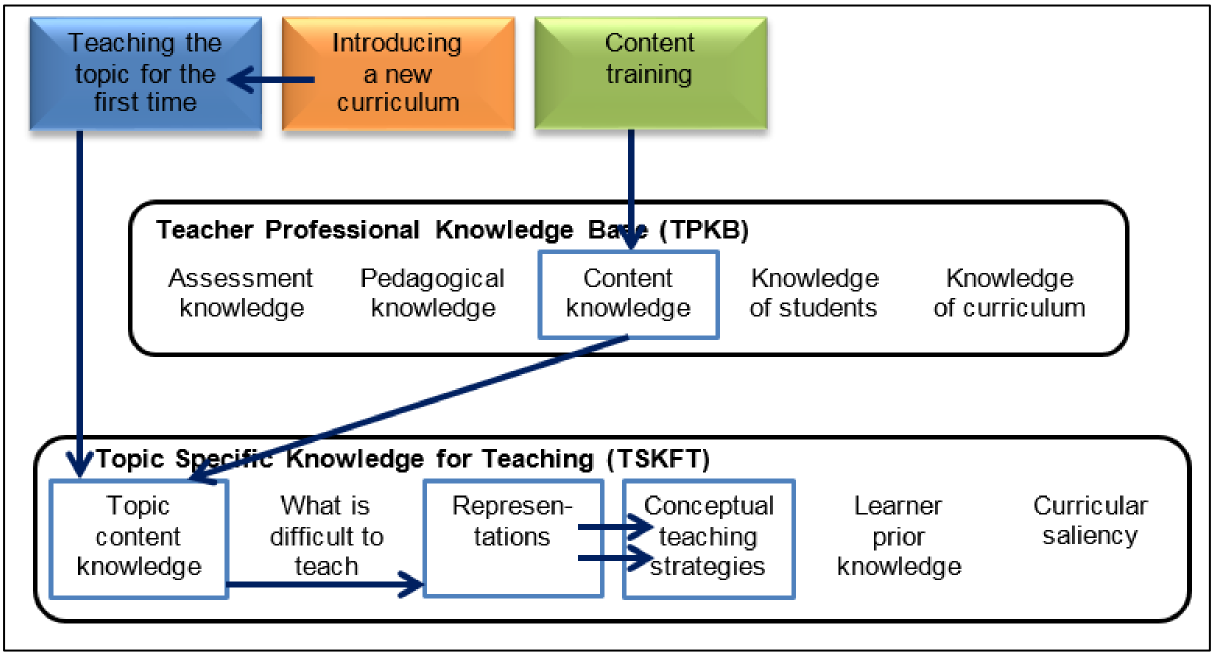


Figure 6.27 Mapping the influence of significant events for Simon

Simon's ability to integrate his knowledge of chemistry and physics supported his ability to teach about chemical bonding, whereas Vuyo's lack of opportunity to apply his knowledge was a limitation. However, as shown earlier, teachers expand on their content knowledge over time, and the hope is that Vuyo will be able to do the same as soon as he has had the opportunity to teach the content.

6.5 Conclusion

This chapter reported on the data analysis and findings from interviewing a purposively selected group of ten teachers. The aim of the analysis was to identify the significant events and factors that played a role in the perceived shifts in the teachers' TSKFT, and to investigate how these events and factors were perceived to have played a role.

A grounded analysis of the interview transcripts revealed three salient themes for significant events, as well as two further factors that played a role in shifting the teachers' perceived knowledge. The themes were teaching experience, changes in the curriculum, and further education, and the two additional factors were the role of colleagues and of students.

The curriculum change events were grouped under three sub-themes: the introduction of a new curriculum, working with the curriculum documents to plan for instruction, and designing curriculum materials. Teachers viewed the furthering of their education as important, especially in the form of post-graduate studies in education and content training. Two teachers also found courses or workshops useful. All the teachers perceived one or more aspects of teaching experience as having played a role in developing their TSKFT. This included teaching the topic for the first time, teaching the topic multiple times, and teaching the topic at different grade levels. Students played an important role in identifying whether teaching strategies are effective in promoting learning, to find out what the students find challenging, and what is difficult to teach. The role of a supportive teaching environment where colleagues can observe each other's lessons, and where teachers can receive content support from knowledgeable colleagues cannot be underestimated.

A further PCK episode analysis revealed how the factors and events contributed to the perceived shifts in teachers' TSKFT over time. The adapted TPK&S Model provided a useful conceptualisation of how teacher professional knowledge bases could interact with each other. Findings reveal that significant events played an important role in teachers' perceptions of the development of their TSKFT. Some of the significant events built the teacher's general professional knowledge base which, in turn, supported development at a topic specific level. Other events had a direct influence on their topic specific knowledge. Teachers also developed their TSKFT through the interaction and integration of the components.

Although single events can make a difference, more often it was a combination of events that initiated growth in the teachers' knowledge. Sometimes the events took place within a short space of time, such as Adrian's planning the teaching for a grade and soon afterwards teaching the content, which made him reflect upon and modify his initial planning. In other cases, such as that of Doreen, the events took place over a number of years. Doreen first had to gain confidence in her content knowledge before she could start paying attention to her students' questions and answers. This set the scene for her further post-graduate studies in education to play a major role in shifting her teaching towards a more student-focussed approach. Development of teacher knowledge is therefore a complex process, with a combination of events playing a role over the entire career of a teacher.

The next chapter presents a cross-case analysis to provide insight into this complexity, shedding more light onto how the events and factors played a role in the teachers' perceived shifts in knowledge for teaching. This allows for the mapping of the learning trajectories of the teachers in this study.

Chapter 7 Discussion

This study set out to map the learning trajectories of physical sciences teachers' topic specific knowledge for teaching (TSKFT) chemical bonding, by using a sequential mixed methods approach. A measuring tool for TSKFT was designed, validated and administered to physical sciences teachers. Ten high scoring teachers were invited to take part in story-line interviews. The findings from the analysis of the teachers' responses to the measuring instrument and story-line interviews were presented in the preceding chapters. Various factors and significant events that were perceived to have played a role in the teachers' performance were also identified. Significant events from the ten cases were discussed, and the influence of these events on the teacher's perceived shifts in topic specific knowledge for teaching was shown. This chapter now presents an integration of all the findings to answer the third research sub-question, and to map learning trajectories for the teachers to answer the overarching research question.

7.1 Introduction

This study was guided by the following overarching research question and three sub-questions:

What are the teachers' learning trajectories with respect to their topic specific knowledge for teaching chemical bonding?

1. How can a valid measure of high quality topic specific knowledge for teaching chemical bonding be obtained?
2. What factors have influenced the quality of the teachers' topic specific knowledge for teaching chemical bonding?
3. How did the factors influence the teachers' perceptions of the shifts in their topic specific knowledge for teaching chemical bonding over time?

The Rasch measurement model was used to design a valid and reliable measuring instrument for TSKFT which can be used with groups of teachers, as well as to predict individual teacher performance. The instrument was administered to a sample of 60 physical sciences teachers. From the quantitative analysis of the teachers' responses to the instrument, three prominent factors that influenced the quality of the teachers' TSKFT were identified. These were:

- The teachers' teaching experience
- The teachers' level of content training

- The teachers’ level of teaching qualification

A further qualitative analysis of the teachers’ instrument responses revealed the following trends in the teachers’ performance on the test:

- Teachers with more teaching experience had a more conceptual approach to teaching, and chose more sophisticated explanatory frameworks.
- Teachers with more teaching experience had fewer alternative conceptions and a better knowledge of chemical bonding models.
- Teachers at different stages of their careers developed different components of TSKFT.
- Teachers with a higher level of content training found some questions less challenging than other teachers.
- Teachers with a master’s degree in education found conceptual teaching strategies less challenging than other teachers.

Ten high performing teachers from across the teaching experience range then participated in story-line interviews. A grounded approach to the analysis of their interview transcripts and story-line graphs revealed significant events and factors under the following themes:

- Curriculum change
- Teaching experience
- Furthering their education
- The influence of colleagues
- The role of students

A further qualitative analysis of PCK episodes revealed how these events and factors influenced the teachers’ TSKFT, as was discussed in Chapter 6. The findings were organised according to individual teachers to capture the complexity of their responses. However, for the purpose of answering the third research sub-question, a cross-case analysis was done, and the findings are interpreted for the ten teachers as a group, together with the findings for the larger group of 60 teachers presented in Chapter 5. In this chapter the cross-case analysis is presented, with the findings regrouped according to the themes that were identified, to show how the various aspects of each theme have influenced the teachers’ TSKFT. The chapter concludes by mapping three learning trajectories which emerged from this study, so as to answer the overarching research question.

7.2 The influence of curriculum change

The grounded analysis of the story-line interview transcripts, as reported in Chapter 6, identified three sub-themes under curriculum change, namely introducing a new curriculum, working with the curriculum documents, and designing curriculum materials for the new curriculum. Figure 7.1 maps the significant events under these three sub-themes similar to the maps in Chapter 6, but across all the teachers. How the events have influenced the teachers' TSKFT is indicated using arrow sets which are colour-coded for each teacher. Nine out of ten teachers perceived one or more of these sub-themes (indicated in the orange boxes) to play a role in influencing their TSKFT. However, to reduce complexity only four are shown in the diagram, but this still represents the variety of responses.

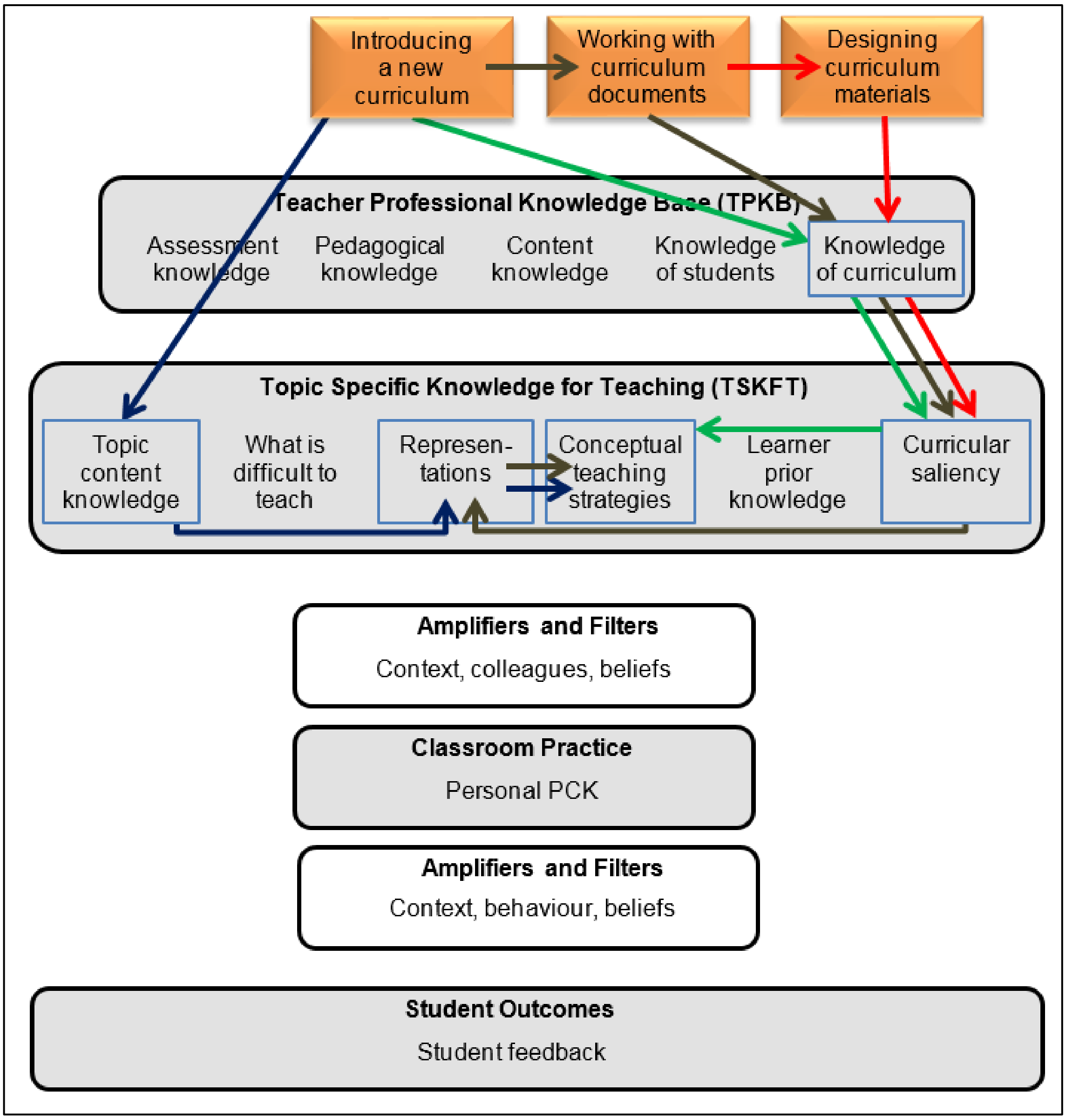


Figure 7.1 The influence of changes in the curriculum on teachers' TSKFT

Simon (see the dark blue arrows in the figure) had to teach new content as a result of the introduction of the new curriculum. This challenged his content knowledge of chemical bonding and resulted in him using a variety of representations, and choosing a conceptually grounded teaching strategy to teach the content. Adrian (brown arrows) worked with both old and new curriculum documents when the CAPS curriculum was introduced, and he had to plan a new teaching sequence. Interacting with the documents gave him an overview of curricula in general, and, in turn, insight into a teaching sequence for chemical bonding. He integrated his knowledge to choose appropriate representations and an effective teaching strategy. Alicia (red arrows) had the same experience when she had to design a teaching sequence in her first teaching job. She learned about curricula in general and the importance of a teaching sequence to ensure conceptual understanding when she teaches. Doreen (green arrows) attended a workshop when the latest curriculum was introduced. As a result of this workshop and the numerous curriculum changes she had experienced, she started to question the prescribed order in which she was supposed to teach the content. She started using her own ideas about sequencing content, and moved away from being textbook-bound to thinking more about what her students need.

Most of the influences related to changes in the curriculum involved curricular knowledge, at the TPKB level, and curricular saliency, specifically in terms of sequencing big ideas for teaching, at the TSKFT level. For some teachers the new curriculum introduced new content which directly challenged their knowledge at a topic level. In both cases a number of different components of TSKFT were influenced.

Curricula that are well-designed can provide scaffolding for teaching, especially in terms of a teaching sequence (Sibanda & Hobden, 2015). When curricula change, this scaffolding is also affected. For most teachers this is unsettling (Rogan, 2007), but the teachers in this study embraced the change.

The current curriculum in South Africa has a spiral design, where topics are revisited and expanded upon over a number of years. This curriculum is underpinned by conceptual progression and scaffolds the learning of chemical bonding models over four years, as was elaborated on in Chapter 2. The current curriculum therefore acts as a guideline and support for conceptual progression from an atomic view to an electrostatic view, as students progress from Grade 8 to Grade 11.

7.3 The influence of teaching experience

Teaching experience was an important factor that was identified in both the quantitative and qualitative analyses. All ten of the interviewed teachers perceived one or more aspects of teaching experience as having played a role in shifting their TSKFT.

The grounded analysis of the story-line interview data identified three sub-themes under 'teaching experience', namely teaching the topic for the first time, teaching the topic multiple times, and teaching the topic to multiple grades. Figure 7.2 shows how some of the teachers perceived the influence of these three sub-themes on their TSKFT. Again, the diagram only represents selected events and not all the events from all the teachers, yet covering the variety of responses presented by the teachers.

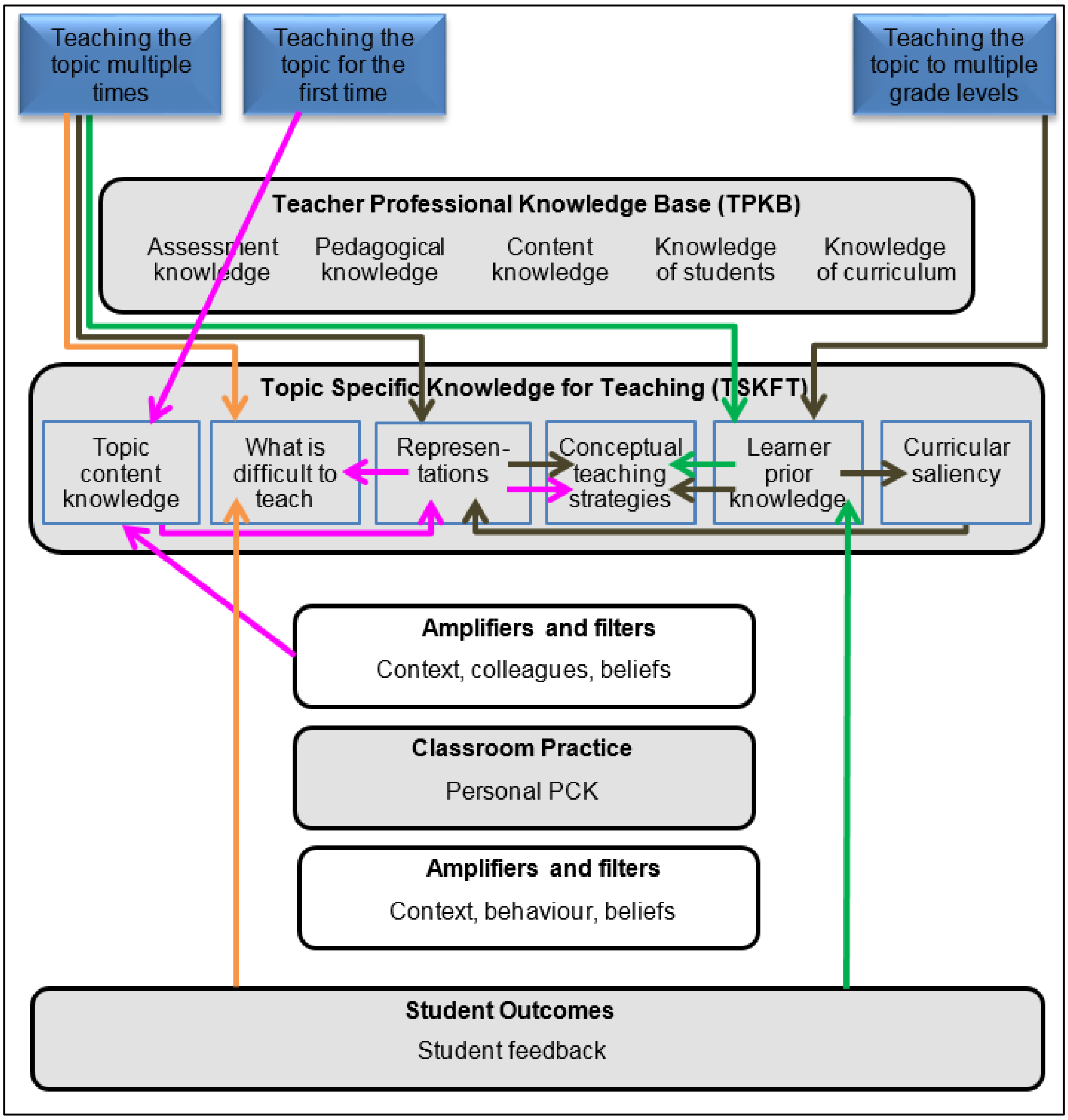


Figure 7.2 The influence of teaching experience on teachers' TSKFT

Teaching the topic for the first time challenged Natalie's content knowledge of chemical bonding (see pink arrows on the diagram). As a result of this event, and with the support of a colleague, she was able to increase her knowledge of content representations. This lead to an increase in her perceived knowledge of what is difficult to teach, and shifted her teaching strategies towards a more conceptual approach. Different knowledge components **interacted** to result in a shift in her teaching strategy.

Teaching the same topic to different grades gave Adrian (brown arrows) knowledge of his students' prior knowledge, which enabled him to derive a teaching sequence and choose appropriate content representations for the section. Teaching the topic multiple times gave him a better understanding of whether the representations he chose were effective, and he used this knowledge to modify his choice for the next year. Adrian was able to **integrate** his knowledge of the various components to derive a teaching sequence and subsequent teaching strategy to ensure conceptual understanding.

Both Jonathan (orange arrows) and Doreen (green arrows) reflected on how they taught the same content multiple times. This gave Jonathan insight into what was difficult to teach, and for Doreen it gave a better understanding of her students' prior knowledge. In both cases the role of student feedback was prominent. The questions that the students asked in class, or the answers they provided to the teacher's questions, supported the perceived shifts in teacher knowledge. The fact that the teachers taught the topic multiple times meant that they also had the benefit of hearing more students respond to the same content each year.

Desmond and Stephanie (not indicated on the diagram) also reflected on teaching the same individuals in consecutive years. Most of the teachers in the sample taught at schools where there were more than one physical sciences class per grade. It was school policy to allocate the same students to a teacher in consecutive years. This helped Stephanie to get to know her students, and Desmond to develop a classroom culture where students are collaborators to their learning.

It was striking to note that none of the teaching experience events influenced the teachers' knowledge at a general level, but rather directly at a topic level, involving all the components in various combinations. It would appear that teaching experience influenced topic specific knowledge 'from the bottom up', from the classroom practice level, and not from the 'top down', via the general knowledge base, as was the case with changes in the curriculum. When teachers reflect on their teaching they do so through the lens of their classroom practice. The aim of the story-line interviews was to get teachers to think back over their careers and *teaching practice* to identify events, and to reflect on the influence of these events on their *teaching*. It is therefore not surprising that the influence of teaching experience was at the topic specific level, as shown in Figure 7.2.

The influence of teaching experience was also investigated in a separate analysis of all the teachers' responses to the measuring instrument as reported in Chapter 5. The following trends in teacher performance were identified:

Teachers with more teaching experience had fewer alternative conceptions, and a better knowledge of chemical bonding models

The detailed item analysis revealed that teachers with more teaching experience had fewer alternative conceptions and better knowledge of chemical bonding models. It was encouraging to find that there were many teachers with good content knowledge of chemical bonding, but disappointing that there were also many teachers who held alternative conceptions about covalent, ionic and metallic bonding. This finding was also reported in a number of other countries - for example Sweden (Bergqvist et al., 2016), Croatia (Vladusic et al., 2016), and Australia/Singapore (Tan & Treagust, 1999). As shown by these and other studies, it is a concern if teachers do not have the required conceptual understanding of the content that they are supposed to teach. Of bigger concern, however, was the finding that, although teachers were able to choose the correct answers and reasons for the alternative conception questions to show that they have the required understanding, very few teachers were able to identify alternative conceptions in student answers, and then link that to possible learning impediments (see page 127). Even the teachers with the most experience were not able to use their knowledge of student alternative conceptions as tools to gain insight into student learning. Therefore, although teachers with more teaching experience had fewer alternative conceptions, they still lacked an understanding of how to transform what they know into strategies to support learning.

Furthermore, the number of years' teaching experience was not necessarily an indication of how many times a specific topic was taught, nor was it a guarantee for well-developed TSKFT. This was shown in Vuyo and Jonathan's cases. Vuyo had some understanding of the bonding continuum, but was not yet able to integrate his knowledge into a teaching strategy for this part of the content. Despite his five years' teaching experience, he had not had the opportunity to teach about this content. This content was not examined in Grade 12, and therefore Vuyo was not required (by his school) to spend too much time on it when teaching Grade 10 or 11. The expected learning trajectory for Vuyo is that his topic content knowledge will expand over time, and that he will develop the ability to integrate and transform this knowledge once he has had the opportunity to teach it.

Jonathan, who also had five years' teaching experience, also commented on teaching about the bonding continuum, and elaborated on a metaphor that he used (see page 149). Jonathan taught the content every year, and was able to transform his content knowledge and refine his teaching strategies over time. In many ways Vuyo is still a beginning teacher when considering this topic, whereas Jonathan is already a mid-career teacher, despite them having the same number of years' teaching experience.

Teachers with more teaching experience had a more conceptual approach to teaching, and chose more sophisticated explanatory frameworks

It is important that teachers possess sophisticated views of the topics they teach (Rollnick, 2016), which provides them with a more complex understanding than what is required at school level, and an extended repertoire of explanatory frameworks to choose from. This study found that teachers with more teaching experience had a more conceptual approach to teaching chemical bonding, and chose more sophisticated explanatory frameworks when reflecting on their content knowledge and their teaching.

The discussion on changes in the curriculum has already identified the designed conceptual progression from Grade 8 to Grade 11 in the current South African curriculum. The explanatory framework analysis in Chapter 5 confirmed that teachers are able to use various frameworks for the purpose of teaching. A closer look at two representative cases (Desmond and Stephanie) revealed that teachers may have a sophisticated view of chemical bonding models, but may choose a less complex view to teach. Their choices may be guided by their curricular saliency, and choosing the level of sophistication based on the grade level of the students. The teacher's choice may also be guided by what they believe the students are capable of, or what is best for them. Both Desmond and Stephanie's choices were guided by prior teaching experience and knowledge of their students.

Teachers at different stages of their careers developed different components of TSKFT

Teachers at different stages of their careers found items more or less difficult than expected. Pre-service teachers, for example, found identifying content representation and big ideas for teaching easier than expected. However, when they had to describe how they would use it in teaching, it was much more challenging. This was also found in a study by Rollnick and

Davidowitz (2016), which compared the performance of subject matter specialists with experienced teachers. In their study the subject matter specialists found representations and identifying the big ideas tor teaching organic chemistry less challenging than the experienced science teachers. The pre-service teachers in this study may be considered subject specialists, since they have recently completed their undergraduate training. The recently acquired content knowledge may have helped them identify the big ideas as well as the strengths and weaknesses of representations, since these TSKFT components are strongly linked to the content, but they still found it challenging to transform this knowledge for the purpose of teaching.

Pre-service teachers also found ‘what is difficult to teach’ (WDT) and identifying alternative conceptions in students’ answers much more challenging than the other teachers. These items required teachers to consider student responses, something to which pre-service teachers have little or no reference. Whilst pre-service teachers found the WDT items challenging, the beginning teachers found this item the least challenging. This may indicate that this is the aspect of TSKFT that beginning teachers learn first when they start their careers. The first stage in a learning trajectory for beginning teachers may therefore be learning to identify what is difficult to teach in a topic.

As the teachers gained teaching experience they found some of the items more challenging, for example representations, curricular saliency and what is difficult to teach, and some less challenging, namely the conceptual teaching strategies items. To some degree it seems that the teachers regressed in their thinking. This may be ascribed to the fact that as teachers gain teaching experience, they are socialised into the system. A stronger focus is placed on exam preparation, resulting in a narrower understanding of the content, and a more ‘streamlined’ content scope to fit this purpose (as was articulated by Vuyo). Over time, as teachers gain teaching experience, their repertoire of representations become limited to the ‘ones that work’, and they find it more difficult to articulate why they use a specific representation, or why a concept is difficult to teach. They may also become less reflective, and therefore do not question their choices and strategies any longer. Schneider and Plasman (2011), in their literature review on teacher learning progressions, also found that some experienced teachers’ thinking regressed over time, especially when teacher became less reflective and where formal instruction was absent.

The role of content knowledge

The item analysis in Chapter 5 showed that university level content training supported some areas of teaching about chemical bonding (for example the bonding dichotomy), but not other concepts that are more uniquely school content (for example bonding in graphite). A number of studies have shown the importance of content knowledge in PCK, and that topic content knowledge is a prerequisite to teaching a topic (Abell, 2007; Kind, 2014b; Rollnick, 2016). When Natalie was confronted with new content she could only instruct her students to rote learn the content, and only once she had mastered the content could she teach it in a more conceptual way. Doreen also first had to become confident in the content before she could shift her attention to other aspects of her teaching. In Vuyo's case he did not have the content knowledge (the bonding continuum in CTS1), and was unable to formulate a teaching strategy, but where he had the content knowledge (how bonding takes place) he was able to draw from it on the spot, despite him not having prepared to teach it. Simon's strong conceptual approach to teaching about chemical bonding was evident in all the answers he provided, and underpinned his teaching. He was ranked third overall. Topic content knowledge is therefore central and important, and if not in place, will hamper further development of TSKFT. The first step in a learning trajectory is therefore ensuring that basic content knowledge is in place, and if the content is not gained at tertiary level, getting to know the content is the first step in learning to teach.

It seems that teachers at different stages of their careers have different developmental trajectories with respect to TSKFT. Some components of TSKFT will develop early in a teacher's career, whilst other components may take longer to develop. Content knowledge appears to be a pre-requisite for TSKFT, but will also develop over time as the content is taught year after year.

7.4 The influence of furthering their education

Nine of the ten teachers mentioned one or more aspects related to further studies. Desmond, who did not do any further studies beyond his teaching diploma, was the only teacher who did not comment under this theme. Three sub-themes were identified, namely content training, furthering their education, and specific short courses or workshops. These sub-themes are indicated with green boxes in Figure 7.3. Glenda (see the light blue arrows) completed a short course on assessment which dramatically shifted her thinking about the importance of assessment in teaching. As a result she now embeds informal assessment in her teaching strategies. Doreen (green arrow set on the far right of the diagram) attended a workshop when the new curriculum was introduced. This gave her an overview of curriculum design in general, and as a result she started questioning the prescribed order in which she was supposed to teach the content. The outcome was that she started using her own ideas about sequencing content, and moved away from the textbook to focus more on what her students needed.

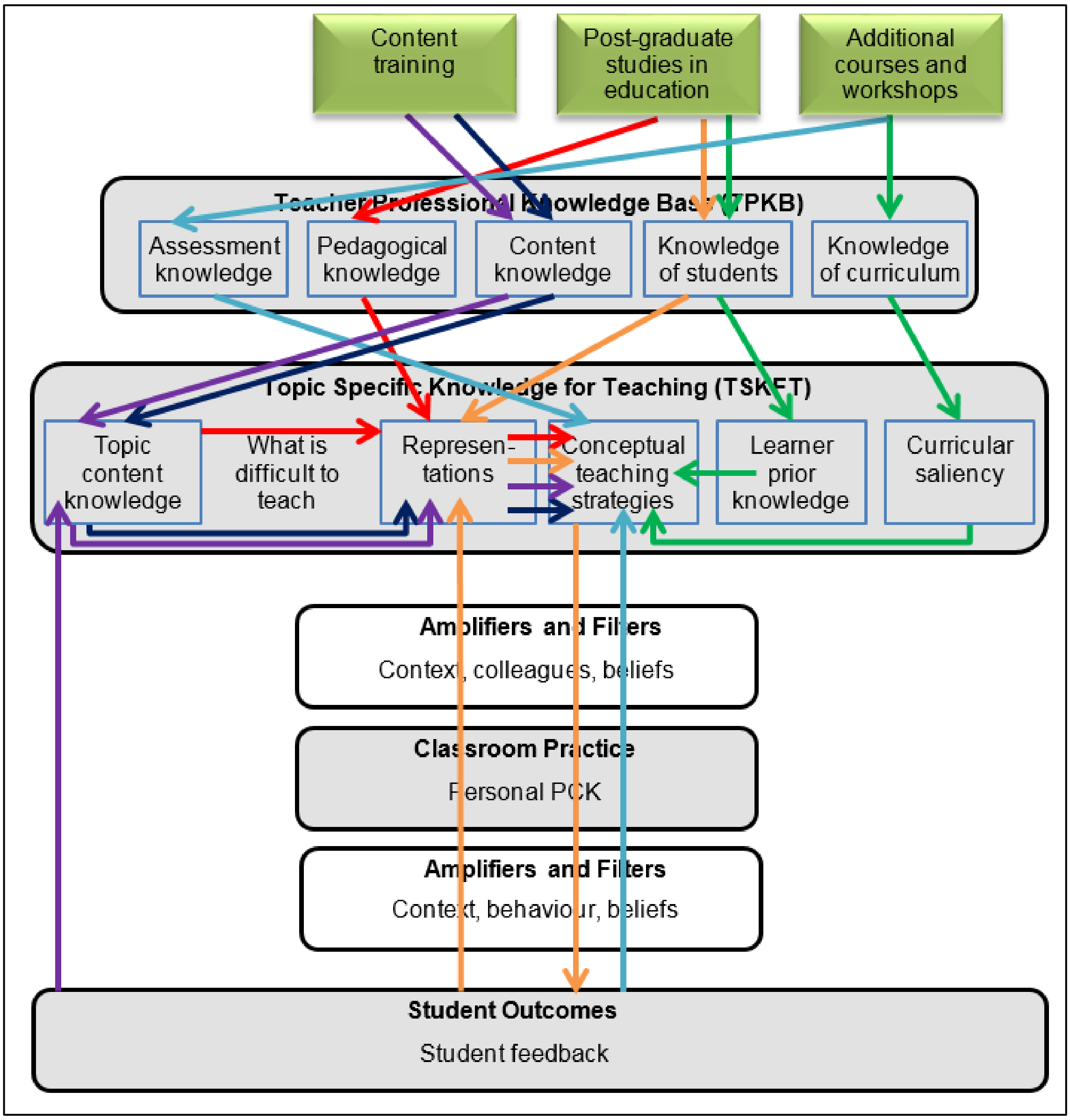


Figure 7.3 The influence of furthering their education on teachers' TSKFT

For both Vuyo (purple arrows) and Simon (dark blue arrows), the undergraduate content training that they received provided them with a content base that they could draw from when teaching about chemical bonding (for Vuyo science content was part of his undergraduate education training). This knowledge helped Vuyo link bonding with the periodic table, and informed Simon's choice of representation to illustrate that a bond is an electrostatic force between protons and electrons. Simon also reflected on the importance of knowledge about electrostatics when teaching chemical bonding. Teaching about chemical bonding requires a solid base in chemistry, as well as knowledge of physics, to provide the grounding from which prior knowledge is drawn.

Only four teachers in the entire group of sixty teachers had a master's qualification in education, and one additional teacher, Glenda, had almost completed hers[6]. All five of these teachers scored above the mean, and were ranked third, fifth, sixth, seventh and twenty-first. Jonathan, who was ranked 21st, had the least experience of all, didn't have a PCGE, and studied chemistry only at a first year level. All five these teachers were interviewed, and they all mentioned doing a master's degree in education as a significant event.

Alicia (red arrows), remembered learning a variety of teaching strategies during her master's degree, and could draw from that when she had to choose one for metallic bonding. Jonathan (orange arrows) and Doreen (green arrows), both remembered learning about how students learn during their post-graduate studies. Jonathan used this knowledge to choose powerful analogies and metaphors, while Doreen used the notion of alternative conceptions in deciphering her students 'incorrect' answers and choosing appropriate teaching strategies to support student learning. In both cases the teachers extensively used the feedback from their students to guide their teaching. Neither these teachers, however, started off teaching in this way. Both teachers reflected on being 'textbook bound' in the beginning, and only after a few years shifting to incorporate more student feedback.

Further studies expanded the teachers' knowledge at a general level, which in turn, provided a solid base from which they could draw to shift their knowledge at a topic level. As with the previous discussion on teaching experience, shifts in one component at the topic level often lead to shifts in knowledge of other components. It became clear that the interaction between components played an important role in the development of quality TSKFT. This was also found in a study by Park and Chen (2012), in which high levels of interaction between the various knowledge components were linked to high levels of topic specific PCK. In addition to the interaction between the various components, teachers with quality topic specific knowledge for teaching were also able to integrate their knowledge. Adrian simultaneously

[6] Glenda was in the final stage of writing up her dissertation. Two additional teachers (Vuyo and Doreen) had, at the time of their interviews, just enrolled for a master's degree in education, but they did not comment on the influence of this programme on their teaching.

drew from a number of knowledge components to design and review his teaching approach. Quality TSKFT involves the interaction of knowledge components, as well as the ability to integrate knowledge for the purpose of teaching.

It was notable that many of the arrows point towards and away from the representations component. Content representations play an important role in the teaching of chemical bonding, since the essence of the topic is the study of bonding *models.* The teaching and learning of chemical bonding is therefore the teaching of, and learning about, content representations of how we understand the interactions between atoms (Bergqvist et al., 2016; Coll & Taylor, 2002). Understanding the role of models in science is therefore essential for the teaching of chemical bonding.

Arrows only point towards conceptual teaching strategies, with no arrows pointing away from it. This is in line with Mavhunga and Rollnick's (2013) description that teachers need to draw together and integrate their knowledge of all the other components, in order to design a conceptual teaching strategy for a topic.

In Chapter 5 it was found that the teachers with a master's degree in education found the conceptual teaching strategies question less challenging than expected. The teaching experience of the master's level teachers varied from five years (Jonathan) to 24 years (Alicia). It seems that it was not their experience that accounted for their increased performance, but rather their increased knowledge at the TPKB level, and their ability to draw from that knowledge, applying it at the topic level, and integrating the various components to suggest a conceptual teaching strategy.

When the influence of the events at the general level is compared with the influence at the topic level, the same level of interaction within each knowledge base was not found. None of the knowledge bases at the TPKB level interacted with each other, whereas a high level of interaction was found at a topic level. Figure 7.4 shows the adapted Model of Teacher Professional Knowledge and Skill, with arrows indicating the interaction between and within the knowledge bases. Question marks have been used where the interactions have not been confirmed in this study, and where more research is needed.

The lack of interaction between knowledge bases at the TPKB level could be an indication that knowledge is gained separately at this level, through formal and informal training programmes, and that the integration takes place at the topic level.

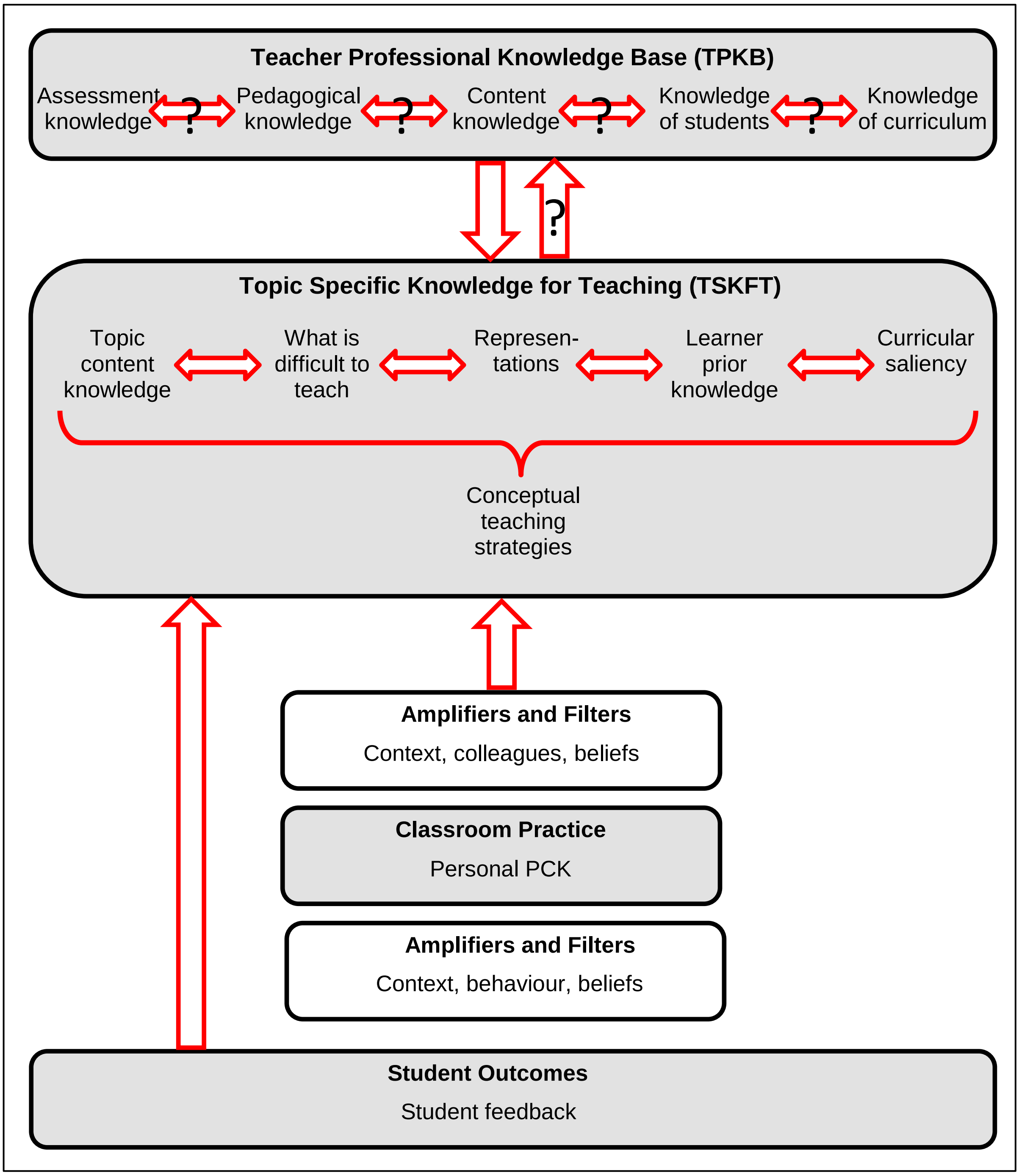


Figure 7.4 Interactions between and within the knowledge bases for teaching

Gess-Newsome (2015) describes the Teacher Professional Knowledge Base as follows:

> This is a formal body of knowledge determined and codified by researchers or experts. Teachers are seen as the consumers of this knowledge as translated for use in teacher education programs or professional development. (Gess-Newsome, 2015, p.32)

She goes further and suggests that 'with active and potentially externally facilitated reflection, it is possible to see how growth in one knowledge base may increase growth in the other'. (Gess-Newsome, 2015, p.34)

This study has shown that both formal and informal training programmes initiated growth in the general knowledge bases, which, in turn, supported growth at the topic specific level. Through story-line interviews, which asked the teachers to reflect on their practice, it was possible to capture the perceived shifts in their knowledge at both general and topic specific knowledge levels.

No evidence was found that the knowledge at a topic specific level influenced knowledge at the general level (the arrow from the second level up to the first level). Gess-Newsome (2015) proposed her model with all the arrows being double sided, indicating the possibility that knowledge flows in both directions, but in contrast this study found that knowledge only flows from the general to the topic specific level.

7.5 The role of colleagues and students

As was demonstrated in this study, colleagues can play an important role in supporting teachers' development of TSKFT, especially by providing content support or allowing teachers to observe each other's lessons.

School culture, as portrayed by colleagues, also played a role in the teachers' knowledge. Doreen was lead to believe that her students are blank slates, and that she should fill them with information. This had a limiting effect on her teaching strategies in the beginning of her career, making her textbook bound and teacher-focussed. It was only later in her career, once she gained confidence in her teaching ability, that she could challenge the status quo at her school, and create her own teaching culture.

Students played an important role as the barometers of effective teaching and learning. Their comments and questions formed an integral part of the teachers' development of TSKFT. Student questions challenged teachers' content knowledge (Vuyo), provided insight into how students understood the content (Doreen), or assisted decisions on whether analogies (Jonathan) or representations (Adrian) are effective. Student feedback also guided teaching decisions - for example Stephanie choosing less complex explanatory frameworks to support student learning, and Desmond choosing more complex explanatory frameworks to prepare his students for tertiary education.

The influence of colleagues and students were prominent in many of the teachers' comments, despite this not being the primary focus of the study. Two arrows leading towards the TSKFT level were included in Figure 7.4 to indicate these influences. It became clear from the findings that these are important aspects that can act as amplifiers or filters of teachers' TSKFT. However, the extent of the influence of colleagues and students were not fully explored in this study and, to do justice to its importance, should be further investigated in a separate study.

7.6 Mapping learning trajectories

The initial assumption for this study was that learning trajectories for teachers would be mapped with respect to their teaching experience, but it became clear that teaching experience was not the only factor playing a role in the teachers' learning. Being in the classroom for longer was not necessarily a guarantee for the development of teacher knowledge. A more productive analysis approach was to rather consider the quality of the teachers' knowledge, and capturing how teachers reached high levels of TSKFT. This approach enabled the mapping of learning trajectories for TSKFT, as well as being able to capture the influence of different factors, including teaching experience, which played a role in shaping these trajectories.

The following three learning trajectories, with respect to the development of content knowledge, the interaction between the components of TSKFT, and the teachers' approach to teaching, have been identified for the group of 60 physical sciences teachers in this study.

Learning trajectory 1: Teachers shifted towards deeper conceptual understanding of the content, and used more sophisticated explanatory frameworks

Quality TSKFT includes deep conceptual understanding of the content and the ability to transform the content to promote student learning (Shulman, 1986). This is accompanied by an extended repertoire of explanatory frameworks, and the ability to choose an appropriate framework to promote conceptual progression amongst students.

Knowing the content that you are supposed to teach is an essential starting point and first step in learning to teach (Kind, 2014a). This study showed that once basic understanding of the content was in place, teachers gained confidence in their ability to teach, and could shift their focus to other aspects of their teaching. Figure 7.5 shows the learning progression for the teachers with respect to content knowledge. The first stage in the trajectory was gaining knowledge of the disciplinary content. This was mostly gained during undergraduate training, but where gaps in knowledge existed, colleagues or additional coursework played a role.

Disciplinary content includes knowledge of the topic under discussion, as well as conceptually related content from other topics - for example knowledge of electrostatics when chemical bonding is taught. The next stage involved expanding content knowledge to include aspects of the content that is unique to teaching at secondary school level (Deng, 2007). This knowledge was gained the first time a topic was taught. As teachers gained teaching experience, and taught the same content multiple times and to multiple grades, their understanding of the content deepened and they expanded their repertoire of explanatory frameworks. Lastly, teachers integrated more sophisticated explanatory frameworks into their conceptual teaching strategies.

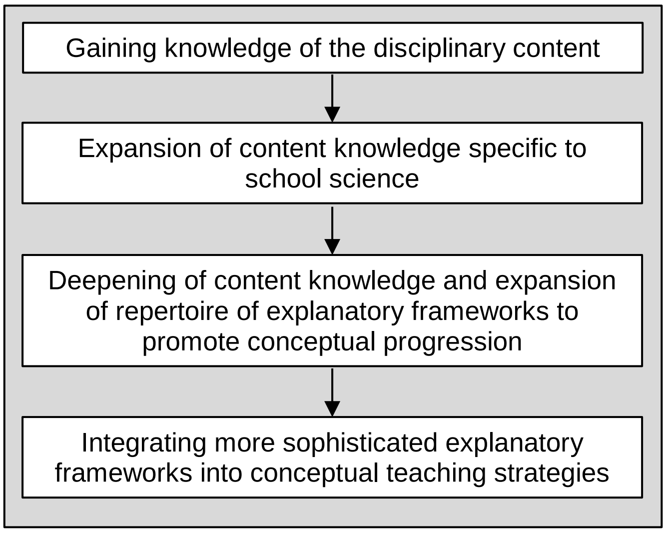


Figure 7.5 Learning trajectory for teachers' content knowledge

Learning trajectory 2: Teachers shifted towards more integrated topic specific knowledge for teaching

Quality TSKFT is characterised by a high level of interaction between its components, and the ability to integrate the components to derive teaching strategies which promote conceptual understanding amongst students.

Friedrichsen et al. (2009) found that teaching experience does not guarantee well-developed knowledge structures and robust instructional strategies. Not all the teachers in this study, who had many years' teaching experience, displayed high levels of integrated knowledge, nor did the early career teachers in this study have to wait until they gained teaching experience, before they were able to integrate their knowledge. Some teachers developed quality TSKFT early in their careers, while others who were at the end of their careers had not developed high quality knowledge.

A learning trajectory for integration of TSKFT components for the teachers in this study was identified and is depicted in Figure 7.6. The first knowledge component that was learned by beginning teachers was what is difficult to teach about the topic. Pre-service teachers were unable to identify what is difficult to teach, whilst beginning teachers were much more able to do so than any other teacher. This was followed by the development of the other TSKFT knowledge components.

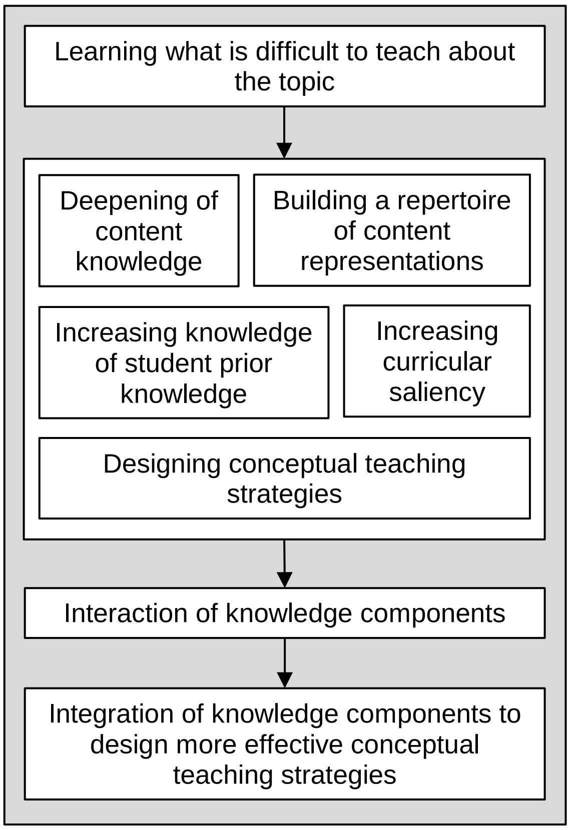


Figure 7.6 Learning trajectory for the integration of TSKFT components

The data did not reveal any specific order in the development of TSKFT components, likely because this is a personal experience, and as Duschl and Hamilton (2011) claimed - ‘learning is framed by our humanness’ (p.82). Teachers gained knowledge about the components each in their own unique way, and influenced by their own unique set of experiences.

Teacher learning, especially in terms of the development of knowledge of the components of TSKFT, was not found to be linear, in line with what Friedrichsen and Berry (2015) suggested. Although learning was idiosyncratic and personal, teachers with more teaching experience were more able to derive conceptual teaching strategies and had higher levels of TSKFT, which indicates that TSKFT develops over time as teachers gain teaching experience.

The next stage involved an interaction between the various components of TSKFT, where an increase in knowledge of one component initiated shifts in knowledge in the other components. The last stage that was identified in this study was an integration of knowledge components, where teachers were able to simultaneously draw from a variety of knowledge components to derive conceptual teaching strategies. This stage was only observed for teachers with the highest quality TSKFT, indicating that this was the last stage in the learning trajectory.

Learning trajectory 3: Teachers shifted from teacher-focussed towards student-focussed teaching approaches

Quality TSKFT is student-focussed. It is characterised by extensive knowledge about alternative conceptions for the topic, and how to recognise these conceptions in student answers, knowledge of what students should know before a topic is taught, and what can be taught afterwards, as well as insight into what students find challenging.

Schneider and Plasman (2011) identified an extensive learning progression for teachers' knowledge of student ideas in their review of PCK literature on teacher learning as described in Chapter 2. The learning progression is included in Figure 7.7 for ease of reference. A number of the interviewed teachers mentioned a shift in their knowledge about student conceptions, but Doreen's experience was the most explicit and the most complete. She described a very similar learning progression to what Schneider and Plasman (2011) found over her career. The right hand column in Figure 7.7 includes quotes from Doreen, demonstrating each of the stages in the progression, except for the last stage. This learning progression can be seen as one of the facets of the third learning trajectory identified in this study, in which teachers shifted from a teacher-focussed approach towards being much more student-focussed in their teaching.

According to Schneider and Plasman (2011), formal instruction seems to positively influence the teacher's development of knowledge. This was also the case with Doreen and many of the other teachers, as described earlier in this chapter, where post-graduate studies in education played a pivotal role in shifting their thinking, as illustrated above.

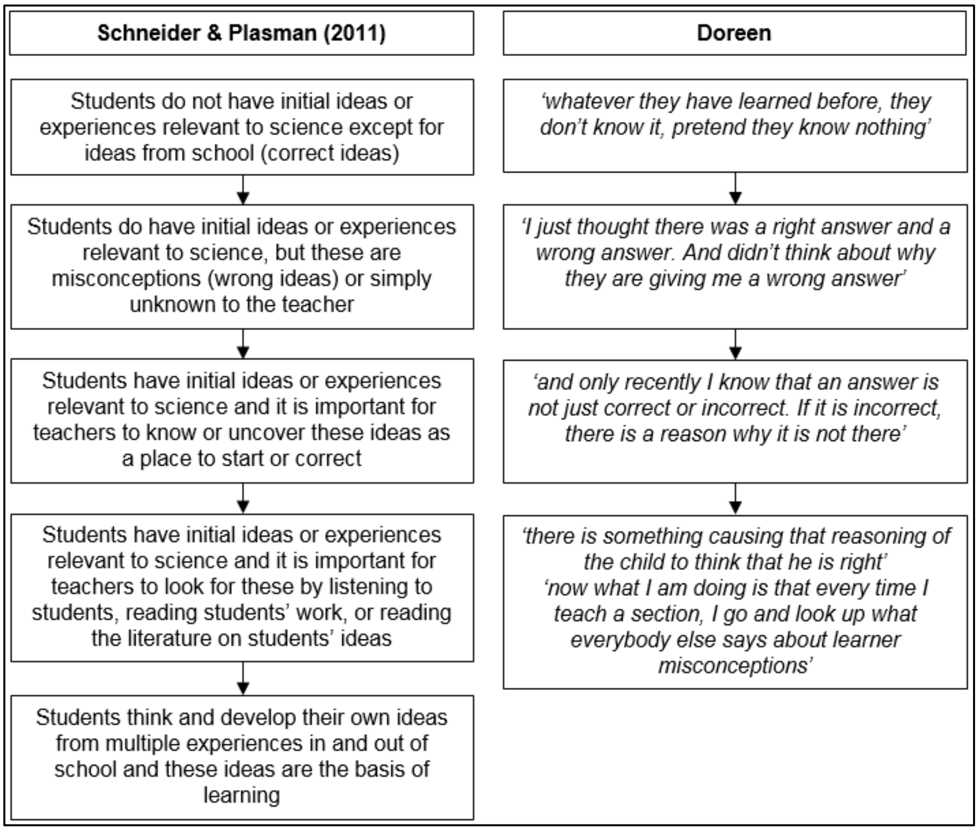


Figure 7.7 Learning progression for teachers' knowledge of student ideas

As teachers reflected on their careers they articulated a shift from focussing on what they should teach and how they should do so (*What do I teach?*), to what their students think and how their students can be better supported to learn more effectively (*What do they learn?*). The learning trajectory for teachers' approach to teaching is shown in Figure 7.8.

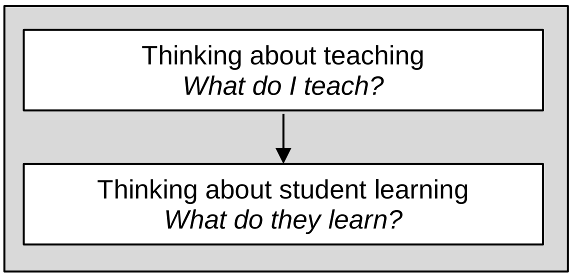


Figure 7.8 Learning trajectory for the teachers' approach to teaching

Although the figure depicts what seems to be a very basic trajectory, it encapsulates shifts in teachers' thinking about many different aspects of teaching, such as the one depicted in Figure 7.7. It is foreseen that many more learning progressions may form part of this over-arching learning trajectory, in which teachers' approach to teaching shifted towards their students. This was the most significant change for most of the teachers interviewed in this study.

7.7 Conclusion

This chapter presented a cross-case analysis to provide the final insight into how factors and events affected the teacher's perceived shifts in TSKFT, and to map learning trajectories for the teachers' TSKFT.

The factors and events influenced the teachers' topic specific knowledge for teaching as follows:

The **changes in the curriculum** mostly influenced the teachers' knowledge of curricula in general, and their curricular saliency at a topic specific level. The introduction of a new curriculum also introduced new content, which challenged teachers' content knowledge and encouraged them to expand their topic content knowledge, on occasion with the support of a colleague.

Furthering their education influenced all aspects of the teachers' general knowledge base, which, in turn, sparked growth of various components at a topic specific level. Post-graduate studies in education, together with the influence of students, promoted shifts towards becoming more student-centred.

Teaching experience influenced the teachers' topic specific knowledge from the classroom practice level by influencing all the components of TSKFT in various combinations.

High quality TSKFT was characterised by high levels of interaction between the knowledge components at a topic level, but not at a general level. The interaction and integration of knowledge components at the topic specific level was prominent as teachers reflected on how they perceived their knowledge to shift over time.

The following three learning trajectories emerged from the synthesis of all the findings in this study:

- Teachers shifted towards deeper conceptual understanding of the content and used more sophisticated explanatory frameworks
- Teachers shifted towards more integrated topic specific knowledge for teaching
- Teachers shifted from teacher-focussed towards student-focussed teaching approaches

The next chapter will conclude the study by summarising the research findings and elaborating on the implications and limitations of this study, as well as recommendations for future research and implementation.

Chapter 8 Conclusion

This chapter concludes the study by summarizing the answers to the research questions. Implications, recommendations and limitations of the study are presented, before closing with some personal reflections.

8.1 Introduction

Education is a national concern in South Africa, and the training and professional development of teachers, especially mathematics and science teachers, have been prioritised by the National Government (DBE & DHET, 2011). There is a growing interest in the professional development of teachers to better support teachers along their career paths. In addition, South Africa has an ageing teacher population of which a large proportion will reach retirement age within the next 10 to 15 years. In an attempt to capture the expertise of the teachers who are currently in our classrooms, this study aimed to map the learning trajectories of a sample of physical sciences teachers' topic specific knowledge for teaching. Understanding how expert teachers' knowledge developed over time and what factors influence this development, can inform the design of professional development programmes to support less experienced teachers in South Africa, and shorten their route to expertise.

For the past three decades scholars have been investigating the special type of content knowledge that is needed for teaching, examples of which include mathematical knowledge for teaching (MKT) (Ball et al., 2008) and pedagogical content knowledge (PCK) (Berry, Friedrichsen, & Loughran, 2015; Shulman, 1986). This provided the theoretical lens through which teacher knowledge was investigated in this study. The construct Topic Specific Knowledge for Teaching (TSKFT) was formulated drawing from the conceptualisations of teacher knowledge in mathematics and science. Six components for TSKFT were identified, namely topic content knowledge, representations, curricular saliency, what is difficult to teach, student prior knowledge, and conceptual teaching strategies. One of the most recent PCK models, the Model of Teacher Professional Knowledge and Skill, including PCK (Gess-Newsome, 2015), was modified by including TSKFT at the topic level, and used as an analytical framework for this study (see Figure 8.1).

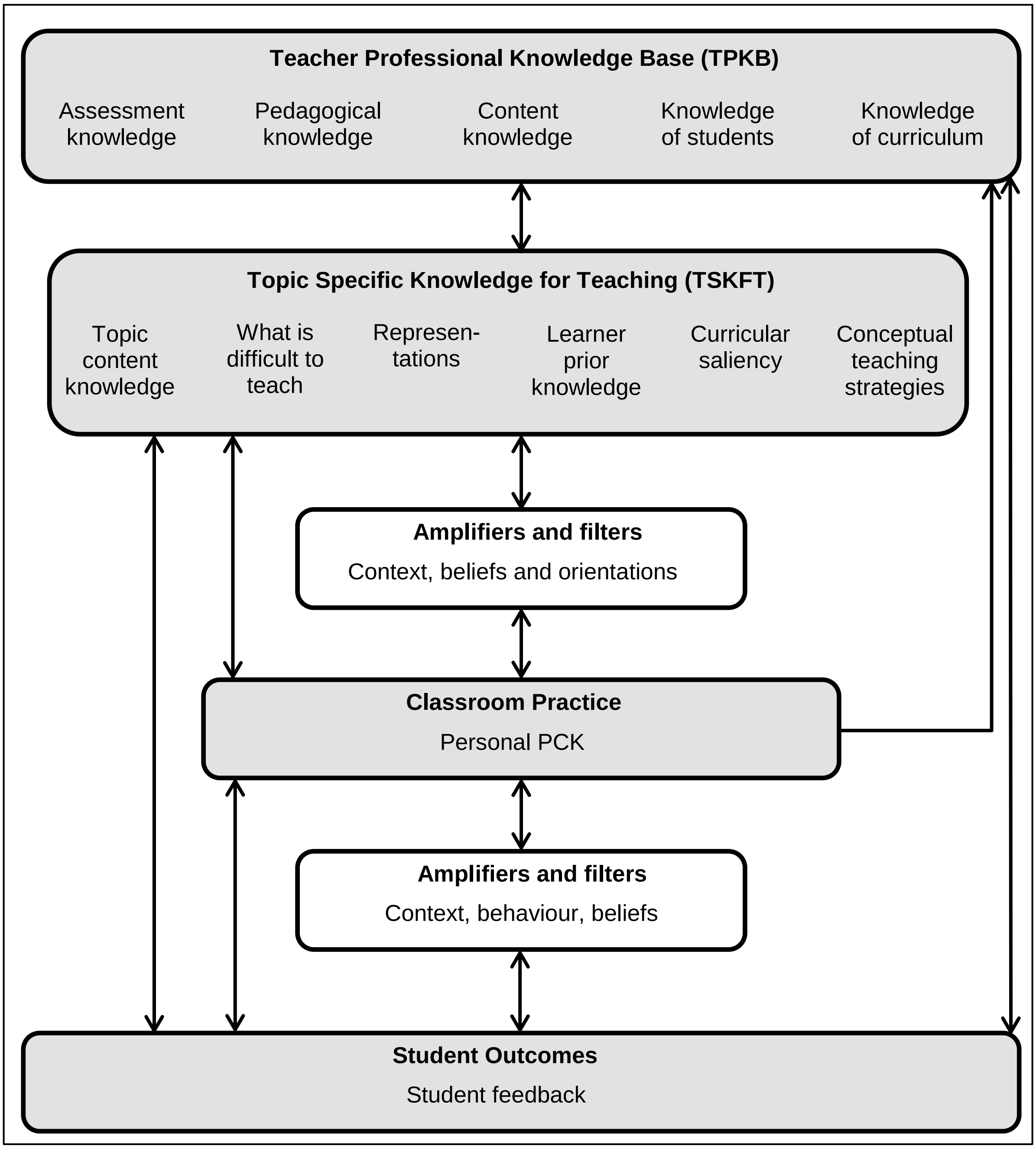


Figure 8.1 Adapted Model of Teacher Professional Knowledge and Skill

A measuring tool for TSKFT was developed and validated to provide a measure of the quality of teachers' knowledge for teaching. The instrument was administered to 60 physical sciences teachers in two provinces in South Africa, and subsequently ten high achieving teachers from this group were invited to participate in story-line interviews. The data for the study consisted of 60 completed questionnaires, as well as interview transcripts and accompanying story-line graphs from the sub-set of ten teachers.

A sequential mixed methods research design was followed, in which the quantitative data collection and analysis preceded a qualitative data collection and analysis, in order to answer the research questions.

8.2 Answering the research questions

The study was guided by the following **over-arching research question**:

What are the teachers' learning trajectories with respect to their topic specific knowledge for teaching chemical bonding?

The **first research sub-question** required the design and validation of a measuring instrument for topic specific knowledge for teaching chemical bonding, and read as follows:

How can a valid measure of high quality topic specific knowledge for teaching chemical bonding be obtained?

The design process for a measuring tool for TSKFT included various measures to ensure a valid and reliable instrument, namely the inclusion of a reference group of experts, conducting a pilot study, moderation of scores, and submitting the final instrument to statistical analysis using the Rasch measurement model. The validity and reliability of the instrument was shown by providing evidence for unidimensionality, showing acceptable infit and outfit statistics, showing a good spread of item difficulties across a range of person abilities, and a high index of person separation. These factors contributed to a high degree of internal consistency, and therefore a reliable instrument. Face validity and content validity was strengthened by regularly consulting a reference group in the development process. The absence of misfitting items suggested strong content as well as construct validity. As expected, content knowledge questions were found to be more difficult than the TSPCK questions. The conceptual teaching strategies items were the most difficult of the TSPCK items, in line with the expectation for TSPCK. No differential item functioning was detected for gender and province.

A valid and reliable instrument for the measurement of topic specific knowledge for teaching chemical bonding was designed, as was fit for use with larger groups of teachers, and to predict individual teacher performance.

The **second research sub-question** asked for the identification of the factors that may have played a role in the quality of the teachers' TSKFT and read as follows:

What factors have influenced the quality of the teachers' topic specific knowledge for teaching chemical bonding?

Quantitative and qualitative data analysis techniques were employed to answer the research question. A differential item functioning (DIF) analysis revealed three possible person factors that may have played a role in the teachers' performance, namely teaching experience, level of chemistry content training, and teaching qualification. A grounded analysis of ten selected teachers' story-line interview data provided more details on these factors, and identified additional factors that have played a role in the teachers' perceived shifts in TSKFT.

The factors which influenced the quality of topic specific knowledge for teaching chemistry bonding are listed below:

- The teachers' *teaching experience*, and more specifically the first time they taught a topic, teaching the topic multiple times, and teaching the topic to multiple grades.
- *Furthering their education*, namely content training, post-graduate studies in education, and additional courses and workshops.
- The *changes in the curriculum*, namely the introduction of a new curriculum, working with curriculum documents, and designing curriculum materials.
- The role of *students* and *colleagues*.

The **third research sub-question** asked how these factors played a role in the teachers' perceived shifts in TSKFT, and read as follows:

How did the factors influence the teachers' perceptions of the shifts in their topic specific knowledge for teaching chemical bonding over time?

A qualitative item analysis, as well as an explanatory framework analysis, of the instrument responses of all 60 participants were performed to identify possible trends in the teachers' performance for each of the factors. The following trends in the teachers' performance were identified:

- Teachers with more teaching experience had a more conceptual approach to teaching, and chose more sophisticated explanatory frameworks.
- Teachers with more teaching experience had fewer alternative conceptions and a better knowledge of chemical bonding models.
- Teachers at different stages of their careers developed different components of TSKFT.
- Teachers with a higher level of content training found some questions less challenging than other teachers.

- Teachers with a master's degree in education found conceptual teaching strategies less challenging than other teachers.

Ten high performing teachers from across the teaching experience range participated in story-line interviews to provide more insight into their experiences and perceptions of the shifts in the TSKFT. An in-depth qualitative analysis of the interview data revealed how the factors influenced the teachers' perceived TSKFT over their careers. The following four ways in which the teachers' TSKFT were influenced were identified as follows:

- Curriculum change events and furthering their education influenced the teachers' general knowledge base, which in turn supported growth at a topic specific level.
- Events relating to teaching experience influenced the teachers' knowledge at a topic specific knowledge for teaching level.
- Increases in knowledge of one component at a topic specific level often initiated shifts in the other components at the topic specific level.
- High levels of TSKFT was characterised by high levels of interaction between the knowledge components, as well as the ability to integrate the components to derive teaching strategies.

The integration of the findings for the three research sub-questions provided the answer to the overarching question to map learning trajectories with respect to topic specific knowledge for teaching. The following three learning trajectories have been identified for the group of physical science teachers who took part in this study:

Learning trajectory 1: Teachers shifted towards deeper conceptual understanding of the content, and used more sophisticated explanatory frameworks

Learning trajectory 2: Teachers shifted towards more integrated topic specific knowledge for teaching

Learning trajectory 3: Teachers shifted from teacher-focussed towards student-focussed teaching approaches

8.3 Implications and recommendations

8.3.1 Methodological implications

This study makes the following three methodological contributions, namely the design of a measuring instrument for chemical bonding, using a DIF analysis to identify factors influencing teacher knowledge, and capturing teacher learning retrospectively over the careers of teachers using the story-line method.

Designing and instrument for measuring the TSKFT of chemical bonding

There is a current call from the PCK research community to develop more instruments for measuring PCK (Smith & Banilower, 2015). A measuring tool for testing teachers' content knowledge as well as their topic specific PCK for chemical bonding was designed and validated as a contribution to this call. The quantitative analysis of the test items showed that the instrument can be used for group as well as individual performance.

Differential item functioning analysis

Differential item functioning (DIF) is a statistical characteristic of an item that shows the extent to which the item may be measuring different abilities for members of separate sub-groups (Badia et al., 2002). A DIF analysis is typically used in instrument design to ensure that items in a test do not discriminate against certain sub-groups of the population for which the test was not intended to discriminate. For example, male or females should not perform statistically differently on a test measuring TSKFT.

In this study a DIF analysis was deliberately used to identify sub-groups of the sample that performed statistically differently (see Appendix 28 and Chapter 5 (page 128) for the analysis). The DIF analysis provided evidence that some items performed differently for some sub-groups of teachers. This suggested that certain factors, for example teaching experience, could have played a role in the quality of topic specific knowledge for teaching and provided reference points for further qualitative analysis. A DIF analysis was therefore used to shed light on how different groups of teachers perform differently to test items. This methodological approach has not yet been used with PCK studies to investigate the influence of factors contributing to the development of PCK. This study contributes to the literature by providing a quantitative analysis approach to investigating the influence of person factors on teachers' PCK.

Capturing teacher learning using the story-line method

The study used an exploratory research design to capture teacher learning retrospectively over the careers of teachers. Typical research designs to capture learning trajectories involve longitudinal studies over extended periods of time. Such longitudinal studies are not common as they are time consuming and expensive. This study explored the use of the story-line method to capture teacher learning, or perceptions of learning, as teachers reflect on past experiences.

The story-line method was first used by Gergen (1988) for research on students' feelings of general well-being, and later modified by Beijaard, Van Driel and Verloop (1999) to investigate teachers' practical knowledge. Nilsson and Van Driel (2010) modified the use of story-lines to investigate primary teachers' physics content knowledge and attitudes towards physics. The technique appeared to be a promising option to help teachers reflect on past experiences, and for this reason it was used in this study.

Story-lines have typically been used to capture general experiences over time (for example Berry & Van Driel, 2013; Nilsson & Van Driel, 2010). In the present study however, the story-line method was modified for use with PCK and aligned with six specific components for TSKFT. Unlike the studies mentioned above, the story-lines in this study were not quantitatively analysed, but rather used as qualitative tools to provide teachers with prompts to initiate conversation. Not all the story-lines provided an equal richness in data, but it helped anchor the teachers' reflections. This study required teachers to reflect on very specific aspects of their teaching. Not only did they have to recall events that took place long ago, they also had to think about the teaching of a very specific section in the chemistry curriculum. At the onset of the study it was a concern that teachers will not be able to do this. However, the use of story-lines for each of the TSKFT components was effective in focussing the teachers' attention on very specific areas of their teaching. The story-lines played a central role in assisting teachers to recall events, and without the use of this method the same richness in data would not have been obtained. Although the use of story-lines is not novel, this study hopes to contribute to an alternative methodological approach to their use in qualitative research.

8.3.2 Theoretical implication

Three theoretical contributions are made by this study. Many and varied conceptualisations of PCK have been published over the past three decades. The International PCK Summit in 2012 attempted to bring together the research field and published a consensus model known as the

Model of Teacher Professional Knowledge and Skill, including PCK (Gess-Newsome, 2015). This study contributes to two aspects of this model, namely the nature of Topic Specific Professional Knowledge, and the interactions between this knowledge base and the other levels of knowledge as proposed in the model.

Firstly, this study proposes a modification of the conceptualisation of Topic Specific Professional Knowledge to more clearly distinguish between knowledge at a general level, and knowledge at a topic specific level. Topic content knowledge and the transformation of content knowledge are suggested as the two domains of topic specific knowledge for teaching. The transformation of topic content knowledge has already been described by Mavhunga and Rollnick (2013) in their Topic Specific Pedagogical Content Knowledge (TSPCK) model. This study brought the TSPCK model and the Model of Teacher Professional Knowledge and Skill together in a productive conceptualisation of the kinds of knowledge teachers draw from when reflecting on their teaching. It should be noted that the introduction of a new construct, TSKFT, also have limitations. This is the first study using the construct as theoretical and analytical framework, and the findings from this study can only be interpreted within the context of this particular setting. The transfer to other contexts will be uncertain, and findings from this present study need to be interpreted with caution.

This study also started to shed light on the interactions between the various components at the topic specific level, as a contribution to the research field's understanding of the mechanisms by which knowledge for teaching develop. In this study knowledge appeared to flow from the general level to the topic level and not back. However, the study was not designed to investigate this 'backwards' flow. More research, specifically designed to investigate this relationship, is needed to better understand the interactions between the various knowledge bases. Quality topic specific knowledge for teaching is also characterised by high levels of interaction between knowledge components and the integration of knowledge components at a topic level, but not at a general level.

Lastly, the identification of learning trajectories in terms of content knowledge, interaction of the components of TSKFT, and teachers' approaches to teaching, also contribute to the research field by providing insight into how teachers grow their knowledge for teaching and guidelines for the professional development programmes to support the development of science teachers' knowledge for teaching.

8.3.3 Recommendations for professional development

The findings from this study provided insight into teachers' understanding of chemical bonding and their knowledge of transforming the content for the purpose of teaching. Some teachers displayed limited content understanding and lacked the ability to transform their content knowledge for teaching. These teachers were not only the pre-service or beginning teachers, but also teachers who had been in the classroom for a much longer time. The following recommendations are suggested for pre-service teacher training and professional development of physical sciences teachers with respect to the teaching of chemical bonding.

Conceptual understanding chemical bonding

This study has shown that conceptual understanding of the content was an essential pre-requisite for building knowledge for teaching chemical bonding. Many teachers had limited knowledge of chemical bonding models. Professional development programmes could support such teachers by providing content training on chemical bonding models and the use of models in science, thus expanding their repertoire of explanatory framework to ensure teaching for conceptual understanding.

Post-graduate studies in education

All the teachers who were interviewed and who had completed post-graduate studies in education, whether at honours or master's level, commented on the positive influence this experience had on their teaching. For most of the teachers the most important shift was in terms of their teaching approach, shifting from being textbook bound or teacher-focussed, towards being much more student-focussed in their teaching approach.

A master's degree is a minimum qualification for teacher certification in many countries (Evagorou, Dillon, Viiri, & Albe, 2015; Zimmerman, 2016). This study has shown that post-graduate studies in education can have a profound effect on the quality of teachers' topic specific knowledge for teaching. Teachers should therefore be encouraged to embark on further studies in education.

Differentiated professional development programmes are needed

Teachers in different stages of their careers had different developmental profiles. Teachers will therefore benefit from differentiated teacher support, based on the stages of the teachers' careers, as opposed to a 'one-size-fits-all' approach. Pre-service teachers will benefit from support with aspects of a topic that is difficult to teach and areas that students typically find challenging. Beginning teachers will benefit from support in developing conceptual teaching strategies, whereas mid- and late-career teachers will benefit from activities that encourage them to reflect on their teaching. Lastly, all teachers will benefit from support on expanding their ability to identify alternative conceptions in student work and how to integrate such knowledge into their current teaching practices. All teachers will also benefit from targeted content support to help them identify explanatory frameworks in student answers, and then derive teaching strategies which will promote conceptual understanding of the content.

Curriculum design

The South African curriculum is a spiral curriculum which is underpinned by conceptual progression. Topics are revisited over an extended period of time and expanded upon each time. This is particularly true for chemical bonding, as the topic is conceptually dense and conceptual development takes time. For this reason, conceptual progression is scaffolded over four years. Teachers in South Africa work closely with the curriculum documents (Sibanda & Hobden, 2015). The curriculum can therefore provide strong guidance in terms of conceptual progression to teachers who need it, for scaffolding teaching, as well as developing the teachers' own understanding of the content. However, this progression needs to be carefully signposted and made explicit so that teachers are aware of it, and are able to implement it in their classrooms.

School policy and structure

Colleagues, and the support that they provide, played an important role in teachers' professional development. This was especially true for early career teachers in this study, or when teachers were teaching content for the first time. Senior teachers at a school can therefore provide support as mentors to their younger and less experienced colleagues. Apart from the content support that colleagues can provide, they also portray the school culture, whether positive or negative, to new teachers.

School management can play a supportive role by ensuring that teachers teach a variety of grade levels so that they can get an overview of the teaching sequence, and expand their knowledge of student prior knowledge. Lastly, teachers can be given the opportunity to get to know their students better by placing the same students in the same teacher's class in consecutive years.

8.4 Limitations

Mapping learning trajectories

The approach for mapping learning trajectories was an exploratory research design, as mentioned earlier in this chapter. Ideally, when learning trajectories are investigated, teachers should be followed over an extended period of time. This study investigated an alternative approach to a longitudinal research design, namely that of retrospective reflection on past experiences. The limitation of such a research design is that findings are limited to perceptions of teacher learning and to what teachers can remember. This, linked with the tacit nature of teacher knowledge, provides only a small window through which teacher knowledge can be investigated. However, the approach was found to be productive, but it needs to be acknowledged that it provides a limited picture of the extent of the teachers' knowledge for teaching.

A further limitation of mapping learning trajectories is that the framework that was used for teacher knowledge, namely TSKFT, provided predetermined levels of knowledge against which the teachers' knowledge was measured. From these measurements, teachers' knowledge was categorised and ranked. The levels of knowledge were informed by the literature and a reference group, and submitted to a validation process. However, despite this rigour, the levels of teachers' knowledge will still be formulated within the limitations of a predetermined framework. The emerging trajectories from this study therefore needs to be interpreted within the boundaries of the TSKFT framework.

Pedagogical content knowledge is topic specific as was shown in the literature review in Chapter 2. This study was therefore designed to investigate teachers' knowledge for teaching a specific topic. Three learning trajectories emerged, and despite the topic specificity of the study, the trajectories appear to be 'generic', applicable to any topic. Teachers shifted towards deeper conceptual understanding of the content, their knowledge became more integrated, and they shifted from teacher-focussed towards student-focussed teaching approaches. Since this study was conducted using only a single topic, this claim of trajectories being 'generic' cannot be made. However, it invites further research using different topics, to investigate the possibility of generic learning trajectories. If this should be the case, it has promising implications for the design of professional development programmes.

Representivity

Due to the nature of the kind of knowledge this study investigates, it can be assumed that teachers who are less confident in their knowledge for teaching would be less willing to complete a questionnaire of this kind. This was illustrated by the spread of teachers who participated in this study, and the lack of representivity at the lower end of the performance spectrum. Another challenge was to find a representative sample. Since I was based in a metropolitan area in Cape Town, it was particularly challenging to find township and rural teachers who were willing to participate. A number of township teachers signed up for workshops but did not arrive, or received the questionnaires (delivered by hand), but never returned them. This challenge remains, and without getting more responses from teachers across all schools our understanding of teachers' knowledge for teaching in South Africa remains limited. This study also did not have enough African teachers who performed well. There were only six black South African teachers who scored above the mean, all of them taught at ex model C schools, and only teacher T30 and Vuyo had more than 3 years teaching experience. As a result the sample was not representative of all teachers in South Africa, and only somewhat representative of the two most 'urban' provinces, the Western Cape and Gauteng.

TSKFT as a new construct

It should be noted that the introduction of a new construct, topic specific knowledge for teaching or TSKFT, has limitations. This is the first study using the construct as theoretical and analytical framework, and the findings from this study can only be interpreted within the context of this particular setting. The transfer to other contexts will be uncertain, and findings from this present study need to be interpreted with caution.

8.5 Personal reflections

Reflecting on the research design

My initial conceptualisation of this project involved designing an instrument to measure teachers' topic specific knowledge for teaching, and then using the quantitative results from the instrument to choose high scoring teachers for further interviews. The interviews were anticipated to be the central data source, with the questionnaire playing a supportive role. However, as I started analysing the questionnaire responses I realised that they provided profound insight into the teachers' knowledge. This was not all surprising since teachers spent a substantial amount of time on completing the questionnaires. The roles of the interviews and questionnaire responses had switched around to some degree. In the end the questionnaires played the anchoring role, with the interviews providing the depth I needed to interpret the initial findings. As a result I had a very large amount of rich data which required complex analysis sequences. Due to a pragmatic approach to answering the research questions the analysis was not linear, but integrated as the findings from one analysis (the DIF analysis) lead to two additional lines of analysis which was not anticipated at the onset of the study (the item analysis of teachers responses and explanatory framework analysis). Presenting the analysis procedures in a linear manner was challenging.

Reflecting on the nature of PCK

Friedrichsen and Berry (2015), in their reflection on PCK learning progressions, calls for a move away from topic specificity if learning progressions for PCK are to be considered. I agree with this call, as it provides a much more useful set of guidelines for teacher professional development. However, I do believe that the study of PCK has to be grounded in a topic. In the beginning of my study I was not sure how to reconcile the topic specific nature of PCK with the generic requirement of a developmental trajectory. I did not anticipate that the learning trajectories that would emerge from my study would indeed be general, since I had a strong and explicit focus on a very specific topic. However, reflecting on my findings, I strongly believe that I would have found similar trends had I chosen a different topic – the details may not have been the same, but the overall findings would be. The study was therefore grounded in a topic, as I believe any study on PCK should be, but the findings are general and can be applied to any topic.

Reflecting on PCK learning progression

I approached this study with the idea to combining learning progressions (LPs), a relatively new research field, and PCK, as it presented the possibility of a productive approach to investigating teacher knowledge. This would essentially map teacher learning and provide insight into how teachers develop their knowledge for teaching. However, LPs are linear by nature, whereas the development of teacher knowledge is known to be non-linear. This presented a fundamental challenge to applying LPs to teacher knowledge. I realised I had to think broader and allow for the complexity of teacher learning, and as a result I decided on a grounded approach to allow for patters to emerge from the data. I therefore did not return to the learning progression literature until closer to the end of my study. This was when I realised that some of my findings were indeed capturing learning progressions - for example, in Doreen’s case, and that some of the other teachers were at the beginning stages of some of the other LPs proposed by Schneider and Plasman (2011). The individual learning progressions were embedded into an over-arching learning trajectory in which teachers shifted towards more student-focussed teaching.

Reflecting on personal learning

This study was about teacher learning and, although I have studied the learning experiences of other teachers, I have experienced incredible personal learning as well. I have expanded my knowledge of chemical bonding, the teaching of chemical bonding, teacher knowledge, and PCK. Towards the end of my journey I had the opportunity to do relief teaching at a secondary school and had to teach about chemical bonding. I had just written up all the findings of my study and now had to implement what I have theorised about for over three years. This was yet another learning experience, and made me reflect deeply about what it really means to implement the findings from a study such as this one.

In closing

I have a passion for supporting science teachers and embarked on this PhD journey to learn more about how teachers gain knowledge. Ultimately I didn't do this project for myself, but for other teachers 'out there'. My future plans therefore include transforming the findings from this study into support programmes for science teachers.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1149). New York: Routledge.

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education*, *30*(10), 1405–1416.

Achinstein, B., & Fogo, B. (2015). Mentoring novices' teaching of historical reasoning: Opportunities for pedagogical knowledge development through mentor-facilitated practice. *Teaching and Teacher Education*, *45*(1), 45–58.

Adair, J. K., & Pastori, G. (2011). Developing qualitative coding frameworks for educational research: immigration, education and the Children Crossing Borders project. *International Journal of Research & Method in Education*, *34*(1), 31–47.

Alonzo, A. C., & Gotwals, A. W. (2012). Leaping in learning progressions in science. In A. C. Alonzo & A. W. Gotwals (Eds.), *Learning progressions in science: Current challenges and future directions* (pp. 3–13). Rotterdam: Sense Publishers.

Alonzo, A. C., & Steedle, J. T. (2009). Developing and assessing a force and motion learning progression. *Science Education*, *93*(3), 389–421.

Andersen, E. B. (1995). Polytomous Rasch models and their estimation. In G. H. Fischer & I. W. Molenaar (Eds.), *Rasch models: Foundations, recent developments and applications* (pp. 271–291). New York: Springer.

Arzi, H. J., & White, R. T. (2007). Change in teachers' knowledge of subject matter: A 17-year longitudinal study. *Science Education*, *92*(2), 221–251.

Atay, D., Kaslioglu, O., & Kurt, G. (2010). The pedagogical content knowledge development of prospective teachers through and experiential task. *Procedia Social and Behavioral Sciences*, *2*(1), 1421–1425.

Aydeniz, M., & Kirbulut, Z. D. (2014). Exploring challenges of assessing pre-service science teachers' pedagogical content knowledge (PCK). *Asia-Pacific Journal of Teacher Education*, *42*(2), 147–166.

Aydin, S., & Boz, Y. (2013). The nature of the integration among PCK components: A case study of two experienced chemistry teachers. *Chemistry Education Research and Practice*, *14*(4), 615–624.

Badia, X., Prieto, L., & Linacre, J. M. (2002). Differential item and test functioning. *Rasch Measurement Transactions*, *16*(889), b27.

Baghaei, P., & Amrahi, N. (2011). The effects of the number of options on the psychometirc characteristics of multiple choice items. *Psychological Test Assessment Model*, *53*(2), 192–211.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching what makes it special? *Journal of Teacher Education*, *59*(5), 389–407.

Barker, V., & Millar, R. (2000). Studens' reasoning about basic chemical thermodynamics and chemical bonding: What changes occur during a context-based post-16 chemistry course? *International Journal of Science Education*, *22*(11), 1171–1200.

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., ... & Tsai, Y. M. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American Educational Research Journal*, 47(1), 133-180.

Beijaard, D., Van Driel, J., & Verloop, N. (1999). Evaluation of story-line methodology in research on teachers' practical knowledge. *Studies in Educational Evaluation*, *25*(1), 47–62.

Bergqvist, A., Drechsler, M., & Chang Rundgren, S. N. (2016). Upper secondary teachers' knowledge for teaching chemical bonding models. *International Journal of Science Education*, *38*(2), 298–318.

Bergqvist, A., Dreschler, M., De Jong, O., & Chang Rundgren, S. N. (2013). Representations of chemical bonding models in school textbooks - help or hindrance for understanding? *Chemistry Education Research and Practice*, *14*(4), 589–606.
Berry, A., Friedrichsen, P., & Loughran, J. (2015). *Re-examining pedagogical content knowledge in science education*. New York: Routledge.
Berry, A., Loughran, J., & Van Driel, J. H. (2008). Revisiting the roots of pedagogical content knowledge. *International Journal of Science Education*, *30*(10), 1271–1279.
Berry, A., & van Driel, J. H. (2013). Teaching about teaching science. Journal of Teacher Education, 64(2), 117-128.
Bertram, A., & Loughran, J. (2012). Science teachers' views on CoRes and PaPeRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education*, *42*(6), 1027–1047.
Birk, J. P., & Kurtz, M. J. (1999). Effect of experience on retention and elimination of misconceptions about molecular structure and bonding. *Journal of Chemical Education*, *76*(1), 124–128.
Bishop, K., & Denley, P. (2007). *Learning science teaching: Developing a professional knowledge base*. New York: McGraw-Hill.
Bond, T., & Fox, C. M. (2015). *Applying the Rasch model: Fundamental measurement in the human sciences* (2nd ed.). New York: Routledge.
Boo, H. K. (1998). Students' understandings of chemical bonds and the energetics of chemical reactions. *Journal of Research in Science Teaching*, *35*(5), 569–581.
Boone, W. J., Townsend, S., & Staver, J. (2011). Using Rasch theory to guide the practice of survey development and survey data analysis in science education and to inform science reform efforts: An exemplar utilizing STEBI self-efficacy data. *Science Education*, *95*(2), 258–290.
Boone, W., & Rogan, J. (2005). Rigour in quantitative analysis: The promise of Rasch analysis techniques. *African Journal of Research in Mathematics, Science and Technology Education*, *9*(1), 25–38.
Broster, P., Horn, W., & James, H. (2011). *Oxford Successful Physical Sciences Learner's Book Grade 10* (2nd ed.). Cape Town, South Africa: Oxford University Press Southern Africa.
Brown, P., Friedrichsen, P., & Abell, S. (2013). The development of prospective secondary biology teachers' PCK. *Journal of Science Teacher Education*, *24*(1), 133–155.
Carlson, J., Stokes, L., Helms, J., Gess-Newsome, J., & Gardner, A. (2015). The PCK Summit. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 14–27). New York: Routledge.
CDE. (2007). *CDE Report No 15 Doubling for Growth: Addressing the maths and science challenge in South Africa's schools*. Johannesburg.
CDE. (2015). *CDE Report: Teacher supply and demand in South Africa: 2013 to 2025*. Johannesburg.
Chen, B., & Wei, B. (2015). Examining chemistry teachers' use of curriculum materials: in view of teachers pedagogical content knowledge. *Chemistry Research and Practice*, *16*(2), 260–272.
Clandinin, D. J., & Connelly, F. M. (1996). Teachers' professional knowledge landscapes: Teachers stories. Stories of teachers. School stories. Stories of schools. *Educational Researcher*, *25*(3), 24–30.
Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical content knowing: and integrative model for teacher preparation. *Journal of Teacher Education*, *44*(4), 263–272.
Cochran-Smith, M., & Lytle, S. L. (1993). *Inside/outside: Teacher research and knowledge*. New York: Teachers College Press.
Cochran-Smith, M., & Lytle, S. L. (1999). The reacher research movement: A decade later. *Educational Researcher*, *27*(8), 15–25.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7th ed.). New York: Routledge.

Coll, R. K., & Taylor, N. (2002). Mental models in chemistry: Senior chemistry students' mental models of chemical bonding. *Chemistry Education: Research and Practice in Europe*, *3*(2), 175–184.

Coll, R. K., & Treagust, D. F. (2001). Learners' mental models of chemical bonding. *Research in Science Education*, *31*(3), 357–382.

Coll, R. K., & Treagust, D. F. (2002). Learners' use of analogy and alternative conceptions for chemical bonding: A cross-age study. *Australian Science Teachers' Journal*, *48*(1), 24–32.

Coll, R. K., & Treagust, D. F. (2003a). Investigations of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching*, *40*(5), 464–486.

Coll, R. K., & Treagust, D. F. (2003b). Learners' mental models of metallic bonding: A cross-age study. *Science Education*, *87*(5), 685–707.

Collins, K. M. T., Onwuegbuzie, A. J., & Sutton, I. L. (2006). A model incorporating the rationale and purpose of conducting mixed-method research in special education and beyond. *Learning Disabilities: A Contemporary Journal*, *4*(1), 67–100.

Cooper, R., Loughran, J., & Berry, A. (2015). Science teachers PCK: Understanding sophisticated practice. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 60–74). New York: Routledge.

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology*, *78*(1), 98–104.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches.* (4th ed.). California: Sage publications, Inc.

Davidowitz, B., & Potgieter, M. (2016). Use of the Rasch measurement model to explore the relationship between content knowledge and topic-specific pedagogical content knowledge for organic chemistry. *International Journal of Science Education*, *38*(9), 1483–1503.

Davidowitz, B., & Rollnick, M. (2011). What lies at the heart of good undergraduate teaching? A case study in organic chemistry. *Chemistry Education Research and Practice*, *12*(3), 355–366.

Davidowitz, B., & Vokwana, N. Q. (2014). Developing an instrument to assess grade 12 teachers' TSPCK in organic chemistry. In H. Venkat, M. Rollnick, J. Loughran, & M. Askew (Eds.), *Exploring mathematics and science teachers' knowledge: Windows into teacher thinking* (pp. 178–194). New York: Routledge.

DBE. (2003). *National curriculum statement grades 10-12 Physical Sciences*. Pretoria, South Africa: Department of Basic Education. Retrieved from www.education.gov.za.

DBE. (2006). *National curriculum statement grades 10-12 Physical Sciences content document*. Pretoria, South Africa: Department of Basic Education. Retrieved from www.education.gov.za.

DBE. (2011a). *Curriculum and assessment policy statement grade 10-12 Physical Sciences*. Pretoria, South Africa. Retrieved from www.education.gov.za.

DBE. (2011b). *Curriculum and assessment policy statement grade 7-9 Natural Sciences*. Retrieved from www.education.gov.za.

DBE. (2016). *National Senior Certificate examination 2015: Diagnostic report*. Pretoria, South Africa. Retrieved from http://www.education.gov.za/Resources/Reports.aspx.

DBE & DHET. (2011). *Integrated strategic planning framework for teacher education and development in South Africa 2011 – 2025: Technical report*. Pretoria, South Africa.

De Jong, O., Van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching*, *42*(8), 947–964.

De Posada, J. M. (1999). The presentation of metallic bonding in high school science textbooks during three decades: Science educational reforms and substantive changes of tendencies. *Science Education*, *83*(4), 423–447.
Deng, Z. (2007). Knowing the subject matter of a secondary-school science subject. *Journal of Curriculum Studies*, *39*(5), 347–386.
Dilley, L. (1991). *Atoms Matter*. Johannesburg: SACHED Trust Maskew Millar Longman.
DoE. (2005). *Report of the ministerial committee on rural education*. Pretoria, South Africa. Retrieved from http://www.education.gov.za/Portals/0/Documents/Reports/Ministerial Report on Rural Education.pdf?ver=2011-01-18-115532-587.
Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education*, *11*(5), 481–490.
Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5–12.
Duschl, R., & Hamilton, R. (2011). Learning science. In R. E. Mayer & P. A. Alexander (Eds.), *Handbook of Research on Learning and Instruction* (pp. 78–107). New York: Routledge.
Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: a review and analysis. *Studies in Science Education*, *47*(2), 123–182.
Evagorou, M., Dillon, J., Viiri, J., & Albe, V. (2015). Pre-service science teacher preparation in Europe: Comparing pre-service teacher preparation programs in England, France, Finland and Cyprus. *Journal of Science Teacher Education*, *26*(1), 99–115.
Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum toe strengthen as sustain teaching. *Teachers College Record*, *103*(6), 1013–1055.
Fenstermacher, G. D. (1994). The knower and the known: The nature of knowledge in research on teaching. In L. Darling-Hammond (Ed.), *Review of Research in Education* (pp. 3–56). Washington, DC: American Educational Research Association.
Fernandez, C. (2014). Knowledge base for teaching and pedagogical content knowledge (PCK): Some useful models and implications for teachers' training. *Problems of Education in the 21st Century*, *1*(60), 79–100.
Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245.
Freelon, D. G. (2010). ReCal: Intercoder reliability calculation as a web service. *International Journal of Internet Science*, *5*(1), 20–33.
Friedrichsen, P., & Berry, A. (2015). Science teacher PCK learning progressions. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 214–228). New York: Routledge.
Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining Biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching*, *46*(4), 357–383.
Gearhart, M., & Osmundson, E. (2009). Assessment portfolios as opportunities for teacher learning. *Educational Assessment*, *14*(1), 1–24.
Geddis, A. N. (1993). Transforming subject-matter knowledge: the role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education*, *15*(6), 673–683.
Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education*, *77*(6), 575–591.
Gergen, M. M. (1988). Narrative structures in social explanation. In C. Antaki (Ed.), *Analysing social explanation* (pp. 94–112). London: Sage Publications Inc.
Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 28–42). New York: Routledge.
Gilbert, J. K., & Treagust, D. F. (2009). *Multiple representations in chemical education* (Vol. 2). Dordrecht: Springer.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and Policy Analysis*, *11*(3), 255–274.
Hashweh, M. (2005). Teachers pedagogical constructions: a reconfiguration of pedagogical content knowledge. *Teachers and Teaching: Theory and Practice*, *11*(3), 273–292.
Hashweh, M. Z. (1996). Effects of science teachers' epistemological beliefs in teaching. *Journal of Research in Science Teaching*, *33*(1), 47–63.
Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence Based Nursing*, *18*(3), 66–67.
Henze, I., Van Driel, J. H., & Verloop, N. (2007). Science teachers' knowledge about teaching models and modelling in the context of a New Syllabus on public understanding of science. *Research in Science Education*, *37*(2), 99–122.
Henze, I., Van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education*, *30*(10), 1321–1342.
Heritage, M. (2008). Learning progressions: Supporting instruction and formative assessment. In *Meeting of Advancing Research on Adaptive Instruction and Formative Assessment*. Philadelphia, PA: Assessment and Accountability Comprehensive Centre and National Center for Research on Evaluation, Standards, & Student Testing. Retrieved from http://www.cpre.org/ccii/images/stories/ccii_pdfs/learning progressions_ heritage.pdf.
Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic specific knowledge of students. *Journal for Research in Mathematics Education*, *39*(4), 372–400.
Hume, A., & Berry, A. (2011). Constructing CoRes - a strategy for building PCK in pre-service science teacher education. *Research in Science Education*, *41*(3), 341–355.
Hume, A., & Berry, A. (2013). Enhancing the practicum experience for pre-service chemistry teachers through collaborative CoRe design with mentor teachers. *Research in Science Education*, *43*(5), 2107–2136.
Jenkins, J. M., & Veal, M. L. (2002). Preservice teachers' PCK development during peer coaching. *Journal of Teaching in Physical Education*, *22*(1), 49–68.
Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, *33*(7), 14–26.
Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, *7*(2), 75–83.
Justi, R., & Gilbert, J. (2002). Models and modelling in chemistry in a laboratory environment. In J. Gilbert, O. de Jong, R. Justi, D. F. Treagust, & J. van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 47–68). Dordrecht: Kluwer Academic Publishers.
Jüttner, M., Boone, W., Park, S., & Neuhaus, B. J. (2013). Development and use of a test instrument to measure biology teachers' content knowledge (CK) and pedagogical content knowledge (PCK). *Educational Assessment, Evaluation and Accountability*, 25(1), 45-67.
Kane, M. T. (2001). Current concerns in validity theory. *Journal of Education Measurement*, *38*(4), 319–342.
Käpylä, M., Heikkinen, J. P., & Asunta, T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education*, 31(10), 1395-1415.
Kaya, O. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers: "Ozone layer depletion" as an example. *International Journal of Science Education*, *31*(7), 961–988.
Kinach, B. M. (2002). A cognitive strategy for developing pedagogical content knowledge in the secondary mathematics methods course: toward a model of effective practice. *Teaching and Teacher Education*, *18*(1), 51–71.

Kind, V. (2004). Beyond appearances: Students' misconceptions about basic chemical ideas. School of Education, Durham University, UK. Retrieved 30 January 2017.

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

Kind, V. (2014a). A degree is not enough: A quantitative study of aspects of pre-service science teachers' chemistry content knowledge. *International Journal of Science Education*, 36(8), 1313-1345.

Kind, V. (2014b). Science teachers' content knowledge. In H. Venkat, M. Rollnick, J. Loughran, & M. Askew (Eds.), *Exploring mathematics and science teachers' knowledge: Windows into teacher thinking* (pp. 15–27). New York: Routledge.

Kind, V. (2015). On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 178–195). New York: Routledge.

Kirschner, S., Borowski, A., Fischer, H. E., Gess-Newsome, J., & Von Aufschnaiter, C. (2016). Developing and evaluating a paper-and-pencil test to assess components of physics teachers' pedagogical content knowledge. *International Journal of Science Education*, *38*(8), 1343–1372.

Kleickmann, T., Richter, D., Kunter, M., Elsner, J., Besser, M., Krauss, S., & Baumert, J. (2013). Teachers' content knowledge and pedagogical content knowledge: The role of structural differences in teacher education. *Journal of Teacher Education*, 64(1), 90-106

Krauss, S., Baumert, J., & Blum, W. (2008). Secondary mathematics teachers' pedagogical content knowledge and content knowledge: validation of the COACTIV constructs. ZDM, 40(5), 873-892.

Krosnick, J. A., & Presser, S. (2010). Question and Questionnaire Design. In *Handbook of Survey Research* (2nd ed., pp. 263–313). Bradford, UK: Emerald Group Publishing Limited.

Kvale, S. (1996). *InterViews: An introduction to qualitative research interviewing*. Washington, DC: Sage Publications.

Levy Nahum, T., Mamlok-Naaman, R., Hofstein, A., & Krajcik, J. (2007). Developing a new teaching approach for the chemical bonding concept aligned with current scientific and pedagogical knowledge. *Science Education*, *91*(4), 579–603.

Linacre, J. M. (2014). *A user's guide to Winsteps Minstep Rasch-model computer programme*. Retrieved from www.winsteps.com.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage.

Loughran, J. (2012). *What expert teachers do: Enhancing professional knowledge for classroom practice*. New York: Routledge.

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. (J. Loughran, Ed.) (1st ed.). Rotterdam: Sense Publishers.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing Science teachers' pedagogical content knowledge*. (J. Loughran, Ed.) (2nd ed.). Rotterdam: Sense Publishers.

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

Lubienski, C., & Lubienski, S. (2006). Charter, private, public schools and academic achievement: New evidence from NAEP mathematics data. New York. Retrieved from www.nepc.colorado.edu.

Luft, J. A., & Dubois, S. L. (2015). *Newly hired teachers of science - a better beginning*. Rotterdam: Sense Publishers.

Luft, J. A., Dubois, S. L., Nixon, R. S., & Campbell, B. K. (2015). Supporting newly hired teachers of science: Attaining teacher professional standards. *Studies in Science Education*, *51*(1), 1–48.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome Lederman, N. (Ed.), *Examining pedagogical content knowledge* (pp. 95–732). Dordrecht, The Netherlands: Kluwer Academic Press.

Malcolm, S. A., & Mavhunga, M. E. (2016). The development and validation of an instrument measuring topic specific PCK in stoichiometry. In *Proceedings of the 24th Annual Conference of the Southern African Association of Research in Mathematics, Science and Technology Education*. Pretoria, South Africa.

Masters, G. N. (1982). A Rasch model for partial credit scoring. *Psychometrika*, *47*(2), 149–174.

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

Mavhunga, E., & Rollnick, M. (2016). Teacher- or learner-centred? Science teacher beliefs related to topic specific pedagogical content knowledge: A South African case study. *Research in Science Education*, *46*(6), 831–855.

Mavhunga, M. E. (2015). The nature of the interactions of the components of topic specific pedagogical content knowledge. In *Proceedings of the 23rd Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education* (pp. 264–278). Maputo, Mozambique.

McCaw, C. S., & Thompson, M. A. (2009). A new approach to chemistry education at pre-university level. *Nature Chemistry*, *1*(2), 95–96.

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, *22*(3), 276–282.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, set, science!: Putting research to work in K-8 science classrooms*. Washington: The National Academies Press.

Mulhall, P., Berry, A., & Loughran, J. (2003). Frameworks for representing science teachers' pedagogical content knowledge. *Asia-Pacific Journal of Teacher Education*, *2*(2), 1–25.

Mulholland, J., & Wallace, J. (2005). Growing the tree of teacher knowledge: Ten years of learning to teach elementary science. *Journal of Research in Science Teaching*, *42*(7), 767–790.

Nakhleh, M. B. (1992). Why some students don't learn chemistry. *Journal of Chemical Education*, *69*(3), 191–196.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. (R. A. Duschl, H. A. Schweingruber, & A. W. Shouse, Eds.). Washington: The National Academies Press.

Ndlovu, M. (2014). *The design of an instrument to measure physical science teachers' topic specific pedagogical content knowledge in electrochemistry*. University of the Witwatersrand. Retrieved from http://hdl.handle.net/10539/14920.

Neumann, K., Viering, T., Boone, W. J., & Fischer, H. E. (2012). Towards a learning progression of energy. *Journal of Research in Science Teaching*, *50*(2), 162–188.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education*, *23*(7), 707–730.

Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education*, *23*(7), 699–721.

Nilsson, P., & Van Driel, J. (2011). How will we understand what we teach? Primary student teachers' perceptions of their development of knowledge and attitudes towards physics. *Reseach in Science Education*, *41*(4), 541–560.

Nilsson, P., & Vikstrom, A. (2015). Making PCK explicit - capturing science teachers pedagogical content knowledge (PCK) in the science classroom. *International Journal of Science Education*, *37*(17), 2836–2857.

Nixon, R. S., Campbell, B. K., & Luft, J. A. (2016). Effects of subject-area degree and classroom experience on new chemistry teachers' subject matter knowledge. *International Journal of Science Education*, 38(10), 1636-1654.

Nunnally, J. C. (1978). Assessment of reliability. In *Psychometric Theory* (2nd ed.). New York: McGraw-Hill.

Onwuegbuzie, A. J., & Leech, N. L. (2007). Sampling designs in qualitative research: Making the sampling process more public. *The Qualitative Report*, *12*(2), 238–254.

Oosterveld, P., & Vorst, H. C. M. (1996). Methoden voor vragenlijstconstructie [Methods of test construction]. *Nederlands Tijdschrift Voor de Psychologie*, *51*, 11–27.

Opie, C. (2004). *Doing educational research*. London: Sage Publications.

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology*, *13*(2), 147–160.

Padilla, K., & Van Driel, J. (2011). The relationship between PCK components: the case of quantum chemistry professors. *Chemistry Education Research and Practice*, *12*(3), 367–378.

Park, S., & Chen, Y. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching*, *49*(7), 922–941.

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

Park, S., & Suh, J. K. (2015). From portraying toward assessing PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 104–119). New York: Routledge.

Petersen, R. F., & Treagust, D. F. (1989). Grade 12 students' misconceptions of covalent bonding and structure. *Journal of Chemical Education*, *66*(6), 459–460.

Pimentel, G. C., & Spratley, R. D. (1969). *Chemical bonding clarified through quantum mechanics*. San Francisco: Holden-Day Inc.

Pitjeng, P. (2014). Novice unqualified graduate science teachers' topic specific pedagogical content knowledge, content knowledge and their beliefs about teaching. In H. Venkat, M. Rollnick, J. Loughran, & M. Askew (Eds.), *Exploring mathematics and science teachers' knowledge: Windows into teacher thinking* (pp. 65–95). New York: Routledge.

Poater, J., Sola, M., & Bickelhaupt, F. M. (2006). A model of the chemical bond must be rooted in quantum mechanics, provide insight, and possess predictive power. *Chemistry - A European Journal*, *12*(10), 2902–2905.

QSR International. (2012). NVivo 10 Qualitative data analysis software package. Doncaster, Victoria, Australia: QSR International.

Rasch, G. (1960). *Probabilistic models for some intelligence and achievement tests*. Copenhagen: Danish Institute for Educational Research.

Reddy, V., Visser, M., Winnaar, L., Arends, F., Juan, A., Prinsloo, C. H., & Isdale, K. (2016). *TIMSS 2015: Highlights of mathematics and science achievement of grade 9 South African learners*. Retrieved from http://www.timss-sa.org.za/download/TIMSS-Grade-9-Highlights.pdf.

Roche, A. (2013). *Evaluation of a targeted intervention method for concept formation in chemical bonding at grade 10 level*. University of Pretoria. Retrieved from http://www.repository.up.ac.za/handle/2263/33172.

Rogan, J. M. (2007). How much curriculum change is appropriate? Defining a zone of feasible innovation. *Science Education*, *91*(3), 439–460.

Rohaan, E. J., Taconis, R., & Jochems, W. M. G. (2009). Measuring teachers' pedagogical content knowledge in primary technology education. *Research in Science and Technological Education*, *27*(3), 327–338.
Rollnick, M. (2016). Learning about semi conductors for teaching - the role played by content knowledge in pedagogical content knowledge (PCK) development. *Research in Science Education*, *1*(1), 1–36.
Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education*, *30*(10), 1365–1387.
Rollnick, M., & Davidowitz, B. (2016). Is topic specific PCK unique to teachers? In J. Lavonen, K. Juuti, A. Lampiselka, A. Uitto, & K. Hahl (Eds.), *Electronic proceedings of the ESERA 2015 Conference. Science education research: Engaging learners for a sustainable future* (pp. 2331–2341). Helsinki, Finland: University of Helsinki.
Rollnick, M., & Mavhunga, E. (2015). The PCK Summit and its effect on work in South Africa. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 135–146). New York: Routledge.
Rollnick, M., & Mavhunga, E. (2016). The place of subject matter knowledge in teacher education. In J. Loughran & M. L. Hamilton (Eds.), *International Handbook of Teacher Education* (pp. 423–452). Singapore: Springer.
Rozenszajn, R., & Yarden, A. (2014). Expansion of biology teachers' pedagogical content knowledge (PCK) during a long-term professional development program. *Research in Science Education*, *44*(1), 189–213.
Schneider, R. M., & Plasman, K. (2011). Science teacher learning progressions: A review of science teachers' pedagogical content knowledge development. *Review of Educational Research*, *81*(4), 530–565.
Schön, D. A. (1983). *The reflective practitioner*. New York: Basic Books.
Schön, D. A. (1987). *Educating the reflective practioner: Toward a new design for teaching and learning in the professions*. San Francisco: Jossey-Bass.
Schwab, J. J. (1978). Education and the structure of the disciplines. In I. Westbury & N. Wilcof (Eds.), *Science, Curriculum and Liberal Education* (pp. 167–183). Chicago: University of Chicago.
Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22*(2), 63–75.
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.
Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23.
Sibanda, D., & Hobden, P. (2015). Planning a teaching sequence for the teaching of chemical bonding. *African Journal of Research in Mathematics, Science and Technology Education*, *19*(1), 23–33.
Slotwinski, J. (1997a). *Chemistry I*. (J. Bradley, Ed.). Johannesburg: Heinemann.
Slotwinski, J. (1997b). *Chemistry II*. (J. Bradley, Ed.). Johannesburg: Heinemann.
Smith, P. S., & Banilower, E. R. (2015). Assessing PCK: A new application of the uncertainty principle. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 88–103). New York: Routledge.
Stevens, S. Y., Delgado, C., & Krajcik, J. S. (2010). Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching*, *47*(6), 687–715.
Taber, K. S. (1997). Student understanding of ionic bonding: Molecular versus electrostatic framework. *School Science Review*, *78*(285), 85–95.
Taber, K. S. (1998). An alternative conceptual framework from chemistry education. *International Journal of Science Education*, *20*(5), 597–608.

Taber, K. S. (2000a). Chemistry lessons for universities?: A review of constructivist ideas. *University Chemistry Education*, *4*(2), 63–72.
Taber, K. S. (2000b). Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education*, *22*(4), 399–418.
Taber, K. S. (2001). Shifting sands: A case study of conceptual development as competition between alternative conceptions. *International Journal of Science Education*, *23*(7), 731–754.
Taber, K. S. (2002). *Chemical misconceptions - Prevention, diagnosis and cure: Theoretical background* (Vol. 1). London: Royal Society of Chemistry.
Taber, K. S. (2003). Mediating mental models of metals: Acknowledging the priority of the learner's prior learning. *Science Education*, *87*(5), 732–758.
Taber, K. S. (2009). Challenging misconceptions in the chemistry classroom: Resources to support teachers. *Educación Química*, *4*(1), 13–20.
Taber, K. S., & Coll, R. K. (2002). Bonding. In J. Gilbert, O. de Jong, R. Justi, D. F. Treagust, & J. van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 213–234). Dordrecht: Kluwer Academic Publishers.
Taber, K. S., & Watts, M. K. (1996). The secret life of the chemical bond: Students' anthropomorphic and animistic references to bonding. *International Journal of Science Education*, *18*(5), 557–568.
Tan, D. K. C., & Treagust, D. F. (1999). Evaluating students' understanding of chemical bonding. *School Science Review*, *81*(294), 75–84.
Tashakkori, A., & Creswell, J. W. (2007). The new era of mixed methods. *Journal of Mixed Methods Research*, *1*(3), 3–7.
Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioural sciences*. Sage Publications Inc.
Tennant, A., & Conaghan, P. G. (2007). The Rasch measurement model in rheumatology: what is it and why use it? When should it be applied, and what should one look for in a Rasch paper? *Arthritis Care & Research*, *57*(8), 1358–1362.
Tepner, O., & Dollny, S. (2012). Chemistry teachers' content knowledge and its correlation to pedagogical content knowledge. In E-Book proceedings of the ESERA 2011 conference: Science learning and citizenship. Part (Vol. 12, pp. 203-208).
Toerien, R. (2013). *Transforming content knowledge: A case study of an experienced science teacher teaching in a typical South African secondary school*. University of Cape Town. Retrieved from http://hdl.handle.net/11427/5609.
Treagust, D. F., & Tsui, C. Y. (2014). General Instructional Methods and Strategies. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education Vol. 2* (pp. 303–320). New York: Routledge.
Usak, M., Özden, M., & Eilks, I. (2011). A case study of beginning science teachers' subject matter (SMK) and pedagogical content knowledge (PCK) of teaching chemical reaction in Turkey. *European Journal of Teacher Education*, 34(4), 407-429.
Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagical content knowledge. *Science Education*, *86*(4), 572–590.
Van Driel, J. H., & Verloop, N. (1999). Teachers' knowledge of models and modelling in science. *International Journal of Science Education*, *21*(11), 1141–1154.
Van Driel, J. H., & Verloop, N. (2002). Experienced teachers' knowledge of teaching and learning of models and modelling in science education. *International Journal of Science Education*, *24*(12), 1255–1272.
Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers´ pedagogical content knowledge. *Journal of Research in Science Teaching*, *35*(6), 673–696.
Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. *Electronic Journal of Science Education*, *3*(4), 1–19.

Visser, P. S., Krosnick, J. A., & Lavrakas, P. J. (2000). Survey research. In H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 223–252). New York: Cambridge Univerity Press. Retrieved from http://web.stanford.edu/dept/communication/faculty/krosnick/Survey_Research.pdf.

Vladusic, R., Bucat, R. B., & Ozic, M. (2016). Understanding ionic bonding - a scan across the Croatian education system. *Chemistry Education Research and Practice*, *17*(4), 685–699.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. Gabel (Ed.), *Handbook of Research on Science Teaching and Learning* (pp. 177–210). New York: Macmillan.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education*, *24*(1), 173–209.

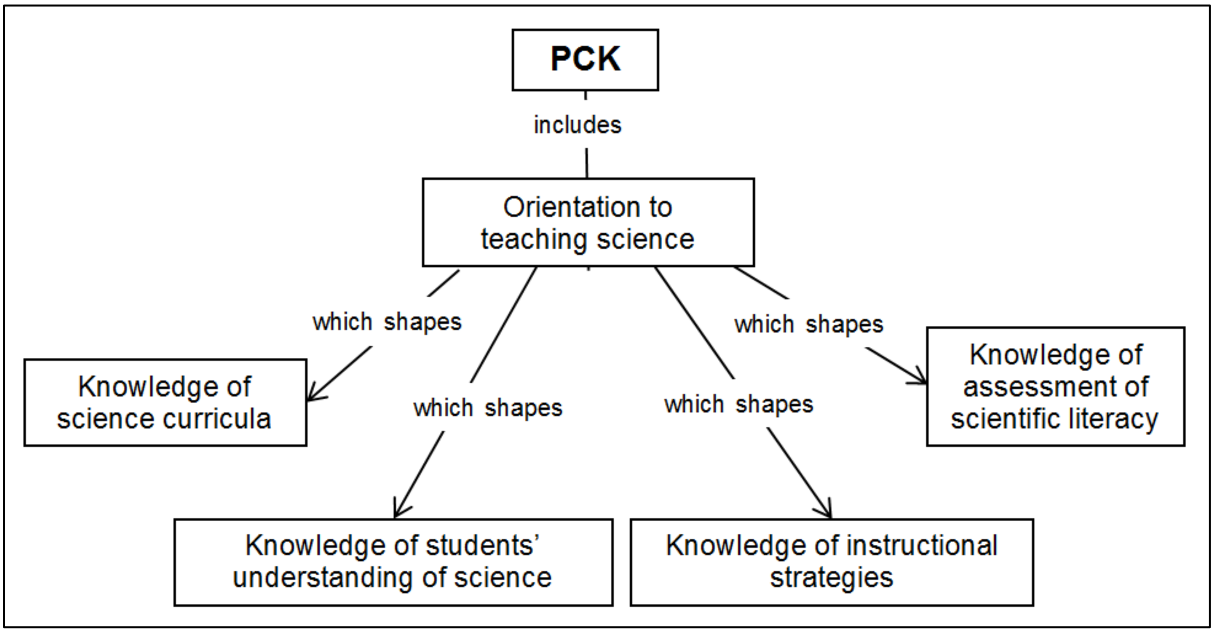
Wilson, S. M., Shulman, L. S., & Richert, A. E. (1988). 150 Different ways of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 104–124). London: Cassell Educational.

Yin, R. (2003). *Case study research: Design and methods* (3rd ed.). Newbury Park, CA: Sage Publications Inc.

Zimmerman, G. J. (2016). *The design and validation of an instrument to measure the topic specific pedagogical content knowledge of physical sciences teachers in electric circuits*. University of the Witwatersrand. Retrieved from http://hdl.handle.net/ 10539/19626.

Appendices

Appendix 1 **PCK model from Magnusson, Krajcik and Borko (1999)**



Appendix 2 **Alternative conceptions in chemical bonding**

Chemical bonds form in order to produce filled shells. Full shells is the driving force for bond formation.	(Taber, 1998)
Ionic bonds are the transfer of electrons. Electrons are transferred to achieve a full shell. An ionic bond is transfer of electrons.	(Taber, 1998) (Barker & Millar, 2000)
Covalent bonding as electron sharing. Electrons are shared to achieve a full shell. A covalent bond is a sharing of electrons.	(Taber, 1998)
Bonding dichotomy. There are only two kinds of bonds: covalent bonds and ionic bonds. Anything else is just a force and not a proper bond.	(Taber, 1998)
NaCl exists as a molecule. NaCl exists as molecules in a lattice with just forces between the molecules. (Ion-pair view)	(Barker & Millar, 2000) (Taber, 1998)
An ionic bond only occurs between the atoms involved in the electron transfer. Thus, sodium ion forms one ionic bond to a chloride ion in solid sodium chloride and is involved in five forces with the other adjacent chloride ions.	(Taber, 1998)
Na^+ and other ions are stable because they have a filled outer shell.	(Taber, 1998)
Metals do not have real bonds only forces.	(Taber, 1998)
Bond polarity: Equal sharing of the electron pair occurs in all covalent bonds. The polarity of a bond is dependent on the number of valence electrons in each atom involved in the bond. Ionic charge determines the polarity of the bond. A substance is neither covalent nor ionic.	(Petersen & Treagust, 1989) (Nicoll, 2001)
Molecular shape: The shape of a molecule is due to the repulsion between the bonds. The V-shape in a molecule is due to the repulsion between the nonbonding electron pairs. Bond polarity determines the shape of a molecule. The lone pairs of electrons have higher energy, they are stronger, or they want more space.	(Petersen & Treagust, 1989) (Nicoll, 2001)
Polarity of molecules: Nonpolar molecules form when the atoms in the molecule have similar electronegativities. Molecules of the type OF_2 are polar as the nonbonding electrons on the oxygen form a partial negative charge.	(Petersen & Treagust, 1989)
Intermolecular forces: Intermolecular forces are the forces within a molecule. Strong intermolecular forces exist in a continuous covalent solid. Covalent bonds are broken when a substance changes shape.	(Petersen & Treagust, 1989)
Octet rule: Nitrogen atoms can share five electron pairs in bonding.	(Petersen & Treagust, 1989)
Lattices: High viscosity of some molecular solids is due to strong bonds in the continuous covalent lattice.	(Petersen & Treagust, 1989)
Chemical bonds are physical entities.	(Boo, 1998)
Electrons in a bond move back and forth between the two atoms.	(Nicoll, 2001)
Bonding electrons in a molecule orbit the atoms in a figure eight.	(Nicoll, 2001)

Appendix 3 **Interview protocol for teachers**

Interview protocol for teachers (to be used as a guide), number 2 and 3 can be swopped or answered at the same time.

1. Tell me a bit about yourself. Where did you go to school, where did you go to university, where did you teach?

2. What events played an important role in your teaching over your career? Why? How did they play a role?

3. Draw graphs for each of the following. Think about your level of knowledge as it is today, and then think back on how this changed over time. (Story-line graphs can be done in any order.)

    a. Content knowledge

    b. Representations

    c. Curricular saliency

    d. What is difficult to teach?

    e. Learner prior knowledge

    f. Teaching strategies

4. Now look at Question 5 of the questionnaire and tell me how you would teach

    a. about the beryllium and bromine

    b. about graphite

[Get teachers to elaborate on what they have written in the questionnaire.]

Appendix 4 **Extract from Stephanie's interview transcript**

R: and your position as HOD, how has that influenced your teaching?

S: uhm, this is a difficult one, my position as HOD, obviously I am overseeing other people, and I always had one person that is definitely under me, and sometimes more than one because of time tabling.

R: ok

S: in terms of teaching I have to make decisions about scaffolding, planning of the year like when you do what, we are quite blessed in a private school that we do get freedom to do what we want, and I know with a government school you have to follow the exact progress plan given out by the department of education, we do try and stick to it, but we do have flexibility in that and I think as HOD I am allowed to make some decisions in terms of what we do when and also what we cover and what we don't cover, and honestly there are some things that we don't cover that we should cover, and there are some other things that we do that other schools don't do, so as HOD I am allowed a bit of flexibility to guide that process

R: how do you make those decisions on what to cover, and in which grades and order to teach it in?

S: I consciously think about it, and I think as I teach more and more like for example in grade 12 you can't do electrochemical cells if you haven't done redox and it is a silly example but somewhere you've got to make sure that you've taught redox reactions before you do electrochemical cells.

R: ok

S: what else, for example when you do electromagnetism and you talk about making electricity the kids need to have an idea of what magnets are all about, or even electricity itself, so yes, there is an order, and yes I do think about, and I definitely got better at thinking about it the more I taught it over the years.

R: ok

S: and I sometimes find, like in grade 11, that I go ahead because I get so enthusiastic because I know they need those information for grade 12, I actually need to be careful that I stick to what we are meant to do in grade 11 [laughs]

R: [laughs] ok

S: I mean that is not a big problem

R: now, with chemical bonding, what do you think would be needed before you teach bonding, what does it afford you to teach after that?

S: ok so there are a lot of things that needs to be taught before bonding, and I know I have mentioned a lot of that in my questionnaire

R: yes

S: so if I go all the way back, basically you have to start with the periodic table, and I would say that you need to start talking about metals on the one side and non-metals on the other, and why that, well because you start talking about how metals generally use electrons and how non-metals gain and that is basically the foundation of ionic bonding, and you start with that, and then you talk about your groups and how groups 1 to 4 they generally losing electrons and the group number is then your valency and that helps again with bonding and then how groups 5 to 7 you know they're gaining electrons and they are 8 minus the groups number, and you need to go through all of that, and it is based on the basic periodic table, which you would do even in grade 8 and then moving into grade 9 when you start to talk about basic formulae, using valency derive the formulae of compounds, so ja, that's probably the foundation, then you would have to start talking about the difference between ionic and covalent, which we do basically in grade 9, but grade 10 is really where we spend time talking about what is a covalent bond, what is an ionic bond.

R: hm

S: and I think for me as well, what has been different in the years of my teaching, is how our syllabus has started to really emphasize that it is not completely separate, ionic and covalent, and which is how I was taught at school and how I was teaching way back in 2001 or whatever, which was very separate, we didn't really have any link, but now we are supposed to teach the spectrum, you know, you have some ionic, and some covalent, and it gradually changes

R: hm

S: so things like Aufbau diagrams, we talk about how the electrons are arranged, and orbitals, like how you've got half-filled orbitals, and they do they want to fill, I mean that is also important, and I know in grade 9 we do the basic Bohr diagram, now I mean Bohr diagrams I would say you want to do first, and then Aufbau, because Bohr is simpler, but I mean all of that is building foundational knowledge about chemical bonding

R: and then after, once you've taught the bonding part, what does that afford you to teach after?

S: ok so once you've got chemical bonding, you can write formulae, you can talk about the grade 11 you know shapes of your molecules, because you need to know how the things have bonded to be able to draw the Lewis diagrams to give you the shapes of the molecules and once you've got the shape you can, I mean intermolecular forces, and once you've got that you can start talking about, you know, will this dissolve in this, will this not dissolve in this, and you can start looking at that kind of thing, dissolution, that whole process

R: ok

Mon 2015/10/12 05:08 PM

RE: Interview transcript - for checking

To rene.toerien@gmail.com

This message has been replied to or forwarded.

Message | Storyline_Interview_SC_Transcription edited - Rene Toerien.docx (43 KB)

Dear Rene

I hope you are well. Attached please find your edited document. I was SO tempted to change the punctuation (like adding in full stops, commas and question marks), but generally did not do that.

Hope you have a great week!

HOD: Physical Sciences

Appendix 5 **Sample teachers ranked according to Rasch person measures**

Teacher code	Gender	Province	School type	Highest chemistry qualification	Highest education qualification	Teaching experience	Rasch person measure
T28	M	WC	EXMODELC	CHEM2	PGCE / HDE	4-10 YEARS	2.64
T27	M	WC	PRIVATE	CHEM3	PGCE / HDE	21+ YEARS	2.54
T26	M	GP	EXMODELC	CHEM2	MASTERS	11-20 YEARS	2.44
T58	F	GP	EXMODELC	CHEM3	HONOURS	11-20 YEARS	1.98
T40	F	WC	PRIVATE	CHEM3	MASTERS	21+ YEARS	1.89
T01	F	WC	PRIVATE	CHEM1	MASTERS	4-10 YEARS	1.71
T09	F	GP	NOT TEACH	CHEM3	PGCE / HDE	21+ YEARS	1.71
T44	F	GP	PRIVATE	CHEM1	HONOURS	21+ YEARS	1.71
T30*	F	GP	EXMODELC	CHEM1	HONOURS	11-20 YEARS	1.63
T54	F	WC	NOT TEACH	CHEMHons	NO ED QUAL	0 YEARS	1.63
T57	M	WC	NOT TEACH	CHEM1	NO ED QUAL	0 YEARS	1.63
T32	F	WC	EXMODELC	CHEM3	BEd	21+ YEARS	1.46
T38	F	WC	PRIVATE	CHEM3	PGCE / HDE	11-20 YEARS	1.46
T29	M	WC	EXMODELC	CHEM1	BEd	11-20 YEARS	1.37
T41	F	WC	PRIVATE	CHEM3	PGCE / HDE	11-20 YEARS	1.37
T36	F	WC	EXMODELC	CHEM3	PGCE / HDE	1-3 YEARS	1.2
T59	M	WC	EXMODELC	CHEM1	TEACH DIP	21+ YEARS	1.2
T03*	M	GP	TOWNSHIP	UNKNOWN	BEd	4-10 YEARS	1.12
T33	F	WC	EXMODELC	CHEM3	PGCE / HDE	21+ YEARS	1.12
T37	M	WC	PRIVATE	CHEM1	PGCE / HDE	4-10 YEARS	1.12
T43	M	WC	EXMODELC	CHEM1	MASTERS	4-10 YEARS	1.04
T02	F	GP	EXMODELC	CHEM1	BEd	1-3 YEARS	0.71
T39	M	WC	EXMODELC	CHEM3	PGCE / HDE	21+ YEARS	0.71
T11	M	GP	RURAL	CHEM1	NO ED QUAL	21+ YEARS	0.63
T45*	M	GP	EXMODELC	CHEM1	HONOURS	4-10 YEARS	0.63
T04	F	GP	EXMODELC	CHEM1	BEd	4-10 YEARS	0.55
T34	M	WC	EXMODELC	CHEM3	BEd	21+ YEARS	0.55
T46*	F	WC	NOT TEACH	CHEMHons	NO ED QUAL	0 YEARS	0.55
T10*	F	GP	EXMODELC	CHEM3	PGCE / HDE	1-3 YEARS	0.3
T31	M	WC	PRIVATE	CHEM2	PGCE / HDE	21+ YEARS	0.3
T35	M	WC	EXMODELC	CHEM3	PGCE / HDE	21+ YEARS	0.3
T05*	M	GP	EXMODELC	CHEM3	PGCE / HDE	1-3 YEARS	0.22
T22	F	GP	NOT TEACH	CHEM1	BEd	21+ YEARS	0.14
T52	F	WC	NOT TEACH	CHEMHons	NO ED QUAL	1-3 YEARS	0.14
T60	M	WC	EXMODELC	CHEM2	NO ED QUAL	1-3 YEARS	0.06
T07	M	GP	NOT TEACH	CHEM1	PGCE / HDE	11-20 YEARS	-0.18
T42	F	WC	EXMODELC	CHEM2	PGCE / HDE	11-20 YEARS	-0.18
T48	F	WC	NOT TEACH	CHEMHons	NO ED QUAL	0 YEARS	-0.18
T23	M	GP	TOWNSHIP	CHEM1	PGCE / HDE	21+ YEARS	-0.35
T06	F	GP	TOWNSHIP	UNKNOWN	BEd	4-10 YEARS	-0.43
T49	F	WC	NOT TEACH	CHEM3	NO ED QUAL	0 YEARS	-0.43
T16	M	GP	TOWNSHIP	UNKNOWN	HONOURS	11-20 YEARS	-0.51
T55	M	WC	NOT TEACH	UNKNOWN	NO ED QUAL	0 YEARS	-0.51
T12	F	GP	EXMODELC	CHEM1	PGCE / HDE	4-10 YEARS	-0.59
T18	F	GP	PRIVATE	CHEM1	NO ED QUAL	11-20 YEARS	-0.92

T47	M	WC	NOT TEACH	CHEM1	NO ED QUAL	0 YEARS	-1.01
T51	F	WC	NOT TEACH	CHEM1	NO ED QUAL	0 YEARS	-1.01
T08	M	GP	TOWNSHIP	CHEM1	BEd	4-10 YEARS	-1.09
T20	M	GP	NOT TEACH	UNKNOWN	BEd	0 YEARS	-1.09
T21	M	GP	EXMODELC	UNKNOWN	PGCE / HDE	11-20 YEARS	-1.25
T17	M	GP	TOWNSHIP	UNKNOWN	BEd	1-3 YEARS	-1.42
T50	M	WC	TOWNSHIP	CHEMHons	NO ED QUAL	1-3 YEARS	-1.42
T56	M	WC	NOT TEACH	UNKNOWN	NO ED QUAL	0 YEARS	-1.42
T25	F	GP	EXMODELC	CHEM1	TEACH DIP	11-20 YEARS	-1.51
T19	M	GP	TOWNSHIP	UNKNOWN	TEACH DIP	4-10 YEARS	-1.59
T24	M	GP	NOT TEACH	CHEM1	BEd	0 YEARS	-1.76
T15	F	GP	RURAL	CHEM3	BEd	1-3 YEARS	-1.93
T53	M	WC	NOT TEACH	UNKNOWN	NO ED QUAL	0 YEARS	-1.93
T13	M	GP	TOWNSHIP	CHEM1	PGCE / HDE	4-10 YEARS	-2.56
T14	M	GP	EXMODELC	UNKNOWN	PGCE / HDE	11-20 YEARS	-2.66

* African teachers scoring above the mean

Appendix 6 **Coding procedures for instrument responses**

All teacher responses were captured in a spreadsheet for ease of further analysis. To illustrate how the coding was done, an original teacher's response (T37) to item 1.2 on representations and the corresponding portion of the spreadsheet, are included in Figure A6.3 and Figure A6.4 on pages 237-241. The rubric for coding the representations section is included in Figure A6.2.

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Subtotal	Total
Representations REP	**1.1 Strengths and weaknesses** • Able to identify appropriate strengths and weaknesses for none or one of the representations. [If the description is detailed, then code as 2.] **1.2a Reason for choice** • Reason for choice is inappropriate, incomplete, vague or difficult to follow **1.2b Use in lesson** • No discussion on how the representation is going to be used or suggested use inappropriate or unworkable	**1.1 Strengths and weaknesses** • Able to identify appropriate strengths and weaknesses for two or three of the representations. [If the description is detailed, then code as 3.] **1.2a Reason for choice** • Reason for choice is appropriate, but limited to a single consideration **1.2b Use in lesson** • Suggested procedure lacks logic or clarity or is limited • Teaching approach is basic and does not include a conceptual orientation	**1.1 Strengths and weaknesses** • Able to identify strengths and weaknesses for four or five of the representations [If the description is very detailed, then code as 4.] • Reasonable reasons without going into specifics [e.g. terms such as 'abstract', limitation/ limited', 'confusion' are used] **1.2a Reason for choice** • Reasons for choice include two or more levels of consideration, e.g. ease of use, effectiveness to confront misconception, learner context, explanatory power • Links to the concept are clear and appropriate **1.2b Use in lesson** • Suggested procedure shows logic and a satisfactory explanation on how the chosen representation is going to be used • There is some evidence of a conceptual orientation	**1.1 Strengths and weaknesses** • Able to identify appropriate strengths and weaknesses for all six representations • Appropriate reasons are provided for most representations • Aware of misconceptions being introduced, e.g. anthropomorphism **1.2a Reason for choice** • Reasons for choice include more than two levels of consideration as well as limitations of the representation • Links to the concept under discussion are clear and appropriate and includes connections to further concepts **1.2b Use in lesson** • Suggested procedure is clear, logical and shows strong conceptual orientation • Use of the representation contributes to understanding and links to further teaching.	1.1 1.2a 1.2b	REP1 REP2 REP3

Figure A6.2 Rubric for coding Representations

Teacher T37 chose representation 2 as the representation he liked most. Figure A6.2 above gives the rubric descriptors that were used to code his responses as follows. In his explanation he linked the use of the representation to student prior knowledge (electron configuration and Bohr models), and included the simplicity of the representation and its link to electron sharing as the reasons for his choice. This was coded as level 3, as it included two considerations (ease of use, and the link to electron sharing). Although more details could have been given to make his reasons clearer, he did make links to prior knowledge. It was not coded as level 4 because he didn't link his choice of representation to further concepts, and it was not coded as level 2 because the response involved more than one consideration.

Chemical Bonding Research Project

Personal code: T37

1.2 Which one of above representations did you like the **most**? Describe how you would use it in a lesson in the space provided below. If you did not like any of these, you can draw your own representation below.

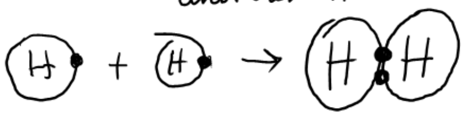
The representation I like most is number 2

I did not like any of them, I prefer this one:

I chose this representation because ... This would lead on from the ideas of electron configuration and the Bohr models It is simple to start with and shows how e^- can be shared.

In a lesson I would use it as follows:

- Start with Bohr model / Lewis diag of H.
- Discuss the idea of a "full" outer shell
- How could H× get a full outer shell?
- Needs another e^- → what if it shared with another H×



- That is why Hydrogen is H_2 ☺
- Use other examples – Cl_2 – N_2 – O_2 – H_2O – CO_2 etc.

4

Figure A6.3 Teacher T37's response to Question 1.2 on Representations

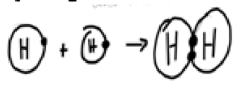
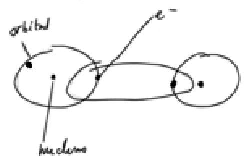
Teacher code	1.2a Like most	1.2a Reason	REP1 code	1.2b Use in lesson	REP2 code
T37	2	This would lead on from the ideas of electron configuration and the Bohr models. It is simple to start with and shows how e^- can be shared.	3	Start with Bohr model/Lewis diagram of H. Discuss the idea of a 'full' outer shell. How could H^x get a full outer shell? Needs another e- → what if it shared with another H^x That is why hydrogen is H_2 .  Use other examples - Cl_2 O_2 N_2 H_2O CO_2 etc.	2
T38	6	Energy is a central concept in chemistry, especially in bonding and needs to be understood. Pupils find it difficult to understand that a release of energy leads to stability (cf. release of heat during crystallisation). Parallels can be drawn.	3	Pupils are given a ball each and approach each other from infinity ∞ (corners of the classroom) - no influence on each other, therefore zero energy by definition, even though they are moving (E_k). As they approach each other they also move their balls lower to mimic the shape of the graph. Great fun is had when they squash their balls against each other to show E_p ↑ and then release balls which then jump apart.	4
T39	2	It shows each atom having 1 e^-. It shows e^-s being shared.	2	Exactly as is, but would add  labels.	1

Figure A6.4 Extract from coding spreadsheet to show how T37 was captured

Teacher T37's next response on how he would use it in teaching did not suggest a strong conceptual focus. It was a basic strategy which used Lewis diagrams and Bohr models to explain how molecules form. Although it could be considered a satisfactory explanation, which would have qualified for a level 3 response, the full octet structure is presented as the driving force for the formation of molecules. This is a known alternative conception and due to the lack of conceptual depth, the response was coded at a level 2. Teacher T37's response here can be compared to that of T38 in the next line. T38 chose representation 6 and suggested using the students to demonstrate the change in energy when two atoms approach each other. This is conceptually rich and draws in students' prior knowledge (potential and kinetic energy). It also involved the students in her class. Her response was coded as a level 4. She provided a reason for her choice of representation, which was coded at a level 3 (see REP1 code).

Although it was a good explanation and two considerations were provided for the choice, it did not include links to further concepts, and could not be coded as a level 4.

T39 in the next line provided a limited, but appropriate reason for his choice of representation and it was coded at a level 2. His explanation of how he would use the representation in teaching was limited to only adding labels to the diagram. No further discussion was offered and his response can only be coded at a level 1.

Appendix 7 **Final TSKFT scores for survey sample (N=60)**

TEACHER	CK1.1 (2)	CK1.2 (2)	CK1.3 (2)	CK1.4 (2)	CK1.5 (2)	CK2.1 (4)	CK2.3 (3)	CK2.4 (3)	CK3.3 (4)	CK4.2 (4)	CK4.3 (4)	CK5.1 (4)	CK5.2 (3)	REP1 (4)	REP2 (4)	REP3 (4)	CS1 (4)	CS2 (4)	CS3 (4)	WDT (4)	LPK1 (4)	LPK2 (4)	LPK3 (4)	CTS1 (4)	CTS2 (4)
T01	2	2	2	2	1	3	2	2	3	2	3	3	3	4	2	3	4	3	3	3	3	4	4	4	4
T02	2	2	1	1	1	2	1	0	2	2	2	3	3	4	3	4	3	2	3	4	2	2	4	3	3
T03	2	2	2	2	2	3	1	2	3	4	3	3	3	2	3	2	2	3	3	3	3	3	3	3	2
T04	2	2	2	1	2	2	2	1	3	3	3	3	1	3	3	3	3	4	2	2	2	2	3	2	1
T05	2	1	0	0	1	4	2	1	2	2	2	1	3	3	1	3	3	3	3	4	3	3	3	2	1
T06	2	1	2	0	1	3	3	0	2	1	1	1	2	3	1	2	2	3	2	3	3	2	1	2	2
T07	0	1	2	2	1	2	2	2	2	1	2	2	1	1	2	3	3	3	2	3	2	2	3	2	2
T08	0	0	2	1	1	2	2	0	3	0	2	1	2	2	2	2	2	2	1	2	2	2	1	1	2
T09	1	2	2	2	2	3	3	2	4	3	3	2	1	3	3	4	4	3	3	4	4	2	3	4	4
T10	1	2	2	1	1	2	1	1	2	2	2	3	1	3	2	2	4	3	4	3	3	3	2	2	2
T11	2	2	2	2	2	3	1	2	4	3	1	3	2	2	2	2	2	2	2	4	3	3	3	2	2
T12	0	2	2	1	2	1	0	0	3	2	3	3	0	2	2	1	2	2	3	3	2	2	2	1	2
T13	0	2	1	1	0	0	1	0	1	0	0	0	0	1	1	1	1	1	2	2	1	1	1	1	1
T14	0	0	0	2	0	0	0	1	1	0	0	1	1	1	1	1	1	1	1	2	1	1	1	1	1
T15	0	1	1	0	0	1	0	0	2	1	0	1	1	1	2	2	1	2	2	2	2	2	1	1	1
T16	1	2	2	2	2	3	2	0	2	2	3	0	0	2	3	3	2	2	1	2	2	1	2	1	2
T17	0	0	1	1	1	3	0	0	1	1	1	1	2	2	2	2	2	2	3	1	1	2	1	2	1
T18	0	2	1	1	2	3	0	0	2	1	2	1	1	2	1	1	2	2	3	3	2	1	1	2	3
T19	0	0	2	1	2	3	0	0	2	1	0	2	0	1	1	1	2	2	2	2	2	2	1	1	1
T20	0	0	0	1	0	2	2	1	1	1	0	1	0	2	3	3	3	1	3	2	3	3	2	2	1
T21	0	2	1	1	2	3	2	0	2	0	0	3	2	1	1	1	2	2	3	1	1	2	1	1	1
T22	2	2	2	1	1	2	2	2	1	2	2	3	3	3	1	3	2	2	2	3	3	3	1	2	2
T23	2	2	2	1	2	2	2	2	1	3	2	3	2	3	2	1	2	2	1	1	2	1	1	2	2
T24	1	2	1	0	1	1	0	1	1	0	0	0	0	2	2	1	2	2	2	2	2	2	1	2	1
T25	0	2	2	1	2	3	0	0	2	1	0	2	0	2	2	2	1	1	2	1	1	2	1	1	1
T26	2	2	2	2	2	4	3	1	3	3	4	4	2	4	4	4	3	4	4	4	3	4	3	4	4
T27	2	2	2	2	2	4	3	3	4	4	4	3	2	4	4	4	4	4	3	3	3	3	4	3	4
T28	2	2	2	2	2	4	3	3	4	4	4	3	3	4	3	3	4	4	4	4	4	3	4	3	3
T29	2	2	2	2	1	4	2	3	3	4	3	3	2	3	2	3	3	3	3	4	2	3	3	3	2
T30	2	2	2	1	2	3	2	2	4	3	4	3	2	3	4	4	3	3	3	3	4	3	3	2	3
T31	2	2	0	2	2	2	2	2	4	1	3	3	1	3	2	1	2	3	3	2	2	2	3	3	2
T32	2	0	2	2	2	3	2	2	4	3	3	3	3	3	3	4	3	3	3	3	2	3	4	3	3
T33	2	2	2	2	1	4	2	1	4	3	4	2	2	3	2	2	3	2	2	4	3	3	3	3	3
T34	2	2	2	2	2	4	3	1	2	2	1	2	1	2	2	2	2	3	4	2	4	3	3	2	2
T35	2	2	1	1	2	4	3	2	2	3	2	3	2	1	2	1	2	2	3	2	2	2	2	3	3
T36	2	2	1	1	2	4	3	2	3	4	4	3	2	3	3	4	2	2	3	3	2	2	3	3	2
T37	2	2	2	2	2	4	1	2	2	4	3	2	3	3	4	2	2	2	3	4	3	2	3	2	3
T38	2	2	1	2	2	3	1	3	4	3	3	3	2	4	3	3	3	3	3	4	3	2	3	3	3
T39	2	2	2	2	2	4	2	2	3	3	3	3	3	2	2	1	2	2	1	3	3	3	3	2	2
T40	2	2	1	2	2	3	2	3	4	3	3	4	2	3	3	4	3	3	3	3	3	4	3	4	4
T41	2	2	1	2	1	3	3	2	2	2	3	2	2	3	3	3	3	3	3	3	4	4	3	4	4
T42	2	2	2	1	2	4	1	0	3	2	2	2	1	2	2	1	2	2	3	2	3	2	2	1	2
T43	2	0	2	2	1	4	1	3	3	2	3	3	2	3	2	2	3	3	3	3	3	4	3	3	3
T44	2	2	2	2	2	3	2	3	3	2	2	3	2	4	3	3	3	4	4	4	4	4	2	3	3
T45	2	1	1	1	1	4	2	1	4	2	2	2	1	4	2	4	3	2	3	3	2	3	3	3	2
T46	2	2	1	1	2	2	2	0	3	3	1	2	1	4	3	3	2	2	2	3	3	4	3	3	3
T47	0	1	2	1	0	2	2	1	2	1	2	1	1	2	1	1	3	3	2	2	2	1	1	1	3
T48	2	2	0	2	2	2	2	1	3	1	1	1	1	3	2	2	3	3	3	2	2	2	2	2	2
T49	2	2	1	0	2	3	2	0	1	3	2	2	0	2	2	1	3	2	3	3	3	2	2	1	1
T50	1	1	2	2	1	1	0	1	1	0	1	2	0	1	2	1	2	2	2	1	2	2	1	2	2
T51	1	1	2	2	1	1	1	0	2	0	1	2	2	2	2	2	2	2	1	1	3	3	2	1	1
T52	0	0	2	2	1	3	2	0	1	3	2	1	2	3	3	3	3	3	3	4	3	2	2	3	1
T53	1	0	1	0	1	2	2	0	1	0	0	1	0	2	2	2	2	1	2	1	1	1	1	2	1
T54	2	2	2	2	2	3	2	3	4	4	3	3	2	4	3	3	3	4	3	3	2	3	3	3	2
T55	0	2	2	2	2	3	2	2	2	0	1	1	2	3	2	2	3	3	3	1	1	1	1	1	2
T56	0	0	1	1	0	2	1	0	1	1	0	1	1	3	2	3	3	3	3	2	1	1	1	1	1
T57	0	2	2	2	2	4	3	3	3	2	3	3	3	4	3	3	4	4	3	3	4	3	2	2	3
T58	2	2	2	2	2	4	2	1	3	3	4	2	3	4	4	4	4	4	4	4	3	3	3	3	2
T59	2	2	2	1	2	4	2	2	4	3	4	2	2	3	3	3	3	2	3	3	3	3	2	3	2
T60	2	2	1	2	2	3	0	1	2	2	2	2	2	2	2	3	3	2	3	3	2	2	2	2	2

Appendix 8 **Thematic analysis process using a grounded approach**

The story-line interview transcripts and story-line graphs were analysed using *NVivo 10*, a qualitative data analysis software package (QSR International, 2012). A grounded approach to the data analysis was used. The interview transcripts were read a number of times to provide an overview for each teacher. NVivo was then used to systematically code the data and provide a list of the factors and events which the teachers identified as significant. The story-line graphs were also included in NVivo. Four teachers' interviews and story-line graphs were analysed to provide the initial list of factors and events (see Figure A8.1). The events were then rearranged to identify emerging themes, and discussed with two members of the reference group (see Figure A8.2). The first four interview transcripts were recoded using the identified themes, after which the remaining interview transcripts were coded. Data saturation became evident after ten interviews. Another round of rearranging, discussion and identification of salient themes followed, before arriving at the final list (see Figure A8.3).

Significant events

Name	Sources	References	Created On
Becoming HOD	1	1	2015/02/20 08:51 AM
Colleagues	4	22	2015/02/18 12:27 PM
Designing curricula	3	7	2015/02/18 04:04 PM
Deskilled by curriculum	1	3	2015/02/18 04:13 PM
Exercise from a textbook	1	1	2015/07/25 11:51 AM
First time teaching	3	15	2015/02/19 02:09 PM
Good textbooks	3	5	2015/02/18 04:00 PM
In charge of a grade	1	4	2015/07/25 08:49 PM
Learners influence	4	30	2015/02/18 12:28 PM
Masters	3	11	2015/02/18 12:28 PM
New curriculum	4	19	2015/02/18 12:28 PM
New teaching approach	1	1	2015/07/25 05:18 PM
Not engaging with the content	1	1	2015/02/18 02:17 PM
Own schooling and university training	3	16	2015/02/18 04:29 PM
Self	3	10	2015/02/18 12:28 PM
Teaching across a grade	4	15	2015/02/18 12:29 PM
Teaching experience at the school	4	14	2015/02/18 02:10 PM
Textbook writing	1	5	2015/02/18 02:14 PM

Figure A8.1 Initial set of codes

Significant events

Name	Sources	References	Created On
Assessment (using it to inform learning)	1	8	2015/09/17 12:20 PM
Curriculum change	7	65	2015/07/29 07:40 AM
Furthering your education	8	58	2015/07/29 07:47 AM
Learners	8	42	2015/02/18 12:28 PM
Personal beliefs	5	23	2015/10/02 08:04 AM
School Context	6	40	2015/07/29 08:14 AM
Taking on leadership roles	5	18	2015/07/29 07:46 AM
Teaching experience	8	67	2015/07/29 07:46 AM

Figure A8.2 Identification of themes

Significant events

Name	Sources	References	Created On	Created By
Curriculum change	9	86	2015/07/29 07:40 A	RT
Designing curriculum materials	7	34	2015/02/18 04:00 P	RT
Introducing a new curriculum	8	44	2015/02/18 12:28 P	RT
Working with curriculum documents	4	8	2015/02/18 04:04 P	RT
Furthering their education	9	64	2015/07/29 07:47 A	RT
Additional courses and workshops	2	6	2015/09/21 04:41 P	RT
Content training	8	27	2015/02/18 04:29 P	RT
Post-graduate studies in education	6	31	2015/02/18 12:28 P	RT
Teaching experience	10	66	2015/07/29 07:46 A	RT
Teaching the topic for the first time	8	22	2015/02/19 02:09 P	RT
Teaching the topic multiple times	8	25	2015/02/18 02:10 P	RT
Teaching the topic to multiple grade	6	19	2015/02/18 12:29 P	RT
The role of colleagues	8	53	2015/07/29 08:14 A	RT
The role of students	9	47	2015/02/18 12:28 P	RT

Figure A8.3 Final themes for significant events

Appendix 9 Codebook for thematic analysis

Themes for significant events

Curriculum change

Creating curriculum resources

The creation of new teaching materials, or writing of textbooks as a result of the introduction of a new curriculum

Introducing a new curriculum

When the introduction of the new curriculum was linked to the teachers' perceived growth in knowledge. This is different from the next category as here teachers do not interact with the actual documents. For example a new curriculum might introduce a new topic, which played a role, but the teachers did not engage with the actual documents

Working with curriculum documents

When the teacher engaged with the actual documents to make sense of them, use them to design a teaching sequence, etc.

Furthering their education

Content training

When referring to undergraduate or post-graduate content training. Can refer to a general level (chemistry or physics) or a topic specific level (chemical bonding)

Post-graduate studies in education

When referring to education studies, for example PGCE, BEd, or a master's degree in education

Workshops or short courses

When referring to a once-off workshop or short course on a specific topic, for example a district workshop on the implementation of the new curriculum, or a short course on the use of assessment in teaching

Teaching experience

Teaching the topic for the first time

When teaching bonding, or some aspect of bonding, for the first time

Teaching the topic multiple times

When teaching bonding more than once

Teaching the topic to multiple grade levels

When teaching bonding to more than one grade level

The role of colleagues

Any influence from another teacher, district official, headmaster, etc., at their own school or from another school

The role of students

Any link to student outcomes, comments from students in class, eliciting responses from students and then using it in teaching

Appendix 10 **PCK episode analysis process**

To illustrate how PCK episodes were identified and analysed, one example from Adrian's interview is presented. Adrian is responding on his drawing of the 'what is difficult to teach' story-line, and he is describing his experiences as he is drawing the line. His story-line is included in Figure A10.1 below.

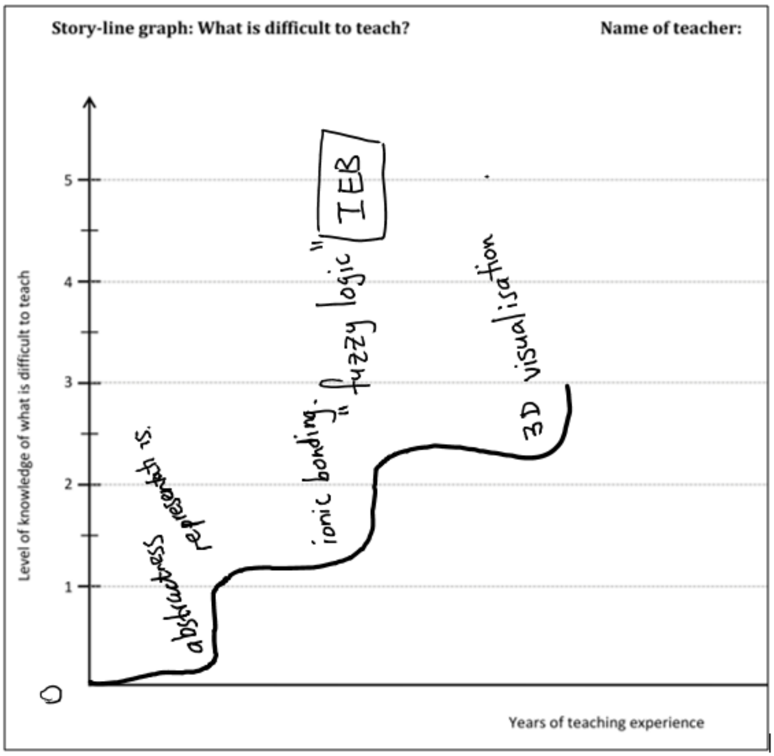


Figure A10.1 Adrian's story-line on 'what is difficult to teach'

The first step in the PCK episode analysis was to read through the transcript and identify instances of explicit PCK. Since the purpose of the analysis was to gain insight into how specific factors influenced the different components of TSKFT, the story-line graphs provided a very useful starting point. For example, Figure 3 on page 246 shows a portion of Adrian's interview in which he reflects (as he is drawing the story-line) on how his knowledge of what is difficult to teach shifted over his career. Notes, using different coloured text, were made on the transcript to identify each of the knowledge components. For each of the PCK episodes, the various knowledge components that Adrian drew from were indicated on the adapted TPK&S model to form 'TSKFT maps'. These TSKFT maps were drawn for each episode and each teacher. In the next round of analysis, all the TSKFT maps for one teacher were superimposed to form a picture of the influence of the factors for the specific teacher. The map for the factors influencing TSKFT for Adrian is included in Figure A10.2 on the next page. In the cross-case analysis all the TSKFT maps for each factor were superimposed to form a picture of how the factors influenced TSKFT for the group of ten teachers as a whole. The findings from this process are presented in Chapter 6 for each individual case, and Chapter 7 for the analysis across the cases. One example showing the TSKFT map of how teaching experience influenced all the teachers, is included in Figure A10.5. Each colour in the diagram represents a different teacher - for example, Adrian is indicated using brown arrows.

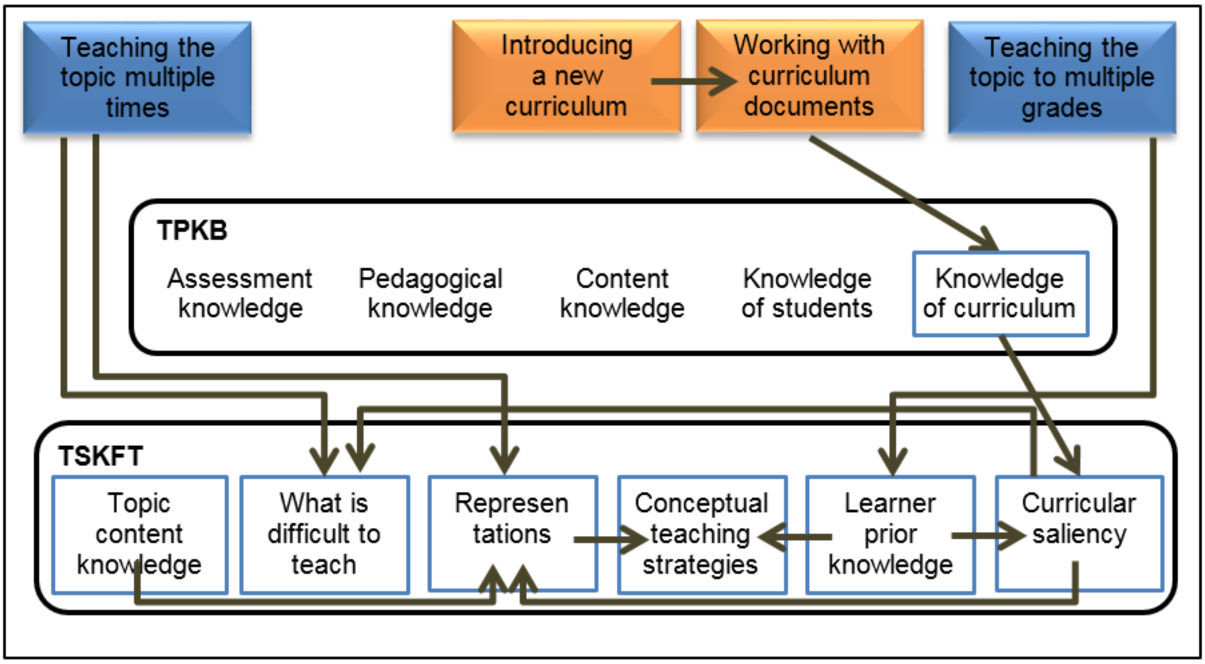


Figure A10.2 Mapping significant events for Adrian

Own experience of learning influencing his view on what is difficult to teach

Awareness of student diversity (knowledge of students)

Ability to identify why chemical bonding is difficult to teach

Knowledge of the integral nature of representations in the teaching of chemical bonding

Adrian: I am going to start myself at zero here, 'cause I went through all my schooling and university experiencing things as easy to learn, giving me zero understanding of what is hard to teach. You know certain things were harder or easier to learn, you know, especially as I went higher up, you know, first year chemistry a lot of that would have been harder to learn, but that still didn't tell me what is harder to teach. So it was only when I started to teach when I realised oh my goodness this is too abstract for grade 10s. That was a mechanics related one that I remember very specifically, so it was just looking at a graph and them not seeing what is just so clear, so graph reading, it is just not obvious, and it is a similar thing with a lot of representations we are using for chemical bonding, so I will draw my Lewis notation and it is a hydrogen and a hydrogen, and two electrons, and I've got the full picture of where that electron came from and what orbital it is in and I have done the quantum mechanics, so I even know what the orbital looks like, I know what its energy is in obscure units like electronvolts, but they see and H and a dot, and another H and a dot, and the brighter ones pick on very quickly that the dot represents the electron, and when they are close together like that, that represents a bond, but as for representing it in that format, it is quite abstract, and you know recognising that that's abstract is part of what is difficult to teach, because teaching it you always have to have some kind of representation. Now you can get ones that are easier, nice visualisations, or little videos, or those that show things in 3D, and that makes it easier for them to visualise what it might look like in real life, but in reality, most of the resources we have are pen and paper and exams, and it is fairly abstract representations. So the abstractness was a big learning curve early on.

First time teaching the topic made him realise that it was difficult to teach

Drawing from his content knowledge gained during university training

Student focussed, aware that student see thing differently, and aware of exactly how they view the representation

Knowledge of a variety of representations that can be used for chemical bonding

Figure A10.3 Excerpt from Adrian's interview to illustrate a PCK episode

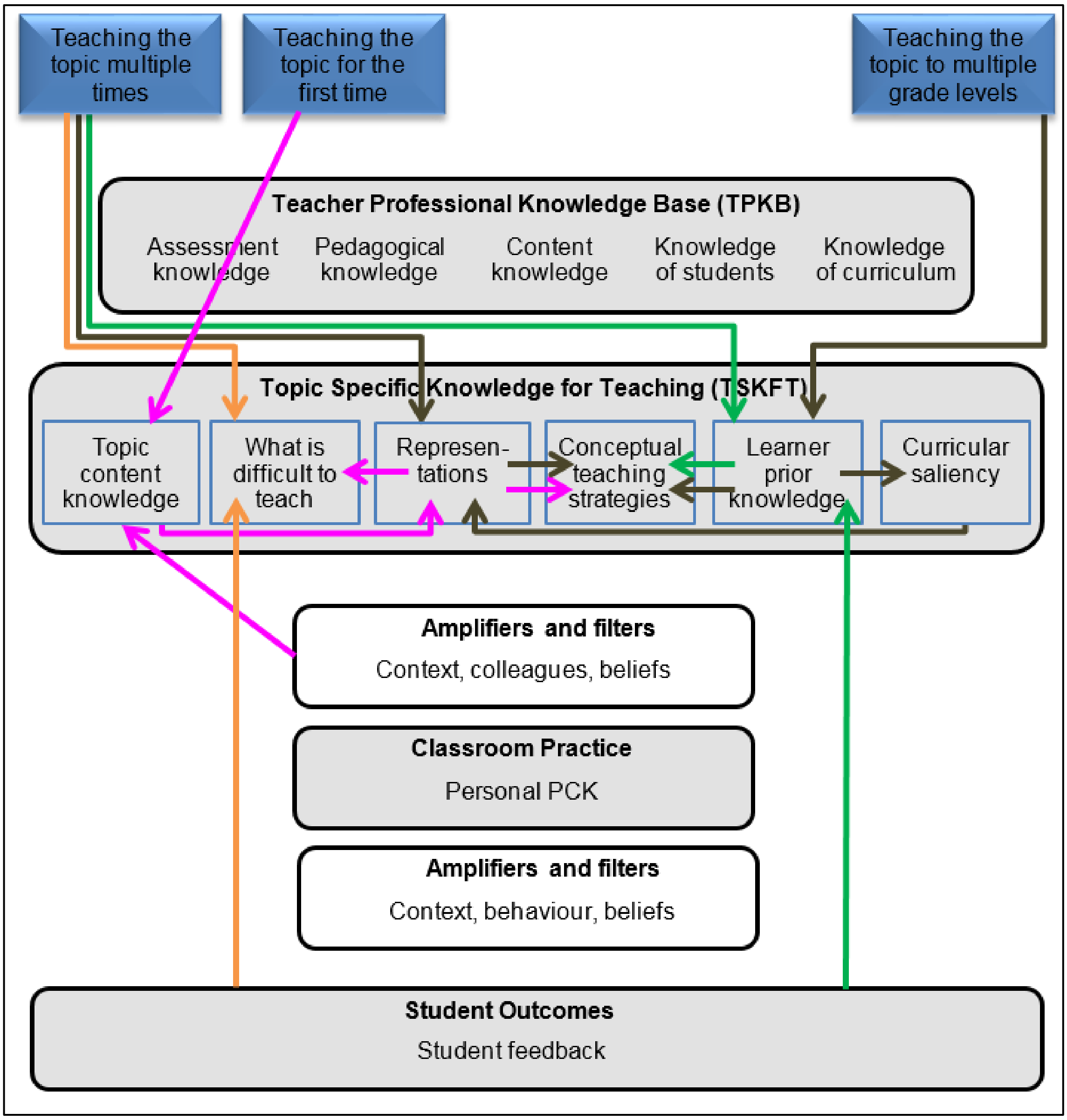


Figure A10.5 Cross-case analysis superimposing the same factor for all ten teachers

Appendix 11 **Ethics application to UCT**

Attention: A/Prof Mastin Prinsloo 25 February 2014

Re: Ethics application for PhD – Rene Toerien (TRNREN001)

Thesis title:

Mapping the learning trajectories of Physical Sciences teachers' topic specific knowledge for teaching chemical bonding

The aim of the research project is to understand what and how much teachers learn over time. The project will focus on Grade 10 and 11 Physical Sciences teachers teaching about chemical bonding.

Data collection will involve both qualitative and quantitative aspects. Questionnaires will be used to determine the breadth and depth of teachers' knowledge about teaching chemical bonding. I anticipate a group of about 50 teachers to complete the questionnaires. They will be asked to complete it in their free time. The questionnaire will take about 90 minutes to complete. An example of such a questionnaire is included in the attached research proposal in Appendix I.

The subsequent qualitative stage of the project will involve a smaller group of teachers, chosen from the larger group in stage one. Semi-structured interviews will be conducted with the second group of teachers to gain further insight into their learning. The interviews will take place in the teacher's free time, after school or on Saturdays. I anticipate about 8 teachers to take part in the interviews. I will also be collecting teacher artefacts like lesson plans and teaching notes and asking the teachers to reflect on the use of these items in their teaching.

The interviews will take 60-90 minutes. A draft of the interview protocol is included in the attached research proposal in Appendix I. The interviews will be voice recorded and transcribed for analysis.

Data collection will not involve any learners, and teachers will be interviewed in their free time to ensure that teaching time is not interrupted.

I am in the process of designing all the protocols and identifying teachers to participate in the study. Consent will be sought from all the teachers involved. Copies of the consent letters are attached in Appendix II.

Yours sincerely

signature removed

Mrs René Toerien

UNIVERSITY OF CAPE TOWN

School of Education

RESEARCH ETHICS: STUDENT/SUPERVISOR JOINT STATEMENT

This form should be completed by the research student and then co-signed by student and supervisor: Tick the YES or NO box, and write in details where appropriate. Please read the UCT Code for Research involving Human Subjects before completing the form. Ask your supervisor for clarification and help if needed.

Student researcher: Rene Toerien (TRNREN001)

Title of research project: Mapping the learning trajectories of Physical Sciences teachers' topic specific knowledge for teaching chemical bonding

Supervisor: Associate Professor Annemarie Hattingh

1. Have you read the UCT Code for Research involving Human Subjects? (available from supervisor or at the UCT web-site - go to Research/ go to Standards and Procedures)	**YES**✓	NO

2. Is your research making use of human subjects as sources of data?	**YES**✓	NO

Research focus

3. In the space below state what your research question/focus is, and give a brief outline of your plans for data collection.

Research questions:

What are the learning trajectories of Physical Sciences teachers with respect to the teaching of chemical bonding?

a. How can a valid measure of high quality topic specific knowledge for teaching chemical bonding be obtained?

b. What is the relationship between teaching experience and high quality topic specific knowledge for teaching chemical bonding?

c. How do teachers' topic specific knowledge for teaching chemical bonding develop over time?

Data collection will involve both qualitative and quantitative aspects. Questionnaires will be used to determine the breadth and depth of teachers' knowledge about teaching chemical bonding. A group of about 50 teachers will participate in this stage. Teachers will be asked to complete the questionnaire in their free time and should take no longer than 90 minutes. The second stage of the project will involve a smaller group of teachers, chosen from the larger group in stage one. Interviews will be conducted with the second group of teachers to gain further insight into their learning. Eight teachers will take part in individual interviews of about 60-90 minutes each. The interviews will be voice recorded and transcribed for analysis.

Data collection will not involve any learners, and teachers will be interviewed in their free time, to ensure that teaching time is not interrupted.

Information

4. Will participants (research subjects) in the research have reasonable and sufficient knowledge about you, your background and location, and your research intentions? Describe briefly below how such information will be given to them. If there is any reason for withholding any information from participants about your identity and your research purpose, explain this in detail below.	**YES✓**	NO
The participants will receive reasonable and sufficient information about myself, and the project. I will be in communication with the participants regarding the intention of the research, the scope of the project and what their involvement entails. Some of the participants might know me as I was a science teacher myself and have been involved in teacher training workshops throughout South Africa over the past 6 years.		

Consent

5. Will you secure the informed consent of all participants in the research? Describe how you will do this in the space below. If your answer is NO, give reasons below.	**YES✓**	NO
Informed consent will be secured from all the participants. An information letter and accompanying consent form will be provided to all the participants, see Appendix II. Teachers will have the freedom to withdraw at any stage of the project.		

6. In the case of research involving children, will you have the consent of their guardians, parents or caretakers? If your answer is NO, give reasons below. If your answer is YES, describe briefly how this consent will be got from the participants.	YES	**NO✓**
The research involves only teachers and no classroom visits or lesson observations will be included. Teacher interviews will also take place in the teacher's free time.		

7. In the case of research involving children, will you have the consent of the children as much as that is possible? If your answer is YES, describe briefly how this consent will be got from the children. If your answer is NO, give reasons below.	YES	**NO✓**
As above. The research involves only teachers and no classroom visits or lesson observations will be included. Teacher interviews will also take place in the teacher's free time.		

Confidentiality

8. Are you able to offer privacy and confidentiality to participants if they wish to remain anonymous? If you answer YES then give details below as to what steps you will take to ensure participants' confidentiality. If there are any aspects of your research where there might be difficulties or problems with regard to protecting the confidentiality and rights of participants and honouring their trust, explain this in detail below	**YES✓**	NO

All data (audio recordings, documents and interview transcriptions) will be handled in confidentiality and only those individuals directly involved in the research will have access to the information. All information gathered will remain anonymous to the reader. Pseudonyms will be used for the teachers and the schools. This information will be included in the consent form to the teacher, an example is provided in Appendix II.

Potential for harm to participants

9. Are there any foreseeable risks of physical, psychological or social harm to participants that might result from or occur in the course of the research? If your answer is YES, outline below what these risks might be and what preventative steps you plan to take to prevent such harm from being suffered.	YES	NO✓

Potential for harm to UCT or other institutions

10. Are there any foreseeable risks of harm to UCT or to other institutions that might result from or occur in the course of the research? e.g., legal action resulting from the research, the image of the university being affected by association with the research project, or a school being compromised in the eyes of the Education Ministry. If your answer is YES, give details and state below why you think the research is nonetheless worthwhile.	YES	NO✓

11. Are there any other ethical issues that you think might arise during the course of the research? (e.g., with regard to conflicts of interests amongst participants and/or institutions) If your answer is YES, give details and say what you plan to do about it.	YES	NO✓

Signed: signature removed

Student: Rene Toerien

Date: 25/02/2014

Co–signed: signature removed

Supervisor: A/Prof Annemarie Hattingh

Date: 25/02/2014

Appendix 12 **Extract from the National Curriculum Statement (NCS) physical sciences document**

Atomic combinations: molecular structure	
• A chemical bond as the net electrostatic force two atoms sharing electrons exert on each other.	Recall the role of models in science and describe the explanations of chemical bonding in this course as an application of a model Deduce the number of valence electrons in an atom of an element Represent atoms using Lewis diagrams Explain, referring to diagrams showing electrostatic forces between protons and electrons, and in terms of energy considerations, why two H atoms form an H_2 molecule, but He does not form He_2 Draw a Lewis diagram for the hydrogen molecule Describe a chemical bond as a shared pair of electrons Describe and apply simple rules to deduce bond formation, viz. • different atoms, each with an unpaired valence electron can share these electrons or form a chemical bond • different atoms with paired valence electrons called lone pairs of electrons, cannot share these four electrons and cannot form a chemical bond • different atoms, with unpaired valence electrons can share these electrons and form a chemical bond for each electron pair shared (multiple bond formation) • atoms with an incomplete complement of electrons in their valence shell can share a lone pair of electrons from another atom to form a co-ordinate or dative covalent bond (e.g. NH_4^+, H_3O^+)
• Chemical bonds as explained by Lewis theory and represented using Lewis diagrams. • Multiple bonds	Draw Lewis diagrams, given the formula and using electron configurations, for • simple molecules (e.g. F_2, H_2O, NH_3, HF, OF_2, HOCℓ) • molecules with multiple bonds (e.g. N_2, O_2 and HCN) • molecules of compounds where atoms display variable valencies (e.g. CO, CH_4, H_2S, SO_2, SO_3) • molecules where a molecule (or molecules) donates a lone pair of electrons (Lewis base) to a molecule or ion with vacant orbitals in the valence shell (Lewis acid) to form a dative covalent bond (e.g. H_3NBF_3, $Cu(NH_3)_4^{2+}$)
• Electronegativity of atoms to explain the polarity of bonds	Explain the concept 'electronegativity' Non-polar bond with examples, e.g. H-H Polar bond with examples e.g. H-Cℓ Show polarity of bonds using partial charges Explain the difference between H^+ and H Compare the polarity of chemical bonds using a table of electronegativities Show how polar bonds do not always lead to polar molecules
• Oxidation number of atoms in molecules to explain their relative "richness" in electrons	Explain the meaning of 'oxidation number' Deduce oxidation numbers by assigning a -1 to the more electronegative atom in each bond and +1 to the more electropositive atom in each bond and finding the algebraic sum of the numbers assigned to a particular atom once this is done for all the bonds involving the particular atom. Atoms in non-polar bonds are assigned zero. Assign oxidation numbers to atoms in various molecules like H_2O, CH_4, CO_2, H_2O_2, HOCℓ Use rules of oxidation to assign oxidation numbers to atoms in a variety of molecules and ions
• Bond energy and length	Explain what is meant by bond strength Describe ways in which atoms in a molecule can move (vibrate) relative to each other Explain the relationship between strength of bond between two chemically bonded atoms and • the length of the bond between them • the size of the bonded atoms • the number of bonds (single, double, triple) between the atoms

Appendix 13 **Extract from the Curriculum and Assessment Policy (CAPS) physical sciences document**

CAPS

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
4 HOURS	**Chemical bonding**	Interactions between matter generate substances with new physical and chemical properties.			
4 hours	Covalent bonding, ionic bonding and metallic bonding	• Draw Lewis dot diagrams of elements • **Covalent bonding**: sharing of electrons in the formation of covalent bond single, double and triple bonds electron diagrams of simple covalent molecules, names and formulae of covalent compounds • **Ionic bonding:** transfer of electrons in the formation of ionic bonding, cations and anions electron diagrams of simple ionic compounds ionic structure as illustrated by sodium chloride • **Metallic bonding:** - Sharing a delocalized electron cloud among positive nuclei in the metal - Revise the cation and the anion table done in grade 9 - Revise the names of compounds - Revise relative molecular mass for covalent molecules - Revise relative formula mass for ionic compounds	**Activities:** (1) Describe and draw the formation of a covalent bond (2) Describe, using electron diagrams, the formation of single, double and triple bonds (3) Write the names and formulae of covalent compounds in terms of the elements present and the ratio of their atoms (4) Describe, using electron diagrams, the formation of ions and ionic bonds (5) Draw the electron diagrams of cations and anions (6) Predict the ions formed by atoms of metals and non-metals by using information in the PT (7) Name ionic compounds based on the component ions (8) Describe the structure of an ionic crystal (9) Describe the simple model of metallic bonding	Ionic crystal lattices can be made with polystyrene balls and wooden sticks and displayed in the classroom	You need to have an explanation of chemical bonding before you describe molecular substances and ionic substances. Ensure that the correct terminology is used here, e.g. ionic substances do not form *molecules* **Electron diagrams refer to Lewis dot diagrams of elements.** **Under Chemical Bonding here only the definitions of covalent bonding, ionic bonding and metallic bonding are done.** On page 25 the applications or the effect of this kind of bonding is done. Given 4 hours, but 2 hours would also be enough

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PHYSICAL SCIENCES GRADES 10-12

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CURRICULUM AND ASSESSMENT POLICY STATEMENT (CAPS)

TERM 2 GRADE 10

GRADE 10 CHEMISTRY *(MATTER AND MATERIALS)* TERM 2

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
8 HOURS	**Particles substances are made of**	Matter is described as anything that has mass and occupies space. All matter is made up of atoms. Atoms can combine to form compounds: molecular compounds (molecules) or ionic compounds (salts) or metals (copper or iron or …)			Describe matter from the concepts: atoms, elements, compounds, chemical reactions.
	Atoms and compounds. • Molecules (molecular substances) are due to covalent bonding. • Ionic substances are due to ionic bonding. (The EFFECT of the different types of chemical bonding are emphasized here.)	• Describe atoms as the very small particles of which all substances are made • State that the only substances found in atomic form are the noble gases at ambient conditions • Describe a COMPOUND as a group of two or more different atoms that are attracted to each other by relatively strong forces or bonds. The atoms are combined in definite proportions • When atoms **share electrons** they are bonded covalently and the resulting collection of atoms are called a molecule. As a general rule molecular substances are almost always composed of nonmetallic elements	**Experiment:** (1) Identify elements and compounds in chemical reactions. Elements and compounds are investigated by doing experiments (2) Determine the products of the electrolysis of water (sodium sulphate added). Identify the elements and the compounds **Demonstration:** (1) Demonstrate visual representations of atoms, molecules, elements and compounds. Use "Jelly Tots" and tooth picks or play dough to make visual presentations of atoms, molecules, compounds, elements, (2) Demonstrate chemical bonding. Use atomic model kits to demonstrate chemical bonding in elements and compounds Visual representations, preferably 3D, is important here to ensure conceptual understanding of the formation of the different types of compounds	**Materials:** (For exp.1) Cal-C-Vita tablets, water, glass beaker, candle, limewater, zinc metal and hydrochloric acid, blue copper (II) sulphate, test tubes and burner. Class activity: different groups can investigate different crystal shapes, building models for each shape and presenting or displaying it in the classroom. This could include covalent molecular and network structures	DON'T explain concepts from atoms to molecules, this leads to misconceptions! Both molecules and ionic substances are COMPOUNDS, respectively due to DIFFERENT chemical bonding! **Remember** these concepts are very abstract to learners. The more visual you can make the concepts, even by using models, the more logical the concepts will become to the learners. Description of molecules and ionic substances make it important to do this section after the concept of chemical bonding. The terms simple molecules and giant molecules are confusing (sugar being anything but a simple molecule if water is seen as a simple molecule!)

PHYSICAL SCIENCES GRADES 10-12

GRADE 11 CHEMISTRY *(MATTER & MATERIALS)* TERM 1

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
6 HOURS	**Atomic combinations: molecular structure**	The type of chemical bond in a compound determines the physical and chemical properties of that compound. Through studying the structures of atoms, molecules and ions, and the bonding in elements and compounds, learners will acquire knowledge of some basic chemical principles. By learning the properties of metals, giant ionic substances, simple molecular substances and giant covalent substances, you can appreciate the interrelation between bonding, structures and properties of substances.			
2 hours	A chemical bond (is seen as the net electrostatic force two atoms sharing electrons exert on each other)	• Recall the role of models in science and describe the explanations of chemical bonding in this course as an application of a model • Deduce the number of valence electrons in an atom of an element • Represent atoms using Lewis diagrams • Explain, referring to diagrams showing electrostatic forces between protons and electrons, and in terms of energy considerations, why - two H atoms form an H_2 molecule, but - He does not form He_2 • Draw a Lewis diagram for the hydrogen molecule • Describe a covalent chemical bond as a shared pair of electrons	**Activity:** Draw Lewis structures of the elements and determine the number of bonds the element can make. **Activity:** (1) Describe the formation of the dative covalent (or co-ordinate covalent) bond by means of electron diagram using H_3O^+ and NH_4^+ as examples.	Use any suitable Teacher Support material that discusses the use of models in science, its benefits and short-comings	The role **of models in scie**nce is a very important issue, it must be handled very well. Bonding is introduced in grade 10. The atom, the arrangement of electrons into core and valence electrons. ****************************** **NB!!!** **Increased stability due to lower potential energy (and higher entropy) to be used as the main reason for bonding.** ****************************** The mainstay of Lewis diagrams is the "rule of two", that is two electrons for a bond rather than the "octet" rule which only applies rigorously to the second period.

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
		• Describe and apply simple rules to deduce bond formation, viz. - different atoms, each with an unpaired valence electron can share these electrons to form a chemical bond - different atoms with paired valence electrons called lone pairs of electrons, cannot share these four electrons and cannot form a chemical bond - different atoms, with unpaired valence electrons can share these electrons and form a chemical bond for each electron pair shared (multiple bond formation) - atoms with an incomplete complement of electrons in their valence shell can share a lone pair of electrons from another atom to form a **co-ordinate covalent or dative covalent bond** (e.g. NH_4^+, H_3O^+) Draw Lewis diagrams, given the formula and using electron configurations, for • simple molecules (e.g. F_2, H_2O, NH_3, HF, OF_2, $HOC\ell$) • molecules with multiple bonds e.g. (N_2, O_2 and HCN)			Start with a known molecule like water, H_2O, and start with the concepts of two H-atoms bond to one O-atom. This leads to the octet rule of electrons. This can again lead to the **Lewis electron pair presentati**on. The "two electrons" per bond is just as untrue as the "octet" rule. Both are just USEFUL MODELS to explain chemical bonding. The octet rule is only problematic if it is taught as an absolute. It is a useful rule of thumb for any but the 'd' block elements. Exceptions are for example BF_3. It is more useful than it is problematic if it is used as a general guideline rather than a rule Co-ordinate covalent or dative covalent bonds must NOT be done in detail, ONLY the definition and an example of the concept is required

PHYSICAL SCIENCES GRADES 10-12

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
1 hour	Electronegativity of atoms to explain the polarity of bonds.	• Explain the concepts - Electronegativity - Non-polar bond with examples, e.g. H-H - Polar bond with examples e.g. H-Cℓ • Show polarity of bonds using partial charges δ+ H - Cl δ- • Compare the polarity of chemical bonds using a table of electronegativities • With an electronegativity difference ΔEN > 2.1 electron transfer will take place and the bond would be ionic • With an electronegativity difference ΔEN > 1 the bond will be covalent and polar • With an electronegativity difference ΔEN < 1 the bond will be covalent and very weakly polar • With an electronegativity difference ΔEN = 0 the bond will be covalent and nonpolar • Show how polar bonds do not always lead to polar molecules	**Activity:** (1) Look at ideal molecular shapes (build with atomic model kits) with all the **end atoms the same** (look at electronegativity) and the bond polarity and molecular polarity (2) Look at ideal molecular shapes (build with atomic model kits) **with DIFFERENT end atoms** (look at electronegativity) and the bond polarity and molecular polarity		Link back to intermolecular forces. **NOTE:** The indications about electronegativety differences are given NOT as exact scientific knowledge but as a guideline for learners to work with in deciding polarity of a molecule. (For teachers: All bonds have covalent and ionic character.)

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
1 hour	Bond energy and length	• Give a definition of bond energy • Give a definition of bond length • Explain what is the relationship between bond energy and bond length • Explain the relationship between the strength of a bond between two chemically bonded atoms and - the length of the bond between them - the size of the bonded atoms - the number of bonds (single, double, triple) between the atoms			Link to potential energy diagram used to explain bonding above and point out the bond energy and bond length on the diagram. BEWARE!! That you don't elevate the Lewis presentations as physical truths in chemical bonding. There are NO PHYSICAL BONDS; the chemical bond just represents an area of high electron density and low potential energy.
10 HOURS	<u>**Intermolecular forces**</u>	In a liquid or a solid there must be forces between the molecules causing them to be attracted to one another, otherwise the molecules would move apart and become a gas. These forces are called intermolecular forces (forces between molecules).			Note: This section falls shortly after electronegativity and polarity have been discussed - this section therefore provides a great rationale for the importance of understanding these concepts

Appendix 14 **Draft CK items**

Chemical bonding content questions

Question 1:

1.1 Sodium chloride exists as a molecule.
- A TRUE
- B FALSE

Reason:
1. The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.
2. After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chlorine ion.
3. Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.
4. Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

1.2 Element C (electronic configuration 2,8,8,18,2) and element E (electronic configuration 2,7) react to form an ionic compound CE_2.
- A TRUE
- B FALSE

Reason:
1. The atom of C will share one pair of electrons with each atom of E to form a covalent molecule CE_2.
2. A macromolecule is produced consisting of covalently bonded atoms of C and E.
3. Atoms of C will each lose two electrons and twice as many atoms of E will each gain one electron to form an ionic compound CE_2.
4. An atom of C will lose one electron to an atom of E to form an ionic compound CE.

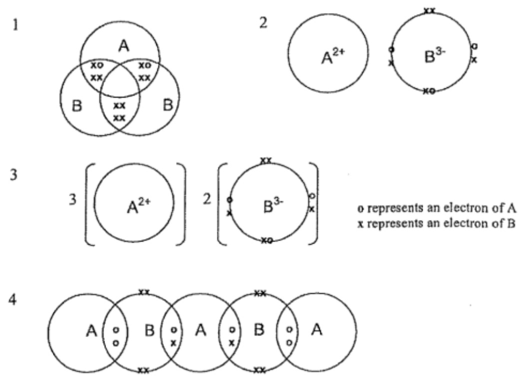
1.3 Graphite can conduct electricity because it has delocalised electrons.
- A TRUE
- B FALSE

Reason:
1. Only three of the four valence electrons of a carbon atom are involved in bonding and the fourth electron is delocalised.
2. Electrons escape from the covalent bonds in graphite and are free to move within the molecule.
3. Graphite can conduct electricity because it has layers of carbon atoms that can slip over each other.
4. Graphite can conduct electricity because in graphite some carbon atoms are delocalised and they conduct electricity.

1.4 An atom of element A has two electrons in its outermost shell while an atom of element B has five electrons in its outermost shell. When A reacts with B, the compound will be …
- A COVALENT
- B IONIC

Reason:

1



Question 2

2.1 The diagram on the right represents a single molecule of hydrogen. Which, if any, of the following labels can be used to identify the interaction between the two H atom shown:

	Yes?	No?	Unsure?
Attraction	☐	☐	☐
Force	☐	☐	☐
Bonding	☐	☐	☐
Chemical bond	☐	☐	☐

(please tick one box in each row)

H—H

Do you think this type of interaction is given a particular name/label? If so, how would you label this type of interaction?____

Describe this interaction in your own words. Give as much detail as you can:

____

____

____

____

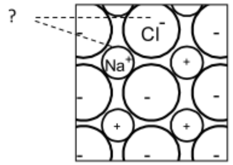
____

2

2.2 The diagram on the right represents part of a layer in a sodium chloride lattice. Which, if any, of the following labels can be used to identify the interaction between the two parts of the system shown:

	Yes?	No?	Unsure?
Attraction	☐	☐	☐
Force	☐	☐	☐
Bonding	☐	☐	☐
Chemical bond	☐	☐	☐

(please tick one box in each row)



Do you think this type of interaction is given a particular name/label? If so, how would you label this type of interaction?______________________________

Describe this interaction in your own words. Give as much detail as you can:

____

____

____

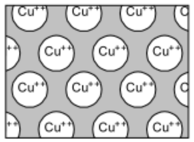
____

____

2.3 The diagram on the right represents the lattice arrangement in copper. Which, if any, of the following labels can be used to identify the interactions holding the copper together?

	Yes?	No?	Unsure?
Attraction	☐	☐	☐
Force	☐	☐	☐
Bonding	☐	☐	☐
Chemical bond	☐	☐	☐

(please tick one box in each row)



Do you think this type of interaction is given a particular name/label? If so, how would you label this type of interaction?______________________________

Describe this interaction in your own words. Give as much detail as you can:

____

____

____

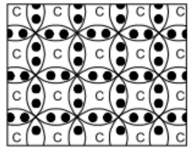
____

____

2.4 The diagram on the right represents part of the diamond structure of carbon. Which, if any, of the following labels can be used to identify the interactions holding the structure together?:

	Yes?	No?	Unsure?
Attraction	☐	☐	☐
Force	☐	☐	☐
Bonding	☐	☐	☐
Chemical bond	☐	☐	☐

(please tick one box in each row)



Do you think this type of interaction is given a particular name/label? If so, how would you label this type of interaction?______________________________

Describe this interaction in your own words. Give as much detail as you can:

____

____

____

____

____

____

Question 2: (alternative)

2.1 What is a chemical bond?

2.2 Draw a picture to illustrate your answer above.

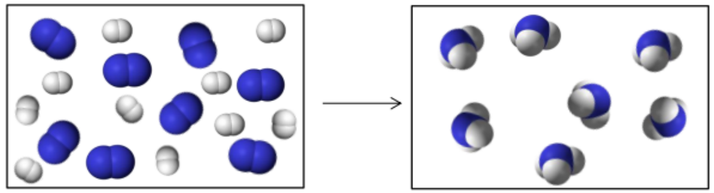
2.3 Why do atoms bond with each other?

2.4 Can the bond between two atoms be both covalent and ionic? Explain your answer.

5

Question 3:

The diagrams below represent the formation of ammonia gas ( ) from nitrogen gas ( ) and hydrogen gas ( ).



3.1 Write a balanced chemical equation for the reaction.

3.2 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

3.3 Describe how the bond mentioned in 3.3 formed?

3.4 Redraw one of the ammonia molecules to clearly show the electron distribution in the molecule.

6

Question 4

Aluminium is often used in foil in the catering industry.

4.1 What is the name of the type of bonding between the atoms in a piece of aluminium?

____

4.2 Describe how the bond mentioned in 4.1 is formed.

4.3 Make use of the properties of this bond and explain why a piece of aluminium is malleable.

Question 5

5.1 What kind of bond is formed when magnesium and bromine combine? Describe how this bond is formed using Lewis diagrams.

5.2 Explain why solid magnesium bromide has a high melting point (711°C).

5.3 What is the difference between molecular network solids and ionic network solids? Provide examples of each.

Appendix 15 Draft chemical bonding instrument used for pilot

Chemical Bonding Research Project

Personal code:

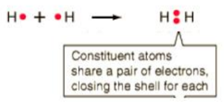
Knowledge for Teaching Chemical Bonding

Section 1: Representations

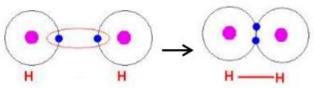
1.1 Chemical bonding is often represented through drawings and diagrams. A few examples of such representations are shown below.

Look at each of the representations and describe what you **like** and what you **don't like** about it as a **tool to teach about chemical bonds** and **why**. Fill in your answers on the next page.

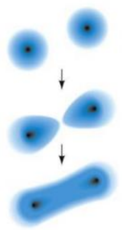
Representation 1



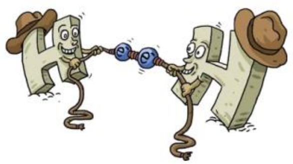
Representation 2



Representation 3



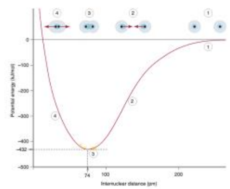
Representation 4



Representation 5

Using the learners in your class to represent chemical bonds as follows:

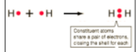
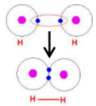
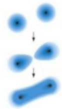
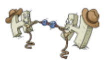
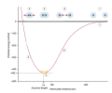
Representation 6



2

Chemical Bonding Research Project

Personal code:

	What I **like** and **why** (Strengths of the representation)	What I **don't like** and **why** (Weaknesses of the representation)
Representation 1 		
Representation 2 		
Representation 3 		
Representation 4 		
Representation 5 		
Representation 6 		

3

Personal code:

1.2 Which one of above representations did you like the **most**? Describe how you would <u>use it in a lesson</u> in the space provided below. If you did not like any of these, you can draw your own representation below.

The representation I like most is number _______
I did not like any of them, I prefer this one:
I chose this representation because …
In a lesson I would use it as follows:

Personal code:

Section 2: Curricular saliency

A list of some of the big ideas and sub-ordinate ideas in chemical bonding is given below. Big ideas are the ideas that underpin the content and which are **central** in **teaching for understanding** chemical bonding.

A. Ionic bonding takes place when electrons are transferred.
B. The chemical bonds in a substance determine its structure.
C. A chemical bond is an electrostatic interaction between a positive and a negative charge.
D. Energy is required to break bonds and energy is released when bonds are formed.
E. Electronic structure influences how atoms bond.
F. Polar covalent bonding takes place when electrons are shared unequally.
G. Chemical bonds are formed to create stability.
H. Substances may be molecular or network structures.
I. There is a spectrum of electron sharing in chemical bonds.
J. Sodium chloride forms a three-dimensional crystal structure due to ionic bonding.
K. Covalent bonding takes place when electrons are shared equally.

2.1 Select <u>three</u> ideas which you consider to be the **Big Ideas** in chemical bonding.

Idea 1: ______________________________

Idea 2: ______________________________

Idea 3: ______________________________

2.2 Using the three ideas in **2.1**, give the sequence you would teach them in, and your reasons for doing so.

Order of teaching (put the first concept you will teach next to the 1, the second next to the 2, etc.)	Reasons for order of teaching the Big Ideas chosen:
1:	
2:	
3:	

Personal code:

2.3 You are now planning a series of lessons on chemical bonding. Use the three ideas from **2.2**, and any additional ideas you think are appropriate, to **draw a mind map** to show how the **ideas are related**.

2.4 Why is it important for learners to learn about chemical bonding? Provide as many different reasons as possible.

Chemical Bonding Research Project

Personal code:

Section 3: What is difficult to teach?

Some of the concepts in chemical bonding are difficult to teach. Below are some of these concepts listed. Space is also provided for you to fill in your own concepts.

3.1 Give reasons why you think these concepts are **difficult to teach**. Choose any three concepts from the options provided, or your own. Fill in your response in the table below.

	Reasons why I think this is difficult to teach:
Concept 1: Metallic bonding	
Concept 2: Ionic bonding	
Concept 3: Polarity of bonds	

Personal code:

Concept 4: Bond energy	
Concept 5: What is a molecule	
You can fill in your own concepts here:	Reasons why I think this is difficult to teach:
Concept 6:	
Concept 7:	

Personal code:

Section 4: Learners' prior knowledge

4.1 Learners need to know about the Periodic Table before chemical bonding can be taught. Some of the ideas that are discussed in the section on the Periodic Table are shown below. Which one of these is the **most important** when **you teach** about chemical bonding for the **first time**? Give a **reason** for your answer and explain **how you would use it** in your teaching.

A: Metals are on the left hand side and non-metals are on the right hand side of the Periodic Table.

B: Elements in the same group have similar chemical properties.

C: The electronic configuration of atoms can be deduced from the Periodic Table.

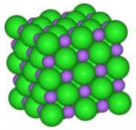
D: The properties of substances can be deduced from the position of the elements in the Periodic Table.

E: Noble gases are found in group 18 and have a full electron shell.

The most important one is: ……
Reason for my choice:
I will use it in teaching in the following way:

Personal code:

4.2 In a class test learners were asked to explain ionic bonding in a sodium chloride crystal lattice. The following answers are from learner scripts. Each answer contains a misconception or incorrect statement.



Identify and **explain** the problem with each statement.

Statement from the learner	Identify and explain the problem with each statement.
A chloride ion is attracted to one sodium ion by a bond and is attracted to up to five other sodium ions just by forces.	
An ionic bond is when one atom donates an electron to another atom, so that they both have full outer shells.	
Sodium chloride molecules form large crystal structures which cannot conduct electricity.	

Personal code:

Section 5: Conceptual teaching strategies

5.1 During a lesson, a learner asks the following question:

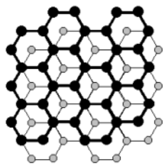
He read on the internet that beryllium bromide ($BeBr_2$) forms an ionic bond because it is a bond between a metal and a non-metal. However, the Periodic Table shows the electronegativity difference between the atoms as 1.3, which makes the bond a covalent bond, according to the rule they have learned in class: 1,3 is less than 1,7, the 'cut-off value' for ionic bonds. Which type of bond is formed in beryllium bromide?

H 2.1									He
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.[illegible]	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.[illegible]	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6

How would you teach about this in a lesson? Consider the following in your response: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

Personal code:

5.2 In a lesson to show the links between the properties of materials and chemical bonding, a teacher uses the diagram on the right to explain why graphite is a good material to use in pencil 'lead':



'Graphite is made of carbon atoms arranged in six-membered rings and packed in layers. It is a good material to use in pencils because the layers can easily slide over each other.'

Despite the explanation the teacher finds that the learners still struggle to understand the links between this property, the structure of graphite and the chemical bonds involved.

How would you teach this lesson? Consider the following in your answer: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

Personal code:

Chemical Bonding Content Knowledge

Question 1: For each of the questions below, choose an option from A or B, and a reason for your choice from 1, 2, 3 or 4. Circle your answer in the space provided, e.g.

A	(B)	1	2	3	(4)

1.1 Sodium chloride exists as a molecule.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.
2. After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chlorine ion.
3. Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.
4. Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

My answer is:

A	B	1	2	3	4

1.2 Element C (electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$) and element E (electronic configuration $1s^2 2s^2 2p^5$) react to form an ionic compound CE_2.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. The atom of C will share one pair of electrons with each atom of E to form a covalent molecule CE_2.
2. A macromolecule is produced consisting of covalently bonded atoms of C and E.
3. An atom of C will lose one electron to an atom of E to form an ionic compound CE.
4. Atoms of C will each lose two electrons and twice as many atoms of E will each gain one electron to form an ionic compound CE_2.

My answer is:

A	B	1	2	3	4

1.3 Metals are hard and strong because the forces which keep the metal atoms together are strong.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. Metallic bonding in a metal is a sea of electrons in between positive nuclei and not a force.
2. Metal atoms are tightly packed which gives the metal properties such as hardness and strength.
3. Metals consist of overlapping orbitals with delocalised valence electrons which are attracted to positively charged nuclei in all directions.
4. The electrons in a metal are free to move and the layers of atoms can easily slide over each other.

My answer is:

A	B	1	2	3	4

Personal code:

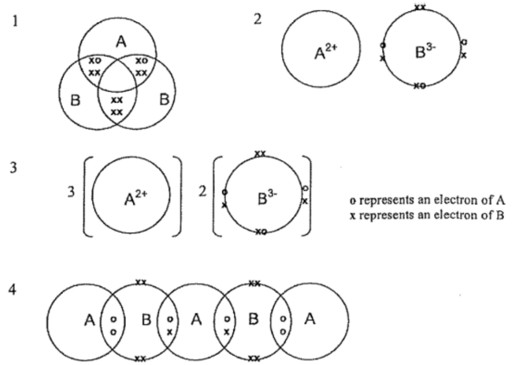
1.4 Graphite can conduct electricity because it has delocalised electrons.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. Only three of the four valence electrons of a carbon atom are involved in bonding and the fourth electron is delocalised.
2. Electrons escape from the covalent bonds in graphite and are free to move within the molecule.
3. Graphite can conduct electricity because it has layers of carbon atoms that can slip over each other.
4. Graphite can conduct electricity because in graphite some carbon atoms are delocalised and they conduct electricity.

My answer is: | A B | 1 2 3 4 |

1.5 An atom of element A has two electrons in its outermost shell while an atom of element B has five electrons in its outermost shell. When A reacts with B, the compound will be …
- A COVALENT
- B IONIC

My reason for choosing A or B is:



My answer is: | A B | 1 2 3 4 |

Personal code:

Question 2:

2.1 What is a chemical bond?

2.2 Draw a detailed picture to illustrate your answer in 2.1 above.

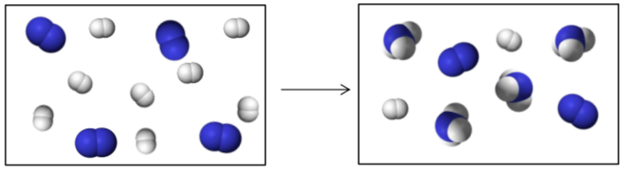
2.3 Why do atoms bond with each other?

2.4 Can the bond between two atoms have both covalent and ionic character? Explain your answer.

Personal code:

Question 3

The diagrams below represent the formation of ammonia gas ( ) from nitrogen gas ( ) and hydrogen gas ( ).



3.1 Write a balanced chemical equation for the reaction.

3.2 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

3.3 Describe how the bond mentioned in 3.2 formed?

3.4 Redraw one of the ammonia molecules to clearly show the electron distribution (valence and core electrons) in the molecule.

Personal code:

Question 4

Aluminium is often used in foil in the catering industry.

4.1 What is the name of the type of bonding between the atoms in a piece of aluminium?

4.2 Describe how the bond mentioned in 4.1 is formed.

4.3 Aluminium is malleable, ductile and conducts electricity. Based on the type of bonding you described in 4.2, explain **one** of these properties of aluminium.

Personal code:

Question 5

5.1 What kind of bond is formed when magnesium metal and bromine gas combine to form magnesium bromide? Describe how this bond is formed using Lewis diagrams.

5.2 Explain why solid magnesium bromide has a high melting point (711°C).

5.3 What is the difference between molecular network solids and ionic network solids? **Provide examples** of each.

THE END

Thank you for completing this questionnaire.

Appendix 16 **Interview protocol for content experts RG3 and RG4**

Interview with ___________________ on ______________________

Thank you for doing this interview.

<u>Teaching experience</u>

Can you tell me about your chemistry training and teaching experience (specifically with regards to chemical bonding)?

<u>Bonding</u>

How do you conceptualise a chemical bond?

How do you think students conceptualise a chemical bond?

What prior knowledge is needed for bonding? Do students have this?

Do you find that students are well-prepared, conceptually, for this section?

Which aspects of bonding do the students find difficult to grasp?

What do you consider the big idea(s) in chemical bonding?

Which aspects of bonding are most difficult to teach? Why? Have you found ways to effectively teach this?

Which misconceptions about bonding have you come across? Which of these are problematic for understanding bonding? (What makes them problematic?) Do you have ways to overcome these misconceptions? Explain.

Which representations do you use? Which of them do students struggle with? Which do you find particularly useful - why?

Conceptually, how does bonding fit into the domain of chemistry?

What do you think should be taught at school level, and what should be left for further studies in chemistry?

Appendix 17 Memorandum for the CK items

Personal code:

Chemical Bonding Content Knowledge

Question 1: For each of the questions below, choose an option from A or B, and a reason for your choice from 1, 2, 3 or 4. Circle your answer in the space provided, e.g. | A | (B) | 1 | 2 | 3 | (4) |

1.1 Sodium chloride exists as a molecule.
- A TRUE
- B FALSE

B3

My reason for choosing A or B is:
1. The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.
2. After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chlorine ion.
3. Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.
4. Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

My answer is: | A | (B) ✓ | 1 | 2 | (3) ✓ | 4 | (2)

1.2 Element C (electronic configuration $1s^22s^22p^63s^23p^64s^2$) and element E (electronic configuration $1s^22s^22p^5$) react to form an ionic compound CE_2.
- A TRUE
- B FALSE

A4

My reason for choosing A or B is:
1. The atom of C will share one pair of electrons with each atom of E to form a covalent molecule CE_2.
2. A macromolecule is produced consisting of covalently bonded atoms of C and E.
3. An atom of C will lose one electron to an atom of E to form an ionic compound CE.
4. Atoms of C will each lose two electrons and twice as many atoms of E will each gain one electron to form an ionic compound CE_2.

My answer is: | (A) ✓ | B | 1 | 2 | 3 | (4) ✓ | (2)

1.3 Metals are hard and strong because the forces which keep the metal atoms together are strong.
- A TRUE
- B FALSE

A3

My reason for choosing A or B is:
1. Metallic bonding in a metal is a sea of electrons in between positive nuclei and not a force.
2. Metal atoms are tightly packed which gives the metal properties such as hardness and strength.
3. Metals consist of overlapping orbitals with delocalised valence electrons which are attracted to positively charged nuclei in all directions.
4. The electrons in a metal are free to move and the layers of atoms can easily slide over each other.

My answer is: | (A) ✓ | B | 1 | 2 | (3) ✓ | 4 | (2)

1

Chemical Bonding Research Project

Personal code:

1.4 Graphite can conduct electricity because it has delocalised electrons.
- A TRUE
- B FALSE

A1

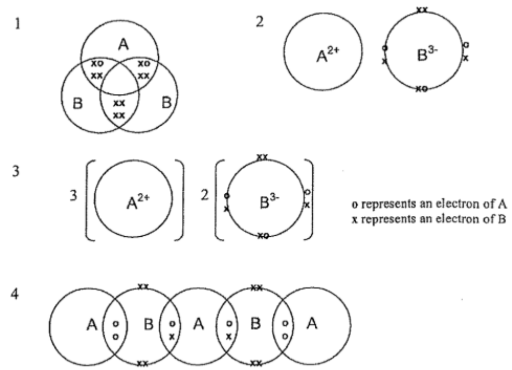
My reason for choosing A or B is:
1. Only three of the four valence electrons of a carbon atom are involved in bonding and the fourth electron is delocalised.
2. Electrons escape from the covalent bonds in graphite and are free to move within the molecule.
3. Graphite can conduct electricity because it has layers of carbon atoms that can slip over each other.
4. Graphite can conduct electricity because in graphite some carbon atoms are delocalised and they conduct electricity.

My answer is: | (A) ✓ | B | (1) ✓ | 2 | 3 | 4 | (2)

1.5 An atom of element A has two electrons in its outermost shell while an atom of element B has five electrons in its outermost shell. When A reacts with B, the compound will be …
- A COVALENT
- B IONIC

B3

My reason for choosing A or B is:



My answer is: | A | (B) ✓ | 1 | 2 | (3) ✓ | 4 | (2)

[10]

2

Chemical Bonding Research Project

Personal code: memo

Question 2:

2.1 What is a chemical bond?

Electrostatic force of attraction/interaction between a proton/positive charge and an electron/negative charge (3)

2.2 Draw a detailed picture to illustrate your answer in 2.1 above.

✓ force is shown accurately
✓ charges are shown
✓ clear where the force(s) are acting (3)

2.3 Why do atoms bond with each other?

To create stability ✓✓ / form a compound at lower energy (2)

2.4 Can the bond between two atoms have both covalent and ionic character? Explain your answer.

Yes, all bonds are both covalent and ionic. Classification as ionic or covalent is only an indication of which is more characteristic.
✓ explanation correct (2)

[10]

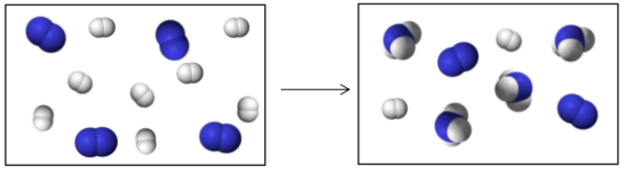
3

Chemical Bonding Research Project

Personal code: memo

Question 3

The diagrams below represent the formation of ammonia gas ( ) from nitrogen gas ( ) and hydrogen gas ( ).



3.1 Write a balanced chemical equation for the reaction.

$N_2 + 3H_2 \rightarrow 2NH_3$ ✓✓ balanced (2) → or ⇌

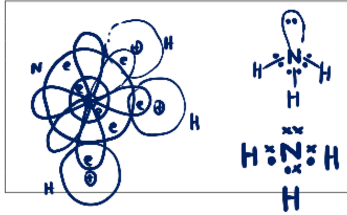
3.2 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

polar ✓ covalent ✓ (2)

3.3 Describe how the bond mentioned in 3.2 formed?

Unequal ✓ sharing / N higher e^- negativity ✓ / e^- pair ✓ lie closer to N (3)

3.4 Redraw one of the ammonia molecules to clearly show the electron distribution (valence and core electrons) in the molecule.



✓ unequal sharing shown clearly electrons closer to nitrogen
✓ clearly shown that core electrons do not take part in bonding
✓ (3)

[10]

4

Chemical Bonding Research Project

Personal code: memo

Question 4

Aluminium is often used in foil in the catering industry.

4.1 What is the name of the type of bonding between the atoms in a piece of aluminium?

metallic bonding ✓✓ (2)

4.2 Describe how the bond mentioned in 4.1 is formed.

metal atoms tightly packed ✓
valence orbitals overlap / electrons are delocalised
valence electrons are shared by all the ✓ metal atoms
Strong attraction ✓ between valence electrons and positive ✓ nuclei in the metal

(4)

4.3 Aluminium is malleable, ductile and conducts electricity. Based on the type of bonding you described in 4.2, explain **one** of these properties of aluminium.

positive nuclei tightly ✓ packed in lattice structure
delocalised electrons

Malleable / Ductile { metal atoms are packed in ✓ layers, layers can easily ✓ slide over each other to ✓ form wires or sheets

OR

Conducts electricity: delocalised ✓ valence e⁻ are free to ✓ move and carry energy

(4)

[10]

Chemical Bonding Research Project

Personal code: memo

Question 5

5.1 What kind of bond is formed when magnesium metal and bromine gas combine to form magnesium bromide? Describe how this bond is formed using Lewis diagrams.

Ionic bond

$Mg: \rightarrow Mg^{2+} + 2e^-$ Mg atom loses ✓ two electrons to form Mg ion

$2:\ddot{Br}\cdot + 2e^- \rightarrow 2[:\ddot{Br}:]^-$ Two Br atoms accepts one ✓ e^- each to form Br^- ions

$Mg^{2+} + 2Br^- \rightarrow MgBr_2$ Mg^{2+} is attracted ✓ to Br^- with an electro-static force called an ionic bond

(3)

5.2 Explain why solid magnesium bromide has a high melting point (711°C).

$MgBr_2$ forms network structure (or lattice)
Strong ionic ✓ bonds (or electrostatic forces) between Mg^{2+} ions and Br^- ions in all ✓ directions
Lots of energy ✓ needed to break ionic bonds therefore high melting point

(3)

5.3 What is the difference between molecular network solids and ionic network solids? **Provide examples** of each.

Molecular network solids consist of ✓ molecules
eg ice ✓ or any other example

Ionic network solid consist of ions ✓
eg NaCl ✓ or any other example

(4) [10]

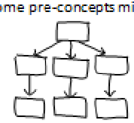
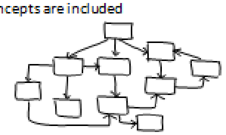
THE END

Thank you for completing this questionnaire.

[50]

Appendix 18 Rubric for TSPCK responses

Rubric for Quantifying TSPCK of Chemical Bonding

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
Represen-tations REP	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for <u>none</u> or <u>one</u> of the representations. [If the description is detailed, then code as 2.]	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for <u>two</u> or <u>three</u> of the representations. [If the description is detailed, then code as 3.]	1.1 Strengths and weaknesses • Able to identify strengths and weaknesses for <u>four</u> or <u>five</u> of the representations [If the description is very detailed, then code as 4.] • Reasonable reasons without going into specifics (for example terms such as 'abstract', 'limitation/limited', 'confusion' are used]	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for all six representations • Appropriate reasons are provided for most representations • Aware of misconceptions being introduced, e.g anthropomorphism	1.1	REP1
	1.2a Reason for choice • Reason for choice is inappropriate, incomplete, vague or difficult to follow	1.2a Reason for choice • Reason for choice is appropriate, but limited to a single consideration	1.2a Reason for choice • Reasons for choice include two or more levels of consideration, e.g. ease of use, effectiveness to confront misconception, learner context, explanatory power • Links to the concept are clear and appropriate	1.2a Reason for choice • Reasons for choice include more than two levels of consideration as well as limitations of the representation • Links to the concept under discussion are clear and appropriate and includes connections to further concepts	1.2a	REP2
	1.2b Use in lesson • No discussion on how the representation is going to be used or suggested use inappropriate or unworkable	1.2b Use in lesson • Suggested procedure lacks logic or clarity or is limited • Teaching approach is basic and does not include a conceptual orientation	1.2b Use in lesson • Suggested procedure shows logic and a satisfactory explanation on how the chosen representation is going to be used • There is some evidence of a conceptual orientation to the teaching approach	1.2b Use in lesson • Suggested procedure is clear, logical and shows strong conceptual orientation • Use of the representation contributes to understanding and links to further teaching.	1.2b	REP3
Curricular Saliency CS	2.1 Big Ideas • Identifies none or one big idea from B C D E G I Other choices include A F H J K 2.2 Reasons for choice • Illogical sequencing of ideas provided • No reasons provided or reasons are inappropriate	2.1 Big Ideas • Identifies two big ideas from B C D E G I 2.2 Reasons for choice • Logical sequencing of the ideas provided • Reasons are provided, but are limited, for example 'the curriculum requires it'	2.1 Big Ideas • Identifies three big ideas from B C D E G I 2.2 Reasons for choice • Logical sequencing of the ideas provided • Reasons provided are appropriate	2.1 Big Ideas • Identifies three big ideas from B E G 2.2 Reasons for choice • Logical sequencing of the ideas provided • Reasons provided are appropriate and include links to prior knowledge or follow-up concepts	2.1 & 2.2	CS1
	2.3 Map • No sub-ordinate ideas are included in the mind map • Sequencing cannot be followed and ideas are illogically placed	2.3 Map • Not all big ideas have sub-ordinate ideas however, those identified are correct • Sequencing can be followed but some ideas are illogically placed • A very basic map is drawn e.g. 	2.3 Map • All big ideas have sub-ordinate ideas • Sequencing can be followed and all ideas follow a logical order • Some cross-links might be included • Some pre-concepts might be included e.g. 	2.3 Map • All big ideas have sub-ordinate ideas and follow a logical order • Uses only big ideas as starting point • Appropriate cross links are included • Pre-concepts are included e.g. 	2.3	CS2
	2.4 Importance to learn • Reasons given for importance of topic limited to general benefit of education e.g everyday life, chemical bonds are everywhere	2.4 Importance to learn • Reasons given may include general interest, everyday life applications or importance for examination purposes, but exclude conceptual considerations.	2.4 Importance to learn • Reasons given may include general interest, everyday life applications or importance for examination purposes. • Reasons include conceptual considerations/ scaffolding/sequential development of understanding of other topics in the subject without specifying the topics.	2.4 Importance to learn • Reasons given may include general interest, everyday life applications or importance for examination purposes. • Reasons include conceptual scaffolding/sequential development of understanding for specified subsequent topics in the subject.	2.4	CS3

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
What makes topic difficult to teach WDT	3.1 & 3.2 & 3.3 • Reasons not given or not applicable	3.1 & 3.2 & 3.3 • Reasons given are broad or generic and not linked to the specific concept under discussion, for example 'abstract' or 'the learners don't understand'	3.1 & 3.2 & 3.3 • Reasons given are specific and related to prior knowledge of students or common misconceptions	3.1 & 3.2 & 3.3 • Reasons given are specific and related to prior knowledge of students or common misconceptions • Reasons given link the concept with other gatekeeping concepts that when not fully understood adds to the difficulty of the concept regarded as difficult, for example electronegativity linked to polarity of bonds	3.1 3.2 3.3	WDT
Learner Prior Knowledge including Misconceptions LPK	4.1a Choice Preferably choice E 4.1b Reason Reasons for choice not related to prior knowledge 4.1c Teaching Use in teaching not appropriate and not linked to learner responses 4.2 Misconceptions None of the central issues/misconceptions are correctly identified Irrelevant or incorrect explanations supplied	4.1a Choice Preferably choice A 4.1b Reason Reasons are linked to prior knowledge 4.1c Teaching Use in teaching is appropriate and linked to content only, not learner response 4.2 Misconceptions One of the central issues/misconceptions correctly identified Explanations are provided but are generic or vague, e.g. 'the learners find it difficult'	4.1a Choice Preferably choice B or D 4.1b Reason Reasons are linked to prior knowledge and to bonding 4.1c Teaching Use in teaching is appropriate and linked to content and learner responses 4.2 Misconceptions Two of the central issues/misconceptions correctly identified Explanations are relevant and appropriate but some are incomplete	4.1a Choice Preferably choice C 4.1b Reason Reasons are linked to prior knowledge, bonding and includes that it is essential for understanding further concepts 4.1c Teaching Use in teaching is extensive, focused on understanding, linked to content and learner responses 4.2 Misconceptions Three of the central issues/misconceptions correctly identified Explanations are accurate and captures the essence of the problem	4.1 4.2	CS
Conceptual teaching strategies CTS	5.1 & 5.2 • Lacks aspects of curriculum saliency • No evidence of acknowledgement of learner prior knowledge • Use only one level of representation • Suggested strategy is largely teacher-centered	5.1 & 5.2 • Overall a very basic strategy. • Limited consideration of learner prior knowledge • Lacks aspects of curriculum saliency • Use only one level of representations • Limited involvement of learners	5.1 & 5.2 • Overall, strategy workable • Some consideration of learner prior knowledge • Some evidence of curricular saliency • Uses at least two different levels of representations • There is some evidence of encouraged learner involvement	5.1 & 5.2 • Overall , excellent strategy to teach required concept • Considers confirmation/confrontation of student prior knowledge • Strong evidence of curricular saliency • Uses multiple representations with the purpose of promoting understanding • Highly learner centered lesson	5.1 & 5.2	CTS

Appendix 19 **Demographic information page**

Personal code:

Chemical Bonding Research Project

This information is for research purposes only: your responses will be treated confidentially. *This page will be detached and stored separately*. Your information will not be shared with anyone who is not directly involved in this project.

General information

Surname:	
Name:	
Gender:	Male / Female
Province:	
Home province:	
Home town:	
Type of school you are currently teaching at: Rural / Township / Ex-model C / Private	
Cell number:	

Physical Sciences teaching experience

Subject & Grade	**Number of years teaching experience**	**Which years (e.g. 2005-2010)**
Phys Sci Gr 12		
Phys Sci Gr 11		
Phys Sci Gr 10		
Nat Sci Gr 9		
Nat Sci Gr 8		
What other subjects and grades do you currently teach? ________________		
Email address:		

Which do you prefer to teach? (Please circle.) **Chemistry / Physics / I like teaching them equally.**

Do you still have your old teaching files, lesson plans or other resources (e.g notes, worksheets, planning, etc.)? (Please circle.) **Yes / No**

Which textbook are you currently using for Grade 10? ________________________________

In which country and province did you matriculate? ________________________________

Qualifications Please complete the following table:

Degree and Diploma (e.g. BSc, HDE, PGCE)	Where did you obtain it?	Main Subjects	Year completed

Professional development Have you been part of any professional development activities which focused on chemistry content or chemistry teaching?

Name of the activity	Who organised it? (e.g. school, district, online course)	What content was covered?	How useful was it? (Please circle, 1=not at all, 5= extremely useful)
			1 2 3 4 5
			1 2 3 4 5

1

Appendix 20 **Letter of consent**

University of Cape Town

Private Bag X3 · Rondebosch · 7701 · South Africa
Website: www.uct.ac.za

Informed consent to participate in a research project

Project Title: Mapping the learning trajectories of Physical Sciences teachers' topic specific knowledge for teaching chemical bonding

Invitation to Participate:
You are invited to participate in a large scale research study conducted with FET Physical Sciences teachers. The study aims to measure the unique knowledge that teachers use to assist learners to understand chemical bonding. I believe that your experience as a practicing teacher would be a very valuable source of information to the study, in turn by participating you may gain considerable knowledge useful to your teaching practices.

Procedures:
During this study, you will be asked to complete a questionnaire which focuses on content knowledge and knowledge for teaching chemical bonding. Your response will provide insight about teaching. As a result of your participation, your own awareness about science teaching in chemical bonding may be increased. Please complete the questionnaire without the aid of a text book or consultation with another teacher. I am also requesting that you do not copy the questionnaires or share the contents with other teachers.

Risks:
There are no potentially harmful risks related to participating in this study.

Disclaimer/Withdrawal:
Your participation is completely voluntary and you may withdraw at any time without any prejudice or penalty against you.

Confidentiality:
All information collected in this study will be kept private and you will not be identified by name. Confidentiality and anonymity will be maintained as pseudonyms will be used.

What signing this form means:
By signing this consent form, you agree to participate in this research project. You can refuse to participate or withdraw from this research project at any time. Refusal to participate in or withdrawal from this study will have no effect on you in any way, whatsoever.

I agree to complete the questionnaire (please tick): **YES** **NO**

Name of participant	Signature of participant	Date

René Toerien	signature removed
Name of researcher	Signature of researcher

"Our mission is to be an outstanding teaching and research university, educating for life and addressing the challenges facing our society."

Appendix 21 **Codes from moderation process**

CK Items	T11 Researcher	T11 Moderator	T14 Researcher	T14 Moderator	T16 Researcher	T16 Moderator
CK1.1	1	1	2	2	2	2
CK1.2	1	1	2	2	2	2
CK1.3	1	1	1	2	2	2
CK1.4	0	0	2	2	1	1
CK1.5	1	1	2	2	2	2
CK2.1	1	1	2	3	2	3
CK2.2	0	0	0	3	3	3
CK2.3	2	0	2	2	2	2
CK2.4	0	0	0	2	2	2
CK3.1	2	2	2	2	2	2
CK3.2	1	1	1	1	1	1
CK3.3	1	1	2	1	3	3
CK3.4	2	1	0	2	3	3
CK4.1	2	2	2	2	2	2
CK4.2	2	2	3	4	3	3
CK4.3	0	0	1	4	4	4
CK5.1	0	0	1	2	2	3
CK5.2	1	2	2	3	1	1
CK5.3	0	0	4	4	4	4

TSPCK Items	T11 Researcher	T11 Moderator	T14 Researcher	T14 Moderator	T16 Researcher	T16 Moderator
REP1	2	2	3	4	4	4
REP2	2	2	3	2	4	4
REP3	2	1	3	3	4	4
CS0	3	3	3	3	3	3
CS1	3	2	3	3	4	4
CS2	2	2	2	3	4	3
CS3	2	2	1	3	3	3
WDT	2	2	3	3	3	3
LPK0	2	2	3	3	4	4
LPK1	1	2	3	3	4	4
LPK2	3	2	3	3	4	4
LPK3	2	1	2	2	4	3
CTS1	1	1	3	3	4	4
CTS2	1	1	3	4	3	3

Appendix 22 **ReCal output for coding moderation**

ReCal 0.1 Alpha for 2 Coders
results for file "Ch4 Inter rater reliability.csv"

File size:	495 bytes
N columns:	2
N variables:	1
N coders per variable:	2

	Percent Agreement	Scott's Pi	Cohen's Kappa	Krippendorff's Alpha (nominal)	N Agreements	N Disagreements	N Cases	N Decisions
Variable 1 (cols 1 & 2)	78.8%	0.719	0.719	0.72	78	21	99	198

Source: http://dfreelon.org/recal/recal2.php

Appendix 23 **Gender DIF table**

DIF class specification is: DIF=@GENDER

PERSON CLASS	OBSERVATIONS COUNT	OBSERVATIONS AVERAGE	BASELINE EXPECT	BASELINE MEASURE	DIF SCORE	DIF MEASURE	DIF SIZE	DIF S.E.	DIF t	Prob.	ITEM Number	Name
F	10	1.60	1.63	1.97	-.03	2.06	.09	.55	.16	.8741	1	CK1.1
M	7	1.71	1.67	1.97	.04	1.85	-.12	.65	-.19	.8576	1	CK1.1
F	10	1.50	1.57	2.14	-.07	2.36	.21	.55	.39	.7062	2	CK1.2
M	7	1.71	1.61	2.14	.10	1.85	-.30	.65	-.46	.6649	2	CK1.2
F	10	1.20	1.16	3.39	.04	3.25	-.13	.55	-.25	.8123	3	CK1.3
M	7	1.14	1.21	3.39	-.07	3.60	.21	.67	.31	.7656	3	CK1.3
F	10	1.50	1.57	2.14	-.07	2.36	.21	.55	.39	.7062	4	CK1.4
M	7	1.71	1.61	2.14	.10	1.85	-.30	.65	-.46	.6649	4	CK1.4
F	10	1.60	1.57	2.14	.03	2.06	-.09	.55	-.16	.8796	5	CK1.5
M	7	1.57	1.61	2.14	-.04	2.27	.13	.66	.19	.8546	5	CK1.5
F	10	3.00	2.98	-1.83	.02	-1.89	-.05	.53	-.10	.9209	6	CK2.1
M	7	3.00	3.02	-1.83	-.02	-1.76	.07	.66	.11	.9157	6	CK2.1
F	10	1.60	1.63	1.97	-.03	2.06	.09	.55	.16	.8741	7	CK2.3
M	7	1.71	1.67	1.97	.04	1.85	-.12	.65	-.19	.8576	7	CK2.3
F	10	2.00	1.75	1.62	.25	.87	-.75	.54	-1.39	.2022	8	CK2.4
M	7	1.43	1.79	1.62	-.36	2.70	1.08	.66	1.64	.1626	8	CK2.4
F	10	2.70	2.62	-.84	.08	-1.06	-.21	.52	-.41	.6898	9	CK3.3
M	7	2.57	2.68	-.84	-.11	-.54	.31	.63	.49	.6445	9	CK3.3
F	10	2.50	2.62	-.84	-.12	-.52	.32	.52	.62	.5510	10	CK4.2
M	7	2.86	2.68	-.84	.17	-1.33	-.49	.64	-.77	.4782	10	CK4.2
F	10	2.50	2.50	-.52	.00	-.52	.00	.52	.00	1.000	11	CK4.3
M	7	2.57	2.57	-.52	.00	-.52	.00	.63	.00	1.000	11	CK4.3
F	10	2.30	2.15	.44	.15	.02	-.42	.53	-.80	.4493	12	CK5.1
M	7	2.00	2.21	.44	-.21	1.03	.59	.63	.93	.3943	12	CK5.1
F	10	1.70	1.92	1.11	-.22	1.76	.65	.55	1.19	.2680	13	CK5.2
M	7	2.29	1.97	1.11	.31	.24	-.87	.62	-1.39	.2243	13	CK5.2
F	10	3.30	3.29	-2.76	.01	-2.80	-.05	.58	-.08	.9394	14	REP1
M	7	3.29	3.30	-2.76	-.02	-2.70	.06	.72	.08	.9398	14	REP1
F	10	2.70	2.86	-1.49	-.16	-1.06	.43	.52	.84	.4269	15	REP2
M	7	3.14	2.91	-1.49	.23	-2.21	-.72	.68	-1.05	.3424	15	REP2
F	10	2.70	2.80	-1.33	-.10	-1.06	.27	.52	.52	.6176	16	REP3
M	7	3.00	2.85	-1.33	.15	-1.76	-.43	.66	-.65	.5432	16	REP3
F	10	3.20	2.92	-1.66	.28	-2.48	-.82	.56	-1.47	.1787	17	CS1
M	7	2.57	2.97	-1.66	-.40	-.54	1.12	.63	1.79	.1327	17	CS1
F	10	2.70	2.56	-.68	.14	-1.06	-.37	.52	-.72	.4913	18	CS2
M	7	2.43	2.63	-.68	-.20	-.15	.54	.62	.86	.4288	18	CS2
F	10	2.70	2.86	-1.49	-.16	-1.06	.43	.52	.84	.4269	19	CS3
M	7	3.14	2.91	-1.49	.23	-2.21	-.72	.68	-1.05	.3424	19	CS3
F	10	2.70	2.80	-1.33	-.10	-1.06	.27	.52	.52	.6176	20	WDT
M	7	3.00	2.85	-1.33	.15	-1.76	-.43	.66	-.65	.5432	20	WDT
F	10	2.70	2.50	-.52	.20	-1.06	-.53	.52	-1.03	.3340	21	LPK1
M	7	2.29	2.57	-.52	-.28	.24	.77	.62	1.23	.2744	21	LPK1
F	10	2.40	2.44	-.37	-.04	-.25	.12	.52	.22	.8303	22	LPK2
M	7	2.57	2.51	-.37	.06	-.54	-.17	.63	-.27	.7947	22	LPK2
F	10	2.50	2.50	-.52	.00	-.52	.00	.52	.00	1.000	23	LPK3
M	7	2.57	2.57	-.52	.00	-.52	.00	.63	.00	1.000	23	LPK3
F	10	2.30	2.27	.12	.03	.02	-.09	.53	-.18	.8653	24	CTS1
M	7	2.29	2.33	.12	-.05	.24	.13	.62	.20	.8482	24	CTS1
F	10	2.50	2.62	-.84	-.12	-.52	.32	.52	.62	.5510	25	CTS2
M	7	2.86	2.68	-.84	.17	-1.33	-.49	.64	-.77	.4782	25	CTS2

Appendix 24 **Province DIF table**

DIF class specification is: DIF=@PROVINCE

PERSON CLASS	OBSERVATIONS COUNT	OBSERVATIONS AVERAGE	BASELINE EXPECT	BASELINE MEASURE	DIF SCORE	DIF MEASURE	DIF SIZE	DIF S.E.	DIF t	Prob.	ITEM Number	Name
GP	6	1.83	1.75	1.97	.08	1.71	-.26	.71	-.36	.7367	1	CK1.1
WC	11	1.55	1.59	1.97	-.05	2.10	.14	.51	.26	.7986	1	CK1.1
GP	6	1.67	1.69	2.14	-.03	2.23	.08	.72	.12	.9137	2	CK1.2
WC	11	1.55	1.53	2.14	.01	2.10	-.04	.51	-.08	.9401	2	CK1.2
GP	6	1.17	1.30	3.39	-.14	3.83	.44	.73	.61	.5776	3	CK1.3
WC	11	1.18	1.11	3.39	.07	3.17	-.22	.52	-.42	.6830	3	CK1.3
GP	6	1.50	1.69	2.14	-.19	2.76	.62	.73	.84	.4478	4	CK1.4
WC	11	1.64	1.53	2.14	.10	1.84	-.30	.51	-.59	.5684	4	CK1.4
GP	6	1.83	1.69	2.14	.14	1.71	-.43	.71	-.61	.5760	5	CK1.5
WC	11	1.45	1.53	2.14	-.08	2.37	.23	.52	.44	.6720	5	CK1.5
GP	6	3.00	3.13	-1.83	-.13	-1.45	.38	.69	.56	.6057	6	CK2.1
WC	11	3.00	2.93	-1.83	.07	-2.04	-.21	.51	-.41	.6913	6	CK2.1
GP	6	2.00	1.75	1.97	.25	1.22	-.74	.69	-1.08	.3410	7	CK2.3
WC	11	1.45	1.59	1.97	-.14	2.37	.40	.52	.78	.4568	7	CK2.3
GP	6	1.50	1.86	1.62	-.36	2.76	1.14	.73	1.56	.1949	8	CK2.4
WC	11	1.91	1.71	1.62	.20	1.04	-.58	.51	-1.12	.2903	8	CK2.4
GP	6	2.50	2.78	-.84	-.28	-.12	.72	.66	1.10	.3326	9	CK3.3
WC	11	2.73	2.57	-.84	.15	-1.27	-.43	.50	-.85	.4187	9	CK3.3
GP	6	3.17	2.78	-.84	.39	-1.94	-1.10	.72	-1.53	.2001	10	CK4.2
WC	11	2.36	2.57	-.84	-.21	-.26	.58	.50	1.16	.2767	10	CK4.2
GP	6	2.83	2.66	-.52	.18	-.99	-.46	.67	-.70	.5248	11	CK4.3
WC	11	2.36	2.46	-.52	-.10	-.26	.27	.50	.53	.6117	11	CK4.3
GP	6	2.00	2.29	.44	-.29	1.22	.78	.69	1.14	.3191	12	CK5.1
WC	11	2.27	2.12	.44	.16	.00	-.45	.51	-.88	.4028	12	CK5.1
GP	6	2.17	2.04	1.11	.13	.76	-.35	.67	-.52	.6330	13	CK5.2
WC	11	1.82	1.89	1.11	-.07	1.31	.20	.52	.39	.7072	13	CK5.2
GP	6	3.50	3.40	-2.76	.10	-3.21	-.45	.88	-.52	.6331	14	REP1
WC	11	3.18	3.24	-2.76	-.05	-2.59	.17	.53	.32	.7538	14	REP1
GP	6	3.17	3.02	-1.49	.15	-1.95	-.45	.73	-.62	.5665	15	REP2
WC	11	2.73	2.81	-1.49	-.08	-1.27	.22	.50	.44	.6676	15	REP2
GP	6	3.00	2.96	-1.33	.04	-1.45	-.12	.69	-.17	.8718	16	REP3
WC	11	2.73	2.75	-1.33	-.02	-1.27	.06	.50	.12	.9102	16	REP3
GP	6	2.83	3.07	-1.66	-.24	-.99	.67	.67	1.01	.3698	17	CS1
WC	11	3.00	2.87	-1.66	.13	-2.04	-.38	.51	-.74	.4768	17	CS1
GP	6	2.67	2.72	-.68	-.05	-.55	.13	.66	.20	.8499	18	CS2
WC	11	2.55	2.52	-.68	.03	-.77	-.08	.50	-.16	.8746	18	CS2
GP	6	2.83	3.02	-1.49	-.18	-.99	.50	.67	.76	.4911	19	CS3
WC	11	2.91	2.81	-1.49	.10	-1.78	-.29	.51	-.57	.5856	19	CS3
GP	6	3.00	2.96	-1.33	.04	-1.45	-.12	.69	-.17	.8718	20	WDT
WC	11	2.73	2.75	-1.33	-.02	-1.27	.06	.50	.12	.9102	20	WDT
GP	6	2.67	2.66	-.52	.01	-.55	-.03	.66	-.04	.9696	21	LPK1
WC	11	2.45	2.46	-.52	.00	-.52	.00	.50	.00	1.000	21	LPK1
GP	6	3.00	2.59	-.37	.41	-1.45	-1.08	.68	-1.58	.1892	22	LPK2
WC	11	2.18	2.40	-.37	-.22	.26	.62	.51	1.22	.2543	22	LPK2
GP	6	2.33	2.66	-.52	-.32	.31	.84	.66	1.27	.2742	23	LPK3
WC	11	2.64	2.46	-.52	.18	-1.02	-.49	.50	-.98	.3519	23	LPK3
GP	6	2.67	2.41	.12	.26	-.55	-.67	.66	-1.01	.3675	24	CTS1
WC	11	2.09	2.23	.12	-.14	.52	.40	.51	.78	.4549	24	CTS1
GP	6	2.83	2.78	-.84	.05	-.99	-.15	.67	-.22	.8384	25	CTS2
WC	11	2.55	2.57	-.84	-.03	-.77	.08	.50	.16	.8798	25	CTS2

Appendix 25 **Final instrument**

Personal code:

Chemical Bonding Research Project

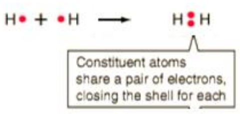
Knowledge for Teaching Chemical Bonding

Section 1: Representations

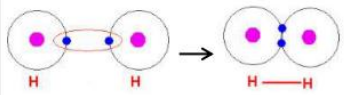
1.1 Chemical bonding is often represented through drawings and diagrams. A few examples of such representations are shown below.

Look at each of the representations and describe what you **like** and what you **don't like** about it as a **tool to teach about chemical bonds** and **why**. Fill in your answers on the next page.

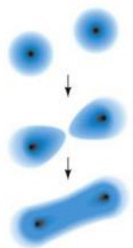
Representation 1



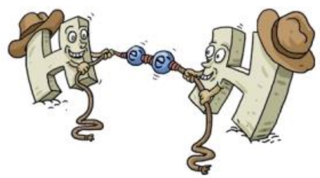
Representation 2



Representation 3



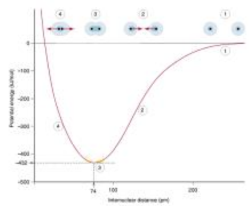
Representation 4



Representation 5

Using the learners in your class to represent chemical bonds as follows:

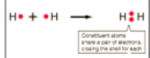
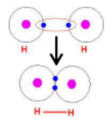
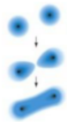
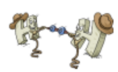
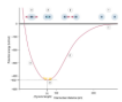
Representation 6



Rene Toerien 2 Chemical Bonding

Personal code:

Chemical Bonding Research Project

	What I **like** and **why** (Strengths of the representation)	What I **don't like** and **why** (Weaknesses of the representation)
Representation 1 		
Representation 2 		
Representation 3 		
Representation 4 		
Representation 5 		
Representation 6 		

Rene Toerien 3 Chemical Bonding

1.2 Which one of above representations did you like the **most**? Describe how you would use it in a lesson in the space provided below. If you did not like any of these, you can draw your own representation below.

The representation I like most is number _______
I did not like any of them, I prefer this one:
I chose this representation because …
In a lesson I would use it as follows:

Section 2: Curricular saliency

A list of some of the big ideas and sub-ordinate ideas in chemical bonding is given below. Big ideas are the ideas that underpin the content and which are **central** in **teaching for understanding** chemical bonding.

A. Ionic bonding takes place when electrons are transferred.
B. The chemical bonds in a substance determine its structure.
C. A chemical bond is an electrostatic interaction between a positive and a negative charge.
D. Energy is required to break bonds and energy is released when bonds are formed.
E. Electronic structure influences how atoms bond.
F. Polar covalent bonding takes place when electrons are shared unequally.
G. Chemical bonds are formed to create stability.
H. Substances may be molecular or network structures.
I. There is a spectrum of electron sharing in chemical bonds.
J. Sodium chloride forms a three-dimensional crystal structure due to ionic bonding.
K. Covalent bonding takes place when electrons are shared equally.

2.1 Select three ideas which you consider to be the **Big Ideas** in chemical bonding.

Idea 1: ____________________

Idea 2: ____________________

Idea 3: ____________________

2.2 Using the three ideas in **2.1**, give the sequence you would teach them in, and your reasons for doing so.

Order of teaching (put the first concept you will teach next to the 1, the second next to the 2, etc.)	Reasons for order of teaching the Big Ideas chosen:
1:	
2:	
3:	

Personal code:

2.3 You are now planning a series of lessons on chemical bonding. Use the three ideas from **2.2**, and any additional ideas you think are appropriate, to **draw a mind map** to show how the **ideas are related**.

2.4 Why is it important for learners to learn about chemical bonding? Provide as many different reasons as possible.

Chemical Bonding Research Project

Personal code:

Section 3: What is difficult to teach?

Some of the concepts in chemical bonding are difficult to teach. Below are some of these concepts listed. Space is also provided for you to fill in your own concepts.

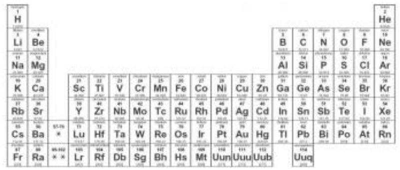
3.1 Give reasons why you think these concepts are **difficult to teach**. Choose any <u>three</u> concepts from the options provided, or your own. Fill in your response in the table below.

	Reasons why I think this is difficult to teach:
Concept 1: Metallic bonding	
Concept 2: Ionic bonding	
Concept 3: Polarity of bonds	

Concept 4: Bond energy	
Concept 5: What is a molecule	
You can fill in your own concepts here:	Reasons why I think this is difficult to teach:
Concept 6:	
Concept 7:	

Section 4: Learners' prior knowledge

4.1 Learners need to know about the Periodic Table before chemical bonding can be taught. Some of the ideas that are discussed in the section on the Periodic Table are shown below. Which one of these is the **most important** when **you teach** about chemical bonding for the **first time**? Give a **reason** for your answer and explain **how you would use it** in your teaching.



A: Metals are on the left hand side and non-metals are on the right hand side of the Periodic Table.

B: Elements in the same group have similar chemical properties.

C: The electronic configuration of atoms can be deduced from the Periodic Table.

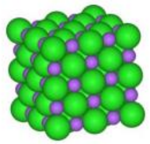
D: The properties of substances can be deduced from the position of the elements in the Periodic Table.

E: Noble gases are found in group 18 and have a full electron shell.

The most important one is: ......
Reason for my choice:
I will use it in teaching in the following way:

Personal code:

4.2 In a class test learners were asked to explain ionic bonding in a sodium chloride crystal lattice. The following answers are from learner scripts. Each answer contains a misconception or incorrect statement.



Identify and **explain** the problem with each statement.

Statement from the learner	Identify the problem with each statement and explain why it is a problem.
A chloride ion is attracted to one sodium ion by a bond and is attracted to up to five other sodium ions just by forces.	
An ionic bond is when one atom donates an electron to another atom, so that they both have full outer shells.	
Sodium chloride molecules form large crystal structures.	

Personal code:

Section 5: Conceptual teaching strategies

5.1 During a lesson, a learner asks the following question:

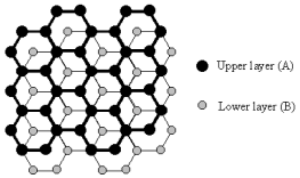
He read on the internet that beryllium bromide ($BeBr_2$) forms an ionic bond because it is a bond between a metal and a non-metal. However, the Periodic Table shows the electronegativity difference between the atoms as 1.3, which makes the bond a covalent bond, according to the rule they have learned in class: 1,3 is less than 1,7, the 'cut-off value' for ionic bonds. Which type of bond is formed in beryllium bromide?

H 2.1									He
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.[illegible]	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.[illegible]	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6

How would you teach about this in a lesson? **Consider the following in your response**: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

5.2 In a lesson to show the links between the properties of materials and chemical bonding, a teacher uses the diagram on the right to explain why graphite is a good material to use in pencil 'lead':

'Graphite is made of carbon atoms arranged in six-membered rings and packed in layers. It is a good material to use in pencils because the layers can easily slide over each other.'



Despite the explanation the teacher finds that the learners still struggle to understand the links between this property, the structure of graphite and the chemical bonds involved.

How would you teach this lesson? **Consider the following in your answer**: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

Chemical Bonding Content Knowledge

Question 1: For each of the questions below, choose an option from A or B, and a reason for your choice from 1, 2, 3 or 4. Circle your answer in the space provided, e.g. | A (B) | 1 2 3 (4) |

1.1 Sodium chloride exists as a molecule.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.
2. After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chlorine ion.
3. Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.
4. Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

My answer is: | A B | 1 2 3 4 |

1.2 Element C (electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$) and element E (electronic configuration $1s^2 2s^2 2p^5$) react to form an ionic compound CE_2.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. The atom of C will share one pair of electrons with each atom of E to form a covalent molecule CE_2.
2. A macromolecule is produced consisting of covalently bonded atoms of C and E.
3. An atom of C will lose one electron to an atom of E to form an ionic compound CE.
4. Atoms of C will each lose two electrons and twice as many atoms of E will each gain one electron to form an ionic compound CE_2.

My answer is: | A B | 1 2 3 4 |

1.3 Metals are strong because the forces which keep the metal atoms together are strong.
- A TRUE
- B FALSE

My reason for choosing A or B is:
1. Metallic bonding in a metal is a sea of electrons in between positive nuclei and not a force.
2. Metal atoms are tightly packed which gives the metal properties such as strength.
3. Metals consist of overlapping orbitals with delocalised valence electrons which are attracted to positively charged nuclei in all directions.
4. The electrons in a metal are free to move and the layers of atoms can easily slide over each other.

My answer is: | A B | 1 2 3 4 |

Personal code:

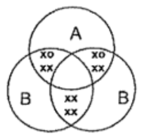
1.4 Graphite can conduct electricity because it has delocalised electrons.
A TRUE
B FALSE

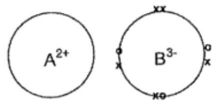
My reason for choosing A or B is:
1. Only three of the four valence electrons of a carbon atom are involved in bonding and the fourth electron is delocalised.
2. Electrons escape from the covalent bonds in graphite and are free to move within the molecule.
3. Graphite can conduct electricity because it has layers of carbon atoms that can slip over each other.
4. Graphite can conduct electricity because in graphite some carbon atoms are delocalised and they conduct electricity.

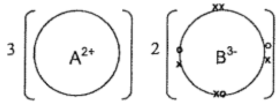
My answer is:	A B	1 2 3 4

1.5 An atom of element A has two electrons in its outermost shell while an atom of element B has five electrons in its outermost shell. When A reacts with B, the compound will be ...
A COVALENT
B IONIC

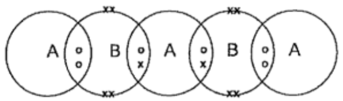
My reason for choosing A or B is:

1


2


3


o represents an electron of A
x represents an electron of B

4


My answer is:	A B	1 2 3 4

Chemical Bonding Research Project

Personal code:

Question 2

2.1 What is a chemical bond?

Draw a detailed picture to illustrate your answer in 2.1 above.

2.2 Why do atoms bond with each other?

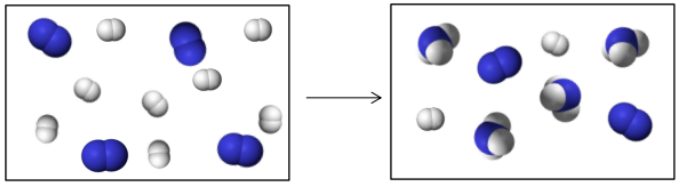
2.3 Can the bond between two atoms have both covalent and ionic character? Explain your answer.

Chemical Bonding Research Project

Personal code:

Question 3

The diagrams below represent the formation of ammonia gas ( ) from nitrogen gas ( ) and hydrogen gas ( ).



3.1 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

____

Describe how the bond mentioned in 3.1 formed?

3.2 Redraw one of the ammonia molecules to clearly show the electron distribution (valence and core electrons) in the molecule.

Chemical Bonding Research Project

Personal code:

Question 4

Aluminium is often used in foil in the catering industry.

4.1 What is the name of the type of bonding between the atoms in a piece of aluminium?

____

Describe how the bond mentioned in 4.1 is formed.

4.2 Aluminium is malleable, ductile and conducts electricity. Based on the type of bonding you described in 4.1, explain **one** of these properties of aluminium.

Personal code:

Question 5

5.1 What kind of bond is formed when magnesium metal and bromine gas combine to form magnesium bromide?

____

Describe how the bond mentioned in 5.1 is formed using Lewis diagrams.

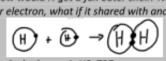
5.2 Explain why solid magnesium bromide has a high melting point (711°C).

THE END

Thank you for completing this questionnaire.

Appendix 26 **Final rubric**

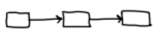
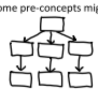
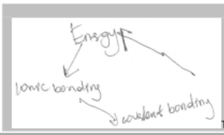
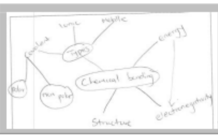
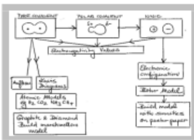
Rubric for Quantifying TSPCK of Chemical Bonding

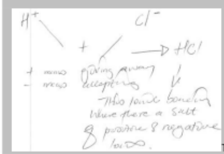
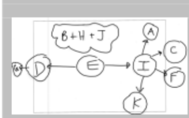
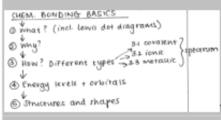
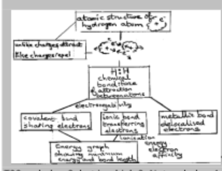
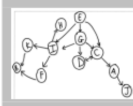
TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
Represen-tations Section 1 REP	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for <u>none</u> or <u>one</u> of the representations (1-3 strengths/weaknesses) [If the description is detailed, then code as 2.] [see next page for examples of appropriate strengths and weaknesses]	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for <u>two</u> or <u>three</u> of the representations (4-7 strengths/weaknesses) [If the description is detailed, then code as 3.]	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for <u>four</u> or <u>five</u> of the represent-tations (8-10 strengths/weaknesses) [If the description is very detailed, then code as 4.]	1.1 Strengths and weaknesses • Able to identify appropriate strengths and weaknesses for all six representations (11-12 strengths/weaknesses) • Aware of misconceptions being introduced, e.g anthropomorphism	**REP1** (1.1)	REP
	1.2a Reason for choice • Reason for choice is inappropriate, incomplete, vague or difficult to follow • Give 0 if no answer is provided. *(Representation 1) It is what I am used to seeing. It includes a lot of information such as e- and H but also is in a form which allows it to be used in calculations, etc.* T47 *(Representation 2&4) It clarifies how many bond or whether is a single or double bond.* T14 *(Representation 5) It illustrates the friendships of learners in a classroom situation. Good examples of pairing the classroom.* T13	1.2a Reason for choice • Reason for choice is appropriate, but limited to a single consideration *(Representation 1) It is the simplest and requires the smallest stretch of the imagination to comprehend where the electrons are between the atoms.* T01 *(Representation 2) It gives a clear picture to learners on how elements bond, using the information on periodic table. It provides a clear picture on why elements are able to bond, while others are not.* T24	1.2a Reason for choice • Reasons for choice include two or more levels of consideration, e.g. ease of use, effectiveness to confront misconception, learner context, explanatory power • Links to the concept are clear and appropriate *(Representation 6) Energy is included. Positions of e- orbitals included and shown above the graph - matching what the graph is doing.*T28 *(Representation 6) Energy is a central concept in chemistry, especially in bonding and needs to be understood. Pupils find it difficult to understand that a release of energy leads to stability (cf. release of heat during crystallization) Parallels can be drawn.* T38	1.2a Reason for choice • Reasons for choice include more than two levels of consideration as well as limitations of the representation • Links to the concept are clear and appropriate and includes connections to prior or further concepts *(Representation 6) At the grade 10 or 11 level, once learners have grasped simple definitions of covalent bonding, it provides depth to their understanding of the covalent bonding model. It illustrates bond length and bond energy fairly well.* T27	**REP2** (1.2a)	
	1.2b Use in lesson • No discussion on how the representation is going to be used or suggested use inappropriate or unworkable • Suggested procedure lacks logic or clarity or is very limited *(Representation 4 or 5) Physical Demo using learners in front of the class.* T35 *(Representation 1) I would use it to compliment a more realistic diagram such as representation 2 or 3 because it translates complex understanding into a useable and fairly realistic form. It is also similar to methods used earlier and later in the subject.* T47	1.2b Use in lesson • Teaching approach is basic and does not include a conceptual orientation *(Representation 2) Start with Bohr model/Lewis diagram of H. Discuss the idea of a 'full' outer shell. How would H get a full outer shell? Needs another electron, what if it shared with another H:*  *That is why hydrogen is H2.* T37 *Introduce Lewis diagrams for individual atoms. Get students to do several examples. Remind students of e neg. Start with covalent bonds (non-metal <=> non-metal). Give example of hydrogen. Then try fluorine. Get students to try HCl. Introduce double bonds.* T43	1.2b Use in lesson • Suggested procedure shows logic and a satisfactory explanation on how the chosen representation is going to be used • There is some evidence of a conceptual orientation to the teaching approach *(Representation 6) First introduce the concept of bonding and explain on why atoms bond. Secondly deal with the concept of energy using numericals from the graph. This will help learners see decrease and increase of the graph. T20* *(Representation 6) I would demonstrate how the energy of the bond depends on the distance between the atoms involved in the bonding by using two spheres attached to each other by a string. As the string bends, the tension is less and hence the potential energy gets lower.* T05	1.2b Use in lesson • Suggested procedure is clear, logical and shows strong conceptual orientation • Use of the representation contributes to understanding and links to further teaching. • Multiple representations can be used *(Representations 1,2,5 &6) Start off with 1 and use H• + •H and explain about the different spins the electron must have, Fig.1. Use Fig 2 and explain that these electrons are moving around the nucleus and must be properly orientated, for the bond to take place. Fig 5, let the learners move around and choose their partners, explaining that the bond only take place if all the circumstances are right. Give learners a class activity, explain to the group how the energy levels influence the formation of bonds with the help of Fig 6.* T22	**REP3** (1.2b)	

Rene Toerien TSPCK Rubric Chemical Bonding Page 1

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
REP Appropriate strengths and weaknesses could include the following	<u>Representation 1</u> <u>Strength</u>: *Clearly involves electrons from each atom in forming the single bond.*T26 *Simple - works well as the next step after looking at Lewis diagrams and electron configurations.* T37 *I like that the representation shows that the two hydrogen atoms are identical and make the same contribution of electrons to the shared pair.* T56 *Lewis diagrams are a simple way to illustrate that covalent bonding involves a sharing of electrons. Also a short-hand way to show bonding.* T26 <u>Weakness</u>: *I only use it for the Lewis dot diagrams and not to explain bonding. It doesn't show that the electron could actually be anywhere, it shows it as stationary. T45* *Representation does not emphasize bond creation this can be a misconception of just putting the electrons together.* T46 *Students think of atoms as a square. Treats electrons as points. Difficult to deal with some polyatomic ions.* T43 <u>Representation 2</u> <u>Strength</u>: *This shows the orbital and the orbital overlap, so spatially kids can see what is going on. Presence of nucleus is good.* T01 *I like the connection to Bohr's model which learners get to understand easy. And circles combine to show that the 2 e-s can be shared to both and they fill the empty orbitals.* T10 <u>Weakness</u>: *Too many dots there's need to explain the difference between the dots outside and inside otherwise the learners may think H has 2 electrons.* T06 *Seems to suggest that electrons 'attract' one another. No charges are shown.* T27 *Bohr model promotes concept of orbits. The ellipse drawn between the atoms is confusing, seems to imply electrons are attracted.* T29	<u>Representation 3</u> <u>Strength</u>: *Illustrates wave nature of the electron better (probabilistic illustration). Shows regions of electron density (high in negative charge)* T28 *I like it because it shows the electron cloud around the atom. I use it when I teach electronegativity to show unequal distribution. The outer shells overlap. T45* *Electron clouds are accurate. I like in part 2 how the shape of the electron clouds changes as the atoms approach. Part 3, good representation of a molecular orbital, learners can see overlapping clouds, not joined nuclei as is sometimes thought.* T58 <u>Weakness</u>: *It is difficult to use it as there is no indication of valence electrons. Learner would have to know more details about the diagrams.* T12 *Hard for learners to visualize and understand.* T48 *Part 2 appears to be repulsion, will be difficult to explain why a bond forms if the electron clouds appear to be repelling each other.* T58 <u>Representation 4</u> <u>Strength</u>: *This representation is a good analogy to illustrate that the bond is a force - that the electrons are attracted to the proton in the atom.* T26 *I like the humorous, cartoon aspect, it draws attention.* T58 <u>Weakness</u>: *Misconceptions can arise from personification 'nuclei want electrons'.* T27 *It appears that the electrons are bound together, not the 'atoms' and the hydrogen atoms seem to be fighting to pull them to themselves instead of overlapping orbitals.* T58 *Not sure if they are fighting or sharing the electron pairs* T60	<u>Representation 5</u> <u>Strength</u>: *Works well for concept of bond number (valency) and form working out the formula of a compound.* T28 *Having the learners enact atoms can be a good way for them to relate to the concepts of bonding.* T51 *This brings the relevance into the concept, something the learners can relate to. If each person represents an atom and the arms the bond.* T46 <u>Weakness</u>: *Very simplified and can therefore be quite challenging to move the learners from this idea to 3D orbitals and energy levels. And the fact that electrons aren't just sitting in between the two atoms but actually constantly moving.* T36 *Will only work for monovalent and divalent atoms. No obvious distinction between atom types. Role of electron not clear/ignored...* T28 *There is no relevance at all, unless the two students were carrying something on their hands. No electron and nothing being shared.* T53	<u>Representation 6</u> <u>Strength</u>: *Symbolic representation of the potential energy graph also has a microscopic representation as atoms approach each other to form bond.* T26 *It represents the stability of the molecule. Different energy corresponding to different distances between atoms which is a good presentation.* T05 *Illustrates the reason for bonds forming (minimizing Ep and maximizing stability) makes high school chem more quantitative rather than the usual qualitative descriptions. Illustrates role of distance which most other representations ignore.* T28 <u>Weakness</u>: *Very static. Best either as animation or simulation. Graphing skills and interpreting graphs is something learners struggle with must be explained step by step.* T26 *Learners struggle to grasp the fact that they have to understand the change in PE as nuclei come closer. They do not understand the distances, role of positive nuclei and negative electrons on the change in PE and then the increase energy as the nuclei come too close.* T09 *Learners struggle to interpret a graph. Negative energy is bonding energy is not easy for them to comprehend.* T11 *Can be very confusing if used too soon! Need knowledge of electrostatics, bonding basics, mole concept.* T28	Examples for 1.1 REP1	

Rene Toerien TSPCK Rubric Chemical Bonding Page 2

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
Curricular Saliency Section 2 CS	2.1 Big Ideas • Identifies none or one big idea from B C D E G I and other ideas from A F H J K 2.2 Reasons for choice • No sequencing or Illogical sequencing of ideas provided • No reasons provided or reasons are inappropriate	2.1 Big Ideas • Identifies two big ideas from B C D E G I and one idea from A F H J K 2.2 Reasons for choice • Logical sequencing of the ideas provided • Reasons are provided, but are limited, for example only focuses on the three kinds of bonds	2.1 Big Ideas • Identifies three big ideas from B C D E G I 2.2 Reasons for choice • Logical sequencing of the ideas provided • Reasons provided are appropriate. Limited aspects of prior knowledge might be mentioned	2.1 Big Ideas • Identifies three big ideas from B C E G 2.2 Reasons for choice • Logical sequencing of the ideas provided • Reasons provided are appropriate and include links to prior knowledge or follow-up concepts or has a strong conceptual focus	**CS1** (2.1 & 2.2)	**CS**
	Big Ideas A H D: This will help with introduction of the chapter and it may enable learners to remember for quite long and it can help to improve learners academic work of chemical bonding. T14	*Big Ideas C D K: [C] Defining chemical bonding will be the first in outlining why we do bonding. For a bond to can form atoms need to be separated and to do so energy is absorbed and when products are formed the same amount of energy is released.[D] Types of bonding (ionic, metallic, covalent). [K] Explaining the sharing of electrons between atoms. T19* *I believe learners must know why reactions take place. A and K - I always start with covalent, sharing of e- and then explain to learners that there are instances where e- are given away and take by certain elements - metals and non-metals.T22* *Big Ideas C K D: Introduce a lesson by stating what is a chemical bond and what are the results. List types of chemical bonding that we have. This will help learners to be able to distinguish reactions. T24*	*Big Ideas C G D: A reason for chemical bonds needs to be established first, why a bond would happen in the first place. Building on that, why chemical bonds are formed, bringing in the energy factor. How energy works in the chemical bond, works well after the 'C' [A chemical bond is an electrostatic interaction between a positive and a negative charge] and 'G' [Chemical bonds are formed to create stability].T55* *Big Ideas G D B: Provides an overview of why atoms bond. If learners understand why atoms bond first, they will then start to wonder how does this happen and this lead to big idea which deals with the issue of energy in chemical bonding and then to idea 3 [the chemical bonds in a substance determine its structure] T20*	*Learners understand electrostatic interactions. This provides for non-polar, polar bonds and ionic bonds. Learners understand energy changes related to forces and changes of position - also NB for endo-, exothermic concepts. T29* *I will start with E [electronic structure influences how atoms bond] so that the learners understand what dictates which bonds can form. Then D [energy is required to break bonds and energy is released when bonds are formed] and G [Chemical bonds are formed to create stability] will be taught quite close to each other to give the students a good grasp of energy in bonds, and systems tendency to settle to a state of lowest potential energy. This idea transcends chemical bonding, and an idea which students would do well to grasp. (but they will need C [A chemical bond is an electrostatic interaction between a positive and a negative charge] as well). T57*		
	2.3 Map • No sub-ordinate ideas are included in the mind map • Sequencing cannot be followed and ideas are illogically placed	2.3 Map • Not all big ideas have sub-ordinate ideas however, those identified are correct • Sequencing can be followed but some ideas are illogically placed • An appropriate, but very basic map is drawn e.g. 	2.3 Map • All big ideas have sub-ordinate ideas • Sequencing can be followed and all ideas follow a logical order • Some cross-links might be included • Some pre-concepts might be included e.g. 	2.3 Map • All big ideas have sub-ordinate ideas and follow a logical order • Uses only big ideas as starting point • Appropriate cross links are included • Pre-concepts are included e.g. 	**CS2** (2.3)	
	 T25	 T15	 T38	 T28		

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
Curricular Saliency Section 2 CS	 T14	 T33  T36	 T29 T29 coded as 3, but is a high 3. Not coded as 4 as it lacks cross-links and Big Ideas are not central	 T04  T26		
	2.4 Importance to learn • Reasons given for importance of topic limited to general benefit of education e.g everyday life, chemical bonds are everywhere. • No specific links to chemistry	2.4 Importance to learn • Reasons given may include general interest, everyday life applications or importance for examination purposes, but exclude conceptual considerations • Links to chemistry is included, e.g atoms react to form molecules, but the centrality of bonding is not mentioned	2.4 Importance to learn • Reasons given may include general interest, everyday life applications or importance for examination purposes • Reasons given explain the centrality of bonding in chemistry, and/or in learning and may include links with specific topics	2.4 Importance to learn • Reasons given may include general interest, everyday life applications or importance for examination purposes • Reasons given explain the centrality of bonding in chemistry, and/or learning and include links with specific topics • Reasons given includes a strong conceptual focus	**CS3** (2.4)	
	It teaches them about nature, why the sky is blue, or appear blue. What is matter? Their body structure, its composition, food they eat and natural element and different diseases that are found in the world. How to improve their lives around them and themselves. The atmosphere and natural phenomenon e.g. rains. T23 *Everything that we do in our daily lives is about bonding of substance of the formation of new products. When baking a cake you must know the ratio of ingredients. When cooking, how much to supply. Any combination of substances, we must know the end results of products to form.* T19 *Their environment is made up of a variety of materials. It is important for them to understand how they are made and how they behave.* T16	*To be able to understand how molecules are formed.* T15 *Learners need to know the 'behaviour' of atoms and how chemical bonds come about. Our economy, everyday living etc. is dependent on chemical bonds e.g. petrol production, hair products, etc.*T4 *They need to because all the molecules they come across in real world have undergone chemical bonding even the food that they eat in their daily life undergoes chemical bonding.* T53 *It forms the basis of all chemical substances in chemistry if they know how bonding occurs they can write formulae.* T06	*It helps the learners to understand the bonds in the compounds they use in their everyday life. It helps them to understand the use of periodic table and give them a basic understanding of compounds, alkenes, organic chemistry in grade 12.* T12 *(low 3)* *Understanding bonding is the stepping stone to understanding chemistry it is applied when looking at acids and bases. It is essential in understanding organic chemistry. You must understand bonding to be able to understand an equation!* T37 *Explain structures and shapes. Why chemical reactions. Linking atomic structure and chemical behaviour. Energy considerations in chemistry and real life. T35*	*The atom is the single most important concept in chemistry. It leads to quantization concept in other areas such as charge and energy. Learners enjoy understanding why compounds form the way they do. The basics of bonding are the starting point in other sections of chemistry, e.g. redox, acids + bases, precipitation, organic.*T34 *Chemistry is about reactions, forming substances, breaking substances. These substances are compounds and also we learn and apply chemistry in a macroscale, not atomic, meaning that substances are a group of atoms, so learners need to know how these atoms combine to form large compounds. Chemical bonding is important in organic chemistry and inorganic chemistry. In writing chemical formulae.* T10		

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
What makes topic difficult to teach Section 3 WDT	3.1 • Reasons not given or not applicable • No answer is provided • Reasons given are broad or generic and not linked to the specific concept under discussion, for example 'abstract' or 'the learners don't understand'	3.1 • Identifies an issue that makes it difficult to teach but reasons are not given or appropriate	3.1 • Reasons given are appropriate, specific and related to prior knowledge of students or common misconceptions	3.1 • Reasons given are specific and related to prior knowledge of students or common misconceptions • Reasons given link the concept with other gatekeeping concepts that when not fully understood adds to the difficulty of the concept regarded as difficult, for example electronegativity linked to polarity of bonds	**WDT1** 3.1 **WDT2** 3.2 **WDT3** 3.3	**WDT**
	Metallic bonding: *How do metal bond with another metal.* T25 *Main reason for all is that it is too abstract to the learner. Difficult for the learner to 'see' this happening.* T21 Ionic bonding: *Not difficult - makes intuitive sense in terms of attraction between positive and negative.* T07 Polarity of bonds: *Confusion of polar regions and reactivity of elements.* T17 *The word polarity is more scientific, the students most of them only hears it only when they are in class. This word doesn't show any relationship or clue on the meaning.* T53 Bond energy: *Not too difficult to teach.* T34 *A wonderful addition to the syllabus but easy for students (and teachers) to get wrong because it is only mathematical.* T31 What is a molecule: *I find that pupils are often just lazy/careless or not bothered to try and grasp the concept.* T34 *This is not difficult to learners. Why? Because they must understand that element + element they form a molecule which is bigger that an element.* T13 Note: If more than three options are filled in, choose the three best answers to evaluate. If only one or two answers are provided, use the best score for the outstanding descriptions	Metallic bonding: *It because we know that like charges repel each other so how can metallic take place.* T14 *Idea of delocalized electrons and metallic properties (e.g. lustre, malleability, ductility, etc.)* T35 Ionic bonding: *They do not understand the positive and negative charges. They must understand why an element must have a positive or a negative charge.* T13 *Learners often asked 'how can one atoms just give away and electron?'* T42 Polarity of bonds: *Understanding the electronegativity and interpretation too much theory.* T25 *The learners get confused when something is a dipole, so I tell them that if it is a polar bond it is a dipole and if it is non-polar it is an induced dipole.*T45 Bond energy: *Difficult to understand bond energy vs bond length in relation to atomic sizes.* T16 *How does one clearly differentiate between bond energy and activation energy?* T35 *Learners struggle to interpret bond energy graphs.* T04 What is a molecule: *Initially they understand, but as more concepts are introduced often get confused between different molecular structures.* T42 *Hard to understand that molecules are only formed through covalent bonding.* T16	Metallic bonding: *There is no change in the formula when you talk of solid metal. If you talk of copper as solid, learners would not think of any bonding taking place. T10* *Students don't like the fact that electrons are not organized in a fixed pattern. The idea of metals being hard and tough doesn't connect with idea even after metals like sodium are cut with a knife.T44* Ionic bonding: *Learners struggle with the formation of ions and charge the ions have. Therefore teaching it means going back to the basics which often where never grasped in the first place.* T30 Polarity of bonds: *This is only considered after learners think all bonds are either ionic or covalent. When interactions like van der Waals or dipole-dipole interactions are introduced by talking about polarity, learners are looking for it to fit as ionic or covalent but they don't fit.* T52 Bond energy: *The learners are always struggling to understand the bond energy because it is mostly explained in terms of graphs. They struggle a lot with interpreting graphs.* T12 What is a molecule: *In 2013 I realized that a molecule is formed in covalent bonds. For me a molecule was anything. The main reason was that textbooks use compound and molecule in the same line, so I assumed they are synonyms. I think my learners have the same problem.* T45	Metallic bonding: *The concept of delocalized electrons introduces another level of sophistication to the atomic model as understood by learners (which most learners understand as having discrete/separate energy levels).* T29 Ionic bonding: *Ionic bonding is difficult to teach because a learner has to know that the atoms are competing for the electrons and are not shared equally. They have to understand polarity first before this section can be done. The difficult part is to understand why are the electrons transferred to the other atom since it requires good imagination skills.*T05 Polarity of bonds: *Requires visualization ability (simulations help). Fuzzy (partial charge no longer absolute). Requires understanding of electronegativity. Requires understanding of wave nature of electron (what an orbital really is in terms of region of probability).* T28 Bond energy: *Bond energy is difficult to grasp since learners do not have a good understanding of chemical bonds as an electrostatic force between charged particles. In physics it is far easier to understand that when a force is exerted over a distance work is done, or that a mass due to its position has potential energy. Also, in CAPS fields are only covered at a basic level at Grade 9 and only dealt with after chemical bonding…* T26 What is a molecule: *This is more problematic in grade 8 + 9. They struggle with the idea of energy between atoms. They think that a change of phase means that the substance is different and struggle to see that the structure is still the same. This is why we spend so much time on particle model, mixtures and compounds.* T44		

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
Learner Prior Knowledge including Misconceptions Section 4 LPK	4.1a&b Choice & Reason • Preferably choice E • Reasons for choice not related to bonding or prior knowledge or the reason for choice is inappropriate	4.1a&b Choice & Reason • Preferably choice A • Reasons are linked to bonding only or prior knowledge only	4.1a&b Choice & Reason • Preferably choice B or D • Reasons are linked to prior knowledge and to bonding	4.1a&b Choice & Reason • Preferably choice C • Reasons are linked to prior knowledge, bonding and includes that it is essential for understanding further concepts	**LPK1** 4.1a& 4.1b	LPK
	(Choice E) Useful to explain the chemical 'behaviour' of elements in various groups. T35 *(Choice B) The periodic group defines the order of the periodic elements in the table according to the mass number of the respective elements.* T56 *(Choice C) It gives a reason for the table, makes it accessible to the students, from that you can teach all the others.* T55	*(Choice A) Because you will be able to know which one can donate electrons and which one can accept the electrons. By knowing that you can be able to explain how covalent bond is forming* T50 *(Choice B) How these elements will behave in bonding. How many bonds they will form and whether they would share or donate electrons.* T23	*(Choice C) Electron configuration is needed so that the idea of stability can be reinforced.* T37 *(Choice C) Bonding is all about the behaviour of electrons.* T33 *(Choice D) This is the fundamental reason for the periodic table. This will show learners that by looking at where elements are in the periodic table will determine their bonding type, which elements they will bond with and not..* (T52)	*(Choice C) After I explain about orbital and octet rule and energy levels I start showing the power of the Periodic Table. It opens up the section for students when they realize they don't have to study but have to understand how the Table works.* T44 *(Choice C) When first dealing with the P Table (but not for bonding purposes A, C, D would already be covered). When using the PT to teach <u>bonding specifically</u> the most important concept is the link between position on PT and electron structure (C). E then follows as a result of this (E is a specific example of C).*T28		
	4.1c Teaching • Use in teaching not appropriate and not linked to learner responses	4.1c Teaching • Use in teaching is somewhat appropriate, link to some content, but no focus on learner responses • Use in teaching may expand on the Periodic Table instead of bonding	4.1c Teaching • Use in teaching is appropriate and linked to content and learner responses	4.1c Teaching • Use in teaching is extensive, focused on understanding, linked to content and learner responses. • It is clear how the learner's prior knowledge is incorporated into teaching.	**LPK2** 4.1c	
	(Choice D) I will relate any concept I teach such as chemical bonding, back to the table as it will allow for an understanding of the properties of substances involved in the topic. (use to explain properties and how they relate to the topic). T47 *(Choice a) Basic understanding of periodic table. Then build up on the knowledge that they need to gain from the periodic table.*T18	*(Choice A) Firstly I will remind them about metals and non-metals. They must give me examples of metals and non-metals. And their use in everyday lives. Secondly I will explain to them what a chemical bond is and show them an example of substance e.g. diamond is carbon atoms joined together. Lastly explain to them what types of bonds do we have, what is happening in each type of bond.* T12 *(Choice A) Linked to valencies - positive for metals and negative for non-metals as a general rule. Then you get onto NH_3, NO_2 N_2O.* T31	*(Choice B) The idea must be taught before any of the others. Trends within & between groups should also be explained in order to get an idea of where a group fits in. From there I would move to point C by explaining the configuration of atoms and how this related to bonding.* T54 *(Choice C) Give learners a few examples of electron configurations with reference to the periodic table. Then get them to practice numerous examples. Highlight the trends once mastery of electron configurations is established.* T27	*(Choice C) I set it as a discovery challenge in groups. Each member has to draw electron configuration of one element in a group. At the end I ask what is similar about the configuration of the group. I then connect number of valence electrons to the group and energy level to the period.* T44		
	4.2 Misconceptions None of the central issues/misconceptions are correctly identified Irrelevant or incorrect explanations supplied	4.2 Misconceptions One of the central issues/misconceptions correctly identified Explanations are provided but are generic or vague, e.g. 'the learners find it difficult'	4.2 Misconceptions Two of the central issues/misconceptions correctly identified Explanations are relevant and appropriate but some are incomplete	4.2 Misconceptions Three of the central issues/misconceptions correctly identified (see next row for accurate information) Explanations are accurate and capture the essence of the problem.	**LPK3** 4.2	
Correct explanation for misconceptions in 4.2	4.2.1 A corrected statement could be: The chloride ion is attracted to up to <u>**six**</u> sodium ions by a bond which is an electrostatic force. Notes: A bond is an electrostatic force. Chloride ion is attracted to six sodium ions and not just one.	4.2.2 Obtaining a full outer shell is not the driving force for bond formation. An ionic bond is an electrostatic interaction or force, not the act of donating or accepting electrons. Ions are present before bonding takes place. Notes: Do not accept if they said that it can donate more than one electron. This is the not the problem in this statement, the 'full outer shell' is the problem.	4.2.3 Sodium chloride does not form molecules. Sodium chloride is a continuous network of bonds throughout a lattice structure. Sodium chloride in solid form cannot conduct electricity, only when it is dissolved (the statement is correct here). Notes: Teachers must mention the molecule issue for their answers to be correct.	Major misconceptions addressed: 1. A bond is not a force 2. Obtaining a full octet structure is the driving force for bonding 3. Ionic substances form molecules		

TSPCK Components	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)	Sub-totals	Total
Conceptual teaching strategies Section 5 CTS	5.1 & 5.2 • Lacks aspects of curriculum saliency • No evidence of acknowledgement of learner prior knowledge • No new representation was used • No specific teaching strategy was mentioned, only content provided 0 awarded if no answer is provided or if teachers indicate that they do not know	5.1 & 5.2 • Overall a very basic strategy. • Limited consideration of learner prior knowledge • Lacks aspects of curriculum saliency • Use only one level of representations • Suggested strategy is largely teacher-centered	5.1 & 5.2 • Overall a workable strategy • Some consideration of learner prior knowledge • Some evidence of curricular saliency • Uses at least two different levels of representations, or one level which is a good and effective choice (e.g. models) • There is some evidence of encouraged learner involvement • Teacher focused with demonstration (include in the above description)	5.1 & 5.2 • Overall an excellent strategy to teach required concept • Effective incorporates student prior knowledge • Strong evidence of curricular saliency • Uses multiple representations with the purpose of promoting understanding • Highly learner centered lesson	**CTS1** 5.1	5
	5.1 Beryllium bromide *I would revisit the concepts properties of materials especially with regard to chemical networks.* T49 *The bond between metal and non-metal. Should be transfer of electron. Electron configuration of each atom and as well as position to determine how many electrons will be transferred. From that should be able to determine the ratio unit formed.* T42 5.2 Graphite *Showing that C will form four bonds with other carbons which also form four with other, some in the first and some in the second layer (upper and lower). In bonding process rings will be formed by 6 carbons.* T15 *Carbon is a semi-metal, it does conduct electricity (allow charges to pass through). Metals are malleable and ductile. Graphite structure is like a crystal lattice. Sharing of electrons.* T25 *Carbon is a non-metal and its compound will be unable to conduct electricity since there are no available ions to conduct electricity. The layers form a giant structure of which it cannot conduct electricity. They have to recall and first cover the part about ions responsible to conduct electricity.*T05	5.1 Beryllium bromide *The distinction between covalent and ionic bonding is closely linked. I would firstly focus on the electronic structure of beryllium. Teach about its atomic structure, shell casing and how that determines its reactivity towards nonmetals. Bromine is electronically 'richer' compared to beryllium. I need ideas on this to teach it.* T17 *Explanation would work as a strategy - explaining the difference in electronegativity of bromine and beryllium. Beryllium donates one electron to bromide. Use of models would help. Learners visualize the type of structure formed at the end of the two atoms bond to each other.* T20 5.2 Graphite *(It was easier to teach this when hybridization of carbon orbitals was in the syllabus) Explain that the bonds between the atoms in a plane are covalent and relatively strong. The bonds between the planes are much weaker with delocalized electrons allowing planes to slide, electrical conductivity, etc.* T29 *I would bring out the link between this and diamond - crazy but there it is! Same covalent bonds but due to one of the four e-s in C being delocalized it shares the layer with another allowing the layers to slide over each other. With diamond all four Cs are bonded in the same way. Show pics - but difficult to see, they need to be 3D.* T31	5.1 Beryllium bromide *I would teach the periodic table and electronegativity trends. Teach polar bonds and non-polar. Learners would draw Lewis diagrams fo different atoms. Then teach types of bonding. T10* *It will introduce the concept of electronegativity to learners. I will make sure that the periodic table is well understood by learners. Calculation of percentage should also be part of pre-knowledge. Question and answer, illustration and worksheets and models to use in method. T23* 5.2 Graphite *Go back to bond theory and the structure and abundance of carbon on earth. Explain delocalization of electrons. Show structure. Do experiment to demonstrate that it conducts electricity and explain how this occurs as the experiment is running. This often makes understanding easier.T18* *I would start with explaining the chemical bonds between different carbon atoms to form different structures. I would use that knowledge to explain how the chemical bonds forming this structure end up in layers, (and not like the diamond for instance). I would bring in a physical model of the layers of graphite and explain the attraction between the layers and show how easily the layers can be removed from each other. T55*	5.1 Beryllium bromide *I would start with prior knowledge of ionic and covalent bonding, which was metal-non-metal and 2 non-metals. Then I would introduce the concept of electronegativity and we'd define it. This would lead to finding this value on the periodic table, so they could use it. Then we would take known molecules or substances and measure the differences. This would lead to a scale for them to use. Then we would talk about how not all covalent bonds are equally shared. I often refer to more electronegative atoms as 'bullies'. Some take your whole sandwich at lunch while other only take it some of the time (or even parts of your sandwich). They find the idea of polarity challenging at its first instance. This bully-analogy seems to help. We would then practice with more examples of polar vs non-polar covalent bonds.* T01 5.2 Graphite *Revise background knowledge, like valency leading to the tetra-valency of carbon. Consolidate metallic bonding, emphasizing delocalized electrons of a model (3D) made of polystyrene or if molymod is available, use it. If not, get leaners to construct a model with toothpicks and jelly tots. Focus attention on the unused 4th bond holding the layers together, allowing for electrical conductivity and the fact that graphite can be broken in fragments.* T27	**CTS2** 5.2	

Appendix 27 **Final memorandum**

Chemical Bonding Research Project

Personal code:

Chemical Bonding Content Knowledge Memorandum

<u>Question 1</u>

1.1 B3 ✓✓
1.2 A4 ✓✓
1.3 A3 ✓✓
1.4 A1 ✓✓
1.5 B3 ✓✓ if A1 then ✓ [10]

<u>Question 2</u>

2.1 What is a chemical bond?

A chemical bond is an electrostatic force ✓of attraction between positively charged and negatively charged particles that hold atoms or ions ✓together. This results in forming a unit that is more stable than the individual atoms that make up a substance.

If An electrostatic force of attraction holding atoms together in a molecule or a crystal. 2/2
If a force between two atoms then 1/2
If an attraction between atoms then 1/2
If when elements combine to form compounds, then 0/2
It is when two or more substances bond with each other. 0/2

2/2

1/2

[4]

2.2 Why do atoms bond with each other?

To get at the lowest possible energy and highest possible stability. 3/3
To achieve greater stability minimizing their potential energy. There is a natural tendency in all systems to minimize energy: maximum stability <=> minimum energy 3/3

To complete their outermost shells so be to stable. 2/3
To maintain stability. 2/3
Obtain stable, lower energy structure 2/3

Atoms are reactive as they have lone pairs that are shared or donates to others to fill the outer shells which needs 8 electrons. So most of the metals have free electrons to donate. 1/3
To reach stable octet rule. 1/3

To form new compounds or molecules. 0/3
Because of the electrons that move around. 0/3

[3]

2.3 Can the bond between two atoms have both covalent and ionic character? Explain your answer.

Yes. A more sophisticated model has ionic bonding just part of a continuum of polar covalent bonding. The more polar (from larger electronegativity differences) the more ionic in character (the less 'fair' the sharing). Ionic bonding is just an extreme case of very unfair sharing. 3/3
Yes, as difference of electronegativity increases sharing of electrons (covalent bond) becomes less and shared electrons come more and more under the influence of the more electronegative atom and ionic nature increases. 3/3

Yes, it's the degree of sharing that determines how covalent or how ionic it is or both. 2/3
Yes, all bonds (except perfect covalent bonds between say Cl-Cl atoms) have various levels of ionic character. 2/3

Yes, this leads to the concept of polar bonds. 1/3
Yes, but would rather talk of a polar covalent bond. 1/3

No. Either sharing or transfer of electrons. 0/3

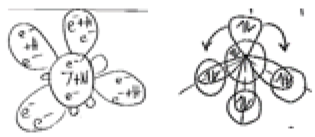
[3]

Question 3

THIS QUESTION IS MARKED AS A WHOLE

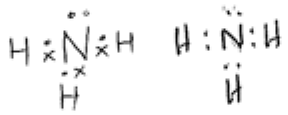
Orbital overlap with energy consideration 4/4
Unequal electron sharing approach 3/4
Octet approach 2/4
Non-metal/non-metal approach 1/4

Both atoms, hydrogen and nitrogen, must first be separated from identical atoms in diatomic molecules, this requires energy. The separated atoms have unpaired electrons in half-filled orbitals. The covalent bonding model suggests that by overlapping these orbitals a lower energy, semi-permanent, bonded state arises, due to sharing of electrons. 4/4

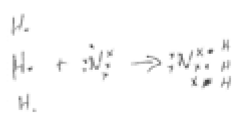


A nitrogen atom has 3 unpaired electrons, one it each of its 2p orbitals. Each of these unpaired electrons is shared with the unpaired electron of an H atom (1s). The nitrogen atom makes three bonds while three H atoms make single bonds with it. [unequal electrons sharing not mentioned, but orbitals were, therefore 3/4]

Nitrogen has 5 valence electrons. To obtain a stable noble gas electron structure it must gain 3 more. It does this by sharing with 3 hydrogen atoms. They in turn also gain a stable electron structure. 2/4



Nitrogen is in group 5 and hydrogen in group 1. They are both non-metals and the bond will be covalent. 1/4



[4]

Question 4

4.1 Describe the bonding between atoms in a piece of aluminium.

Metallic bonding is the electrostatic attraction between closely packed positive metal ions ✓and a sea of delocalised electrons✓. Each metal atoms loses one or more of its loosely held electrons ✓to contribute to a sea of electrons. The electrostatic forces between the sea of electrons and the positive metal ions is called metallic bonding. ✓

[4]

4.2 Aluminium is malleable, ductile and conducts electricity. Based on the type of bonding you described in 4.1, explain **one** of these properties of aluminium.

Aluminium is malleable. The metal cations a cushioned between the sea of electrons such that they simply slide over each other when a force is applied, instead of shattering. The attraction between the sea of valence electrons and the metal cations ensure that the structure stays intact. 4/4

Ability to conduct electricity: valence e-s are very loosely held/delocalized so when a potential difference is set up across two points of the metal electrons will naturally move due to the electric field which sets up the potential difference in the first place. 4/4

Aluminium conducts electricity because pool of delocalized electrons acts as a charge carriers. 3/4
There are no fixed bonds in metals, the atoms below can easily move away making place for the atoms hammered on to move in between them and the metal flattens 3/4

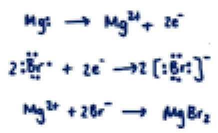
The free electrons are responsible for conducting electricity since they are able to move around within the substance.2/4
It is malleable because the valence electrons can move between the atoms 2/4
Because some of the electrons are delocalized so it then conducts electricity. 1/4
It is a metal therefore it has high conductivity 0/4

[4]

Question 5

5.1 Describe the bond that is formed between magnesium metal and bromine gas.

Ionic bond ✓
Shows that two electrons are transferred from Mg to Br^- ✓
Shows that there is an attraction between cations and anions and not a molecule that is formed ✓



[3]

5.2 Explain why solid magnesium bromide has a high melting point (711°C).

Ionic compounds form lattice structures whereby the atoms are closely packed and as a result, to melt and ionic compound, you need to 'dismantle' the lattice structure which requires a lot of energy to break the electrostatic forces, hence a high melting point 3/3
Mg is a small atom so its positive charge is confined to a small volume when it loses its two electrons. Thus it has a high charge density and forms a strong bond with Br. 2/3
Because the strong bond between Mg & Br 1/3

[3]

Appendix 28 **DIF analysis procedures**

Differential item functioning (DIF), is a statistical characteristic of an item that shows the extent to which the item may be measuring different abilities for members of separate subgroups (Badia, Prieto, & Linacre, 2002). In a DIF analysis, the item difficulty for one group in the sample is compared to the item difficulty for all the other groups combined. DIF results are considerably influenced by sample size, and since this sample was very small in comparison to typical Rasch analyses, the results need to be interpreted with caution.

A DIF size greater than 0.50 indicates the possibility of DIF (Linacre, 2014), but the DIF size needs to be statistically significant. Statistical significance is indicated by a t-value > 2.0 and a probability less than 0.05. Positive DIF size values indicate that items are more challenging than predicted, whereas negative DIF size values indicate items which are less challenging than predicted by the model.

Winsteps generates a set of DIF analysis tables to analyse potential DIF for different person classes. A portion of *Winsteps* Table 30.2 for gender is shown in Figure A28.6.

```
TABLE 30.2 Final data file all items for DIF wit ZOU870WS.TXTt Mar 16 10:03 2016
INPUT: 60 PERSON  25 ITEM  REPORTED: 60 PERSON  25 ITEM  5 CATS  MINISTEP 3.81.0
--------------------------------------------------------------------------------

DIF class specification is: DIF=@GENDER
```

PERSON CLASS	OBSERVATIONS COUNT	AVERAGE	BASELINE EXPECT	MEASURE	DIF SCORE	DIF MEASURE	DIF SIZE	DIF S.E.	DIF t	Prob.	ITEM Number	Name
F	27	1.52	1.47	1.65	.05	1.54	-.11	.28	-.39	.6987	1	CK1.1
M	33	1.15	1.20	1.65	-.05	1.75	.10	.26	.39	.6997	1	CK1.1
F	27	1.74	1.69	1.18	.05	1.08	-.11	.28	-.39	.7011	2	CK1.2
M	33	1.36	1.41	1.18	-.04	1.28	.10	.26	.37	.7116	2	CK1.2
F	27	1.59	1.69	1.18	-.10	1.38	.20	.28	.72	.4782	3	CK1.3
M	33	1.48	1.41	1.18	.08	1.02	-.16	.25	-.65	.5221	3	CK1.3
F	27	1.37	1.57	1.43	-.20	1.85	.42	.28	1.50	.1473	4	CK1.4
M	33	1.45	1.29	1.43	.16	1.08	-.35	.25	-1.37	.1811	4	CK1.4
F	27	1.59	1.64	1.29	-.05	1.38	.09	.28	.34	.7372	5	CK1.5
M	33	1.39	1.36	1.29	.04	1.21	-.08	.26	-.30	.7691	5	CK1.5
F	27	2.70	2.94	-1.43	-.24	-.91	.52	.28	1.85	.0766	6	CK2.1
M	33	2.85	2.65	-1.43	.20	-1.88	-.45	.27	-1.68	.1029	6	CK2.1
F	27	1.67	1.81	.94	-.14	1.23	.29	.28	1.05	.3048	7	CK2.3
M	33	1.64	1.52	.94	.11	.70	-.24	.25	-.95	.3506	7	CK2.3
F	27	1.15	1.41	1.76	-.27	2.33	.57	.29	2.01	.0552	8	CK2.4
M	33	1.36	1.15	1.76	.22	1.28	-.48	.26	-1.87	.0716	8	CK2.4
F	27	2.74	2.66	-.81	.08	-.99	-.17	.28	-.62	.5411	9	CK3.3
M	33	2.30	2.37	-.81	-.07	-.68	.14	.25	.54	.5906	9	CK3.3
F	27	2.30	2.18	.18	.12	-.06	-.25	.28	-.90	.3790	10	CK4.2
M	33	1.79	1.89	.18	-.10	.39	.20	.25	.81	.4231	10	CK4.2
F	27	2.33	2.23	.08	.11	-.14	-.22	.28	-.80	.4316	11	CK4.3
M	33	1.85	1.94	.08	-.09	.26	.18	.25	.72	.4755	11	CK4.3
F	27	2.33	2.29	-.05	.04	-.14	-.08	.28	-.30	.7636	12	CK5.1
M	33	1.97	2.00	-.05	-.03	.01	.07	.25	.27	.7884	12	CK5.1
F	27	1.67	1.76	1.04	-.09	1.23	.19	.28	.67	.5083	13	CK5.2
M	33	1.55	1.47	1.04	.07	.89	-.15	.25	-.60	.5511	13	CK5.2
F	27	2.96	2.79	-1.10	.17	-1.48	-.38	.29	-1.31	.2015	14	REP1
M	33	2.36	2.50	-1.10	-.14	-.81	.29	.25	1.16	.2538	14	REP1
F	27	2.48	2.48	-.43	.01	-.43	.00	.28	.00	1.000	15	REP2
M	33	2.18	2.19	-.43	.00	-.43	.00	.25	.00	1.000	15	REP2
F	27	2.70	2.56	-.60	.14	-.91	-.31	.28	-1.09	.2878	16	REP3
M	33	2.15	2.27	-.60	-.12	-.36	.24	.25	.97	.3395	16	REP3

Figure A28.6 A portion of the person DIF table for gender

Two gender classes were used, namely female and male. The class name and number of individuals in each class are shown in the first two columns in the table. All values are given in log-odd units, or logits. AVERAGE (column 3) shows the item difficulty for the class (e.g. 1.52 logits for females for CK1.1, see rows outlined in blue). The higher the logit number, the more difficult the item was. BASELINE EXPECT (column 4) is the expected value for the class when there is no DIF (e.g. 1.47 for females for CK1.1) and BASELINE MEASURE (column 5) is what the overall item difficulty for the total sample would be without DIF (e.g. 1.65 for CK1.1). DIF SCORE is the difference between the observed and the expected average item difficulty (e.g. 0.05 = 1.52 – 1.47 for females for CK1.1). DIF MEASURE is the measured item difficulty for the class (1.54 logits for females for CK1.1). DIF SIZE is the difference between the DIF measure for the class and the baseline difficulty for the group (0.11 = 1.65 – 1.54). Item CK1.1 is 0.11 logits less difficult for females than for the whole group (row 1), and 0.10 logits more difficult for males than for the whole group (row 2). DIF S.E. is the standard error of the difference and DIF t is the t-value, with Prob. being the probability of the t-value. The item numbers and names are listed in the last two columns.

Potential differential item functioning was detected for item CK2.4, as indicated in Figure A28.6 (see column outlined in red). The DIF size for the item was greater than 0.50 (0.57 logits, as indicated with a dot in the figure). The t-value was marginally greater than 2.0 (t = 2.01), and the probability slightly greater than 0.05 (prob. = 0.0552). The presence of potential DIF was therefore noted, but the DIF was only marginal, and since the sample size was small, DIF was considered insignificant.

One other case of potential DIF was detected for item CK2.1 (DIF size = 0.52), but it was not considered to be significant as the t-value was less than 2.0 (t = 1.85), and the probability greater than 0.05 (Prob. = 0.0766). These two items, CK2.4 and CK2.1 were, respectively, the most difficult and easiest items in the test.

Some person classes were very small and were not considered in the analysis - for example there were only two teachers teaching at rural schools, and only three teachers who had a teaching diploma.

A DIF analysis for all the other person factors, namely the province the teacher was teaching at, the level of content training, the highest education qualification, and the years' of teaching experience, were also performed. DIF tables are included in the Appendices 29-32. Potential DIF is indicated on each table, and a summary of the DIF results are included on page 110 of the body of the thesis.

Appendix 29 **School type DIF table for the survey sample**

TABLE 30.2 Final data file all items for DIF wit ZOU870WS.TXTt Mar 16 10:03 2016
INPUT: 60 PERSON 25 ITEM REPORTED: 60 PERSON 25 ITEM 5 CATS MINISTEP 3.81.0

DIF class specification is: DIF=@SCHOOLTYP

PERSON CLASS	OBSERVATIONS COUNT	OBSERVATIONS AVERAGE	BASELINE EXPECT	BASELINE MEASURE	DIF SCORE	DIF MEASURE	DIF SIZE	DIF S.E.	DIF t	Prob.	ITEM Number	Name
EXMODELC	24	1.63	1.51	1.65	.12	1.40	-.25	.30	-.83	.4154	1	CK1.1
NOT TEACH	16	.88	1.10	1.65	-.22	2.16	.51	.39	1.31	.2100	1	CK1.1
PRIVATE	9	1.78	1.82	1.65	-.04	1.73	.08	.48	.17	.8676	1	CK1.1
RURAL	2	1.00	.94	1.65	.06	1.51	-.14	1.11	-.13	.0000	1	CK1.1
TOWNSHIP	9	.89	.79	1.65	.10	1.41	-.24	.50	-.48	.6482	1	CK1.1
EXMODELC	24	1.67	1.73	1.18	-.06	1.31	.13	.30	.44	.6677	2	CK1.2
NOT TEACH	16	1.31	1.32	1.18	.00	1.18	.00	.36	.00	1.000	2	CK1.2
PRIVATE	9	2.00	2.04	1.18	-.04	1.26	.08	.48	.17	.8729	2	CK1.2
RURAL	2	1.50	1.13	1.18	.37	.37	-.81	1.03	-.79	.0000	2	CK1.2
TOWNSHIP	9	1.11	.99	1.18	.12	.93	-.26	.48	-.53	.6105	2	CK1.2
EXMODELC	24	1.58	1.73	1.18	-.14	1.49	.31	.30	1.03	.3146	3	CK1.3
NOT TEACH	16	1.44	1.32	1.18	.12	.94	-.25	.36	-.69	.5004	3	CK1.3
PRIVATE	9	1.33	2.04	1.18	-.70	2.67	1.49	.48	3.07	.0181	3	CK1.3
RURAL	2	1.50	1.13	1.18	.37	.37	-.81	1.03	-.79	.0000	3	CK1.3
TOWNSHIP	9	1.78	.99	1.18	.79	-.42	-1.61	.47	-3.40	.0114	3	CK1.3
EXMODELC	24	1.42	1.61	1.43	-.19	1.84	.41	.30	1.38	.1808	4	CK1.4
NOT TEACH	16	1.31	1.20	1.43	.11	1.19	-.24	.36	-.66	.5179	4	CK1.4
PRIVATE	9	1.89	1.92	1.43	-.03	1.50	.07	.48	.14	.8963	4	CK1.4
RURAL	2	1.00	1.03	1.43	-.03	1.50	.07	1.11	.06	.0000	4	CK1.4
TOWNSHIP	9	1.22	.88	1.43	.34	.70	-.74	.48	-1.54	.1667	4	CK1.4
EXMODELC	24	1.63	1.68	1.29	-.05	1.40	.11	.30	.38	.7105	5	CK1.5
NOT TEACH	16	1.25	1.27	1.29	-.02	1.32	.03	.36	.09	.9269	5	CK1.5
PRIVATE	9	1.78	1.99	1.29	-.21	1.73	.44	.48	.91	.3919	5	CK1.5
RURAL	2	1.00	1.09	1.29	-.09	1.49	.20	1.11	.18	.0000	5	CK1.5
TOWNSHIP	9	1.33	.94	1.29	.39	.47	-.82	.47	-1.73	.1275	5	CK1.5
EXMODELC	24	3.25	2.96	-1.43	.29	-2.13	-.70	.33	-2.12	.0457	6	CK2.1
NOT TEACH	16	2.31	2.58	-1.43	-.27	-.85	.58	.36	1.60	.1328	6	CK2.1
PRIVATE	9	3.11	3.26	-1.43	-.15	-1.07	.36	.51	.72	.4964	6	CK2.1
RURAL	2	2.00	2.40	-1.43	-.40	-.63	.80	.99	.81	.0000	6	CK2.1
TOWNSHIP	9	2.22	2.26	-1.43	-.04	-1.35	.08	.48	.16	.8753	6	CK2.1
EXMODELC	24	1.71	1.84	.94	-.13	1.23	.29	.30	.96	.3469	7	CK2.3
NOT TEACH	16	1.88	1.44	.94	.44	.05	-.89	.36	-2.49	.0261	7	CK2.3
PRIVATE	9	1.78	2.16	.94	-.38	1.73	.79	.48	1.64	.1460	7	CK2.3
RURAL	2	.50	1.24	.94	-.74	2.60	1.66	1.15	1.44	.0000	7	CK2.3
TOWNSHIP	9	1.22	1.11	.94	.12	.70	-.24	.48	-.51	.6268	7	CK2.3
EXMODELC	24	1.29	1.46	1.76	-.17	2.11	.35	.30	1.18	.2513	8	CK2.4
NOT TEACH	16	1.13	1.05	1.76	.08	1.59	-.17	.37	-.46	.6535	8	CK2.4
PRIVATE	9	2.22	1.77	1.76	.46	.80	-.95	.48	-2.00	.0860	8	CK2.4
RURAL	2	1.00	.90	1.76	.10	1.51	-.25	1.12	-.22	.0000	8	CK2.4
TOWNSHIP	9	.56	.74	1.76	-.19	2.26	.50	.57	.88	.4088	8	CK2.4
EXMODELC	24	2.83	2.68	-.81	.15	-1.14	-.33	.30	-1.09	.2867	9	CK3.3
NOT TEACH	16	2.00	2.30	-.81	-.30	-.20	.61	.36	1.71	.1085	9	CK3.3
PRIVATE	9	3.11	3.00	-.81	.11	-1.07	-.25	.51	-.49	.6375	9	CK3.3
RURAL	2	3.00	2.09	-.81	.91	-2.66	-1.84	1.04	-1.77	.0000	9	CK3.3
TOWNSHIP	9	1.78	1.97	-.81	-.19	-.43	.39	.48	.81	.4437	9	CK3.3
EXMODELC	24	2.42	2.20	.18	.21	-.26	-.45	.29	-1.52	.1431	10	CK4.2
NOT TEACH	16	1.56	1.81	.18	-.25	.68	.50	.36	1.41	.1811	10	CK4.2
PRIVATE	9	2.44	2.52	.18	-.08	.35	.16	.48	.34	.7409	10	CK4.2
RURAL	2	2.00	1.59	.18	.41	-.63	-.82	.99	-.82	.0000	10	CK4.2
TOWNSHIP	9	1.33	1.48	.18	-.14	.47	.29	.47	.60	.5650	10	CK4.2
EXMODELC	24	2.54	2.25	.08	.29	-.52	-.61	.30	-2.05	.0522	11	CK4.3
NOT TEACH	16	1.44	1.86	.08	-.42	.94	.86	.36	2.40	.0310	11	CK4.3
PRIVATE	9	2.89	2.57	.08	.31	-.57	-.65	.49	-1.34	.2224	11	CK4.3
RURAL	2	.50	1.64	.08	-1.14	2.08	2.00	1.08	1.86	.0000	11	CK4.3
TOWNSHIP	9	1.44	1.53	.08	-.08	.25	.16	.47	.35	.7384	11	CK4.3
EXMODELC	24	2.54	2.32	-.05	.23	-.52	-.47	.30	-1.59	.1262	12	CK5.1
NOT TEACH	16	1.63	1.93	-.05	-.30	.56	.61	.35	1.73	.1062	12	CK5.1
PRIVATE	9	2.67	2.64	-.05	.02	-.11	-.05	.48	-.11	.9176	12	CK5.1
RURAL	2	2.00	1.71	-.05	.29	-.63	-.58	.99	-.58	.0000	12	CK5.1
TOWNSHIP	9	1.44	1.59	-.05	-.15	.25	.30	.47	.64	.5450	12	CK5.1
EXMODELC	24	1.83	1.79	1.04	.04	.96	-.08	.30	-.28	.7811	13	CK5.2
NOT TEACH	16	1.25	1.39	1.04	-.14	1.32	.28	.36	.77	.4521	13	CK5.2
PRIVATE	9	2.00	2.11	1.04	-.11	1.26	.22	.48	.46	.6619	13	CK5.2
RURAL	2	1.50	1.19	1.04	.31	.37	-.67	1.03	-.65	.0000	13	CK5.2
TOWNSHIP	9	1.22	1.06	1.04	.17	.70	-.35	.48	-.73	.4906	13	CK5.2

EXMODELC	24	2.71	2.81	-1.10	-.10	-.87	.23	.30	.76	.4578	14	REP1
NOT TEACH	16	2.69	2.43	-1.10	.26	-1.66	-.56	.37	-1.50	.1548	14	REP1
PRIVATE	9	3.33	3.13	-1.10	.21	-1.62	-.52	.55	-.95	.3714	14	REP1
RURAL	2	1.50	2.24	-1.10	-.74	.36	1.46	1.00	1.46	.0000	14	REP1
TOWNSHIP	9	1.89	2.10	-1.10	-.21	-.66	.44	.48	.93	.3848	14	REP1
EXMODELC	24	2.38	2.50	-.43	-.12	-.18	.26	.29	.87	.3949	15	REP2
NOT TEACH	16	2.25	2.11	-.43	.14	-.72	-.29	.36	-.80	.4398	15	REP2
PRIVATE	9	2.78	2.82	-.43	-.05	-.34	.10	.48	.20	.8478	15	REP2
RURAL	2	2.00	1.90	-.43	.10	-.63	-.20	.99	-.20	.0000	15	REP2
TOWNSHIP	9	1.89	1.78	-.43	.11	-.66	-.22	.48	-.47	.6532	15	REP2
EXMODELC	24	2.58	2.58	-.60	.00	-.60	.00	.30	.00	1.000	16	REP3
NOT TEACH	16	2.44	2.20	-.60	.24	-1.12	-.51	.37	-1.40	.1834	16	REP3
PRIVATE	9	2.67	2.90	-.60	-.24	-.11	.50	.48	1.04	.3308	16	REP3
RURAL	2	2.00	1.99	-.60	.01	-.63	-.03	.99	-.03	.0000	16	REP3
TOWNSHIP	9	1.67	1.86	-.60	-.20	-.20	.40	.47	.85	.4240	16	REP3
EXMODELC	24	2.67	2.76	-.99	-.10	-.79	.21	.30	.69	.4955	17	CS1
NOT TEACH	16	2.81	2.38	-.99	.43	-1.93	-.94	.37	-2.52	.0245	17	CS1
PRIVATE	9	2.89	3.08	-.99	-.19	-.57	.42	.49	.87	.4156	17	CS1
RURAL	2	1.50	2.18	-.99	-.68	.36	1.35	1.00	1.35	.0000	17	CS1
TOWNSHIP	9	1.89	2.05	-.99	-.16	-.66	.34	.48	.70	.5054	17	CS1
EXMODELC	24	2.54	2.71	-.89	-.17	-.52	.36	.30	1.23	.2332	18	CS2
NOT TEACH	16	2.56	2.33	-.89	.23	-1.38	-.50	.37	-1.36	.1961	18	CS2
PRIVATE	9	3.00	3.03	-.89	-.03	-.81	.07	.50	.15	.8877	18	CS2
RURAL	2	2.00	2.13	-.89	-.13	-.63	.25	.99	.26	.0000	18	CS2
TOWNSHIP	9	2.11	2.00	-.89	.11	-1.12	-.23	.48	-.48	.6442	18	CS2
EXMODELC	24	2.92	2.83	-1.14	.09	-1.33	-.19	.30	-.63	.5360	19	CS3
NOT TEACH	16	2.50	2.45	-1.14	.05	-1.25	-.11	.37	-.31	.7605	19	CS3
PRIVATE	9	3.11	3.14	-1.14	-.03	-1.07	.07	.51	.14	.8937	19	CS3
RURAL	2	2.00	2.25	-1.14	-.25	-.63	.50	.99	.51	.0000	19	CS3
TOWNSHIP	9	1.89	2.12	-1.14	-.23	-.66	.48	.48	1.00	.3495	19	CS3
EXMODELC	24	2.92	2.86	-1.21	.05	-1.33	-.12	.30	-.39	.7000	20	WDT
NOT TEACH	16	2.44	2.48	-1.21	-.04	-1.12	.09	.37	.25	.8036	20	WDT
PRIVATE	9	3.22	3.17	-1.21	.05	-1.33	-.12	.53	-.24	.8197	20	WDT
RURAL	2	3.00	2.29	-1.21	.71	-2.70	-1.49	1.07	-1.39	.0000	20	WDT
TOWNSHIP	9	1.89	2.15	-1.21	-.27	-.66	.55	.48	1.15	.2863	20	WDT
EXMODELC	24	2.50	2.66	-.78	-.16	-.44	.34	.29	1.16	.2571	21	LPK1
NOT TEACH	16	2.44	2.28	-.78	.16	-1.12	-.34	.37	-.92	.3727	21	LPK1
PRIVATE	9	3.00	2.99	-.78	.01	-.81	-.03	.50	-.07	.9488	21	LPK1
RURAL	2	2.50	2.08	-.78	.42	-1.64	-.86	1.03	-.84	.0000	21	LPK1
TOWNSHIP	9	2.00	1.95	-.78	.05	-.89	-.11	.48	-.22	.8307	21	LPK1
EXMODELC	24	2.63	2.60	-.64	.03	-.70	-.06	.30	-.20	.8444	22	LPK2
NOT TEACH	16	2.19	2.21	-.64	-.02	-.59	.05	.36	.14	.8899	22	LPK2
PRIVATE	9	2.89	2.92	-.64	-.03	-.57	.07	.49	.14	.8914	22	LPK2
RURAL	2	2.50	2.00	-.64	.50	-1.64	-1.00	1.03	-.97	.0000	22	LPK2
TOWNSHIP	9	1.78	1.88	-.64	-.10	-.43	.21	.48	.44	.6705	22	LPK2
EXMODELC	24	2.63	2.43	-.29	.19	-.70	-.40	.30	-1.37	.1859	23	LPK3
NOT TEACH	16	1.88	2.05	-.29	-.17	.05	.35	.36	.98	.3459	23	LPK3
PRIVATE	9	2.89	2.76	-.29	.13	-.57	-.28	.49	-.57	.5884	23	LPK3
RURAL	2	2.00	1.83	-.29	.17	-.63	-.34	.99	-.34	.0000	23	LPK3
TOWNSHIP	9	1.33	1.71	-.29	-.38	.47	.76	.47	1.61	.1509	23	LPK3
EXMODELC	24	2.33	2.42	-.26	-.08	-.09	.17	.29	.58	.5689	24	CTS1
NOT TEACH	16	2.00	2.03	-.26	-.03	-.20	.06	.36	.16	.8731	24	CTS1
PRIVATE	9	3.11	2.74	-.26	.37	-1.07	-.81	.51	-1.59	.1562	24	CTS1
RURAL	2	1.50	1.81	-.26	-.31	.37	.63	1.02	.62	.0000	24	CTS1
TOWNSHIP	9	1.67	1.70	-.26	-.03	-.20	.06	.47	.12	.9066	24	CTS1
EXMODELC	24	2.17	2.35	-.12	-.18	.26	.38	.30	1.29	.2100	25	CTS2
NOT TEACH	16	1.88	1.96	-.12	-.09	.05	.18	.36	.49	.6286	25	CTS2
PRIVATE	9	3.33	2.67	-.12	.66	-1.59	-1.47	.51	-2.86	.0242	25	CTS2
RURAL	2	1.50	1.74	-.12	-.24	.37	.49	1.02	.48	.0000	25	CTS2
TOWNSHIP	9	1.67	1.63	-.12	.04	-.20	-.08	.47	-.17	.8721	25	CTS2

Appendix 30 **Highest level of content DIF table for the survey sample**

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TABLE 30.2 Final data file all items for DIF wit ZOU870WS.TXTt Mar 16 10:03 2016
INPUT: 60 PERSON  25 ITEM  REPORTED: 60 PERSON  25 ITEM  5 CATS  MINISTEP 3.81.0
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DIF class specification is: DIF=@HAQUAL
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PERSON CLASS	OBSERVATIONS COUNT	OBSERVATIONS AVERAGE	BASELINE EXPECT	BASELINE MEASURE	DIF SCORE	DIF MEASURE	DIF SIZE	DIF S.E.	DIF t	Prob.	ITEM Number	Name
CHEM1	23	1.22	1.29	1.65	-.07	1.80	.16	.31	.50	.6208	1	CK1.1
CHEM2	5	2.00	1.72	1.65	.28	1.09	-.56	.63	-.89	.4410	1	CK1.1
CHEM3	16	1.75	1.66	1.65	.09	1.46	-.19	.36	-.52	.6091	1	CK1.1
CHEMHons	5	1.40	1.28	1.65	.12	1.40	-.25	.64	-.39	.7258	1	CK1.1
UNKNOWN	11	.55	.72	1.65	-.17	2.12	.47	.51	.91	.3847	1	CK1.1
CHEM1	23	1.65	1.50	1.18	.15	.87	-.31	.30	-1.04	.3117	2	CK1.2
CHEM2	5	2.00	1.95	1.18	.05	1.09	-.09	.63	-.15	.8907	2	CK1.2
CHEM3	16	1.75	1.88	1.18	-.13	1.46	.27	.36	.76	.4626	2	CK1.2
CHEMHons	5	1.40	1.51	1.18	-.11	1.40	.22	.64	.34	.7577	2	CK1.2
UNKNOWN	11	.82	.92	1.18	-.10	1.41	.23	.46	.50	.6324	2	CK1.2
CHEM1	23	1.78	1.50	1.18	.28	.60	-.58	.30	-1.95	.0652	3	CK1.3
CHEM2	5	1.40	1.95	1.18	-.55	2.28	1.10	.64	1.72	.1842	3	CK1.3
CHEM3	16	1.44	1.88	1.18	-.44	2.12	.93	.36	2.57	.0221	3	CK1.3
CHEMHons	5	1.40	1.51	1.18	-.11	1.40	.22	.64	.34	.7577	3	CK1.3
UNKNOWN	11	1.27	.92	1.18	.35	.44	-.74	.43	-1.73	.1177	3	CK1.3
CHEM1	23	1.35	1.39	1.43	-.04	1.52	.09	.31	.28	.7819	4	CK1.4
CHEM2	5	1.80	1.83	1.43	-.03	1.48	.05	.63	.08	.9390	4	CK1.4
CHEM3	16	1.44	1.76	1.43	-.32	2.12	.68	.36	1.89	.0800	4	CK1.4
CHEMHons	5	1.80	1.38	1.43	.42	.58	-.85	.64	-1.33	.2759	4	CK1.4
UNKNOWN	11	1.18	.81	1.43	.37	.63	-.80	.43	-1.87	.0942	4	CK1.4
CHEM1	23	1.39	1.45	1.29	-.06	1.42	.13	.31	.44	.6651	5	CK1.5
CHEM2	5	2.00	1.90	1.29	.10	1.09	-.20	.63	-.32	.7718	5	CK1.5
CHEM3	16	1.63	1.83	1.29	-.20	1.72	.43	.36	1.19	.2536	5	CK1.5
CHEMHons	5	1.60	1.45	1.29	.15	.99	-.30	.64	-.47	.6719	5	CK1.5
UNKNOWN	11	1.18	.87	1.29	.31	.63	-.66	.43	-1.54	.1584	5	CK1.5
CHEM1	23	2.57	2.76	-1.43	-.20	-1.01	.42	.30	1.40	.1776	6	CK2.1
CHEM2	5	3.40	3.13	-1.43	.27	-2.17	-.74	.77	-.96	.4067	6	CK2.1
CHEM3	16	3.31	3.11	-1.43	.20	-1.93	-.50	.41	-1.22	.2419	6	CK2.1
CHEMHons	5	2.20	2.77	-1.43	-.57	-.24	1.19	.64	1.84	.1627	6	CK2.1
UNKNOWN	11	2.45	2.19	-1.43	.26	-1.99	-.56	.44	-1.28	.2333	6	CK2.1
CHEM1	23	1.43	1.62	.94	-.19	1.33	.39	.31	1.28	.2135	7	CK2.3
CHEM2	5	1.80	2.08	.94	-.28	1.48	.54	.63	.87	.4487	7	CK2.3
CHEM3	16	2.13	2.00	.94	.13	.67	-.27	.36	-.75	.4673	7	CK2.3
CHEMHons	5	1.60	1.62	.94	-.02	.99	.05	.64	.08	.9417	7	CK2.3
UNKNOWN	11	1.36	1.03	.94	.33	.26	-.68	.43	-1.59	.1465	7	CK2.3
CHEM1	23	1.39	1.24	1.76	.15	1.42	-.33	.31	-1.09	.2881	8	CK2.4
CHEM2	5	1.40	1.66	1.76	-.26	2.28	.52	.64	.82	.4739	8	CK2.4
CHEM3	16	1.63	1.61	1.76	.02	1.72	-.04	.36	-.10	.9221	8	CK2.4
CHEMHons	5	1.00	1.23	1.76	-.23	2.25	.49	.66	.74	.5152	8	CK2.4
UNKNOWN	11	.55	.68	1.76	-.13	2.12	.36	.52	.70	.5022	8	CK2.4
CHEM1	23	2.52	2.47	-.81	.05	-.92	-.10	.30	-.33	.7412	9	CK3.3
CHEM2	5	3.20	2.88	-.81	.32	-1.61	-.80	.72	-1.10	.3525	9	CK3.3
CHEM3	16	2.88	2.84	-.81	.04	-.89	-.08	.37	-.21	.8331	9	CK3.3
CHEMHons	5	2.40	2.47	-.81	-.07	-.66	.16	.64	.24	.8247	9	CK3.3
UNKNOWN	11	1.64	1.90	-.81	-.26	-.28	.53	.43	1.24	.2475	9	CK3.3
CHEM1	23	1.87	1.99	.18	-.12	.42	.24	.30	.80	.4341	10	CK4.2
CHEM2	5	2.40	2.44	.18	-.04	.27	.08	.65	.13	.9050	10	CK4.2
CHEM3	16	2.75	2.36	.18	.39	-.63	-.81	.36	-2.24	.0419	10	CK4.2
CHEMHons	5	2.20	1.99	.18	.21	-.24	-.43	.64	-.67	.5525	10	CK4.2
UNKNOWN	11	1.00	1.40	.18	-.40	1.01	.82	.44	1.87	.0944	10	CK4.2
CHEM1	23	2.13	2.04	.08	.09	-.11	-.19	.30	-.65	.5254	11	CK4.3
CHEM2	5	3.00	2.49	.08	.51	-1.10	-1.18	.69	-1.70	.1869	11	CK4.3
CHEM3	16	2.69	2.41	.08	.28	-.50	-.58	.36	-1.60	.1315	11	CK4.3
CHEMHons	5	1.60	2.04	.08	-.44	.99	.91	.64	1.42	.2511	11	CK4.3
UNKNOWN	11	.82	1.45	.08	-.64	1.40	1.32	.44	2.97	.0157	11	CK4.3
CHEM1	23	2.22	2.10	-.05	.11	-.29	-.23	.30	-.78	.4427	12	CK5.1
CHEM2	5	2.80	2.55	-.05	.25	-.62	-.57	.68	-.83	.4658	12	CK5.1
CHEM3	16	2.44	2.47	-.05	-.04	.02	.08	.36	.21	.8364	12	CK5.1
CHEMHons	5	1.80	2.11	-.05	-.31	.58	.63	.64	.99	.3952	12	CK5.1
UNKNOWN	11	1.36	1.52	-.05	-.16	.26	.32	.43	.74	.4778	12	CK5.1
CHEM1	23	1.65	1.57	1.04	.08	.87	-.17	.30	-.57	.5738	13	CK5.2
CHEM2	5	1.80	2.02	1.04	-.22	1.48	.44	.63	.70	.5330	13	CK5.2
CHEM3	16	1.88	1.95	1.04	-.07	1.20	.15	.36	.42	.6843	13	CK5.2
CHEMHons	5	1.20	1.57	1.04	-.37	1.82	.77	.65	1.19	.3191	13	CK5.2
UNKNOWN	11	1.18	.98	1.04	.20	.63	-.42	.43	-.97	.3598	13	CK5.2

CHEM1	23	2.70	2.61	-1.10	.09	-1.29	-.19	.31	-.61	.5502	14	REP1
CHEM2	5	3.00	3.00	-1.10	.00	-1.10	.00	.70	.00	1.000	14	REP1
CHEM3	16	2.75	2.97	-1.10	-.22	-.63	.47	.36	1.30	.2136	14	REP1
CHEMHons	5	3.00	2.61	-1.10	.39	-1.95	-.85	.67	-1.26	.2980	14	REP1
UNKNOWN	11	2.00	2.03	-1.10	-.03	-1.03	.07	.44	.16	.8790	14	REP1
CHEM1	23	2.22	2.29	-.43	-.07	-.29	.14	.30	.48	.6336	15	REP2
CHEM2	5	2.60	2.72	-.43	-.12	-.17	.26	.67	.40	.7183	15	REP2
CHEM3	16	2.56	2.66	-.43	-.09	-.24	.19	.36	.54	.5965	15	REP2
CHEMHons	5	2.60	2.29	-.43	.31	-1.08	-.65	.65	-.99	.3931	15	REP2
UNKNOWN	11	1.91	1.71	-.43	.20	-.84	-.41	.43	-.95	.3683	15	REP2
CHEM1	23	2.35	2.37	-.60	-.02	-.55	.05	.30	.17	.8689	16	REP3
CHEM2	5	2.40	2.79	-.60	-.39	.27	.87	.65	1.34	.2724	16	REP3
CHEM3	16	2.75	2.74	-.60	.01	-.63	-.02	.36	-.06	.9511	16	REP3
CHEMHons	5	2.40	2.37	-.60	.03	-.66	-.05	.64	-.08	.9382	16	REP3
UNKNOWN	11	2.00	1.79	-.60	.21	-1.03	-.43	.44	-.98	.3528	16	REP3
CHEM1	23	2.52	2.56	-.99	-.04	-.92	.08	.30	.25	.8031	17	CS1
CHEM2	5	2.80	2.96	-.99	-.16	-.62	.37	.68	.54	.6266	17	CS1
CHEM3	16	2.88	2.92	-.99	-.05	-.89	.10	.37	.27	.7926	17	CS1
CHEMHons	5	2.60	2.56	-.99	.04	-1.08	-.08	.65	-.13	.9042	17	CS1
UNKNOWN	11	2.18	1.98	-.99	.20	-1.41	-.42	.44	-.96	.3612	17	CS1
CHEM1	23	2.43	2.51	-.89	-.07	-.73	.15	.30	.50	.6204	18	CS2
CHEM2	5	3.00	2.91	-.89	.09	-1.10	-.22	.70	-.31	.7777	18	CS2
CHEM3	16	2.75	2.87	-.89	-.12	-.63	.26	.36	.71	.4885	18	CS2
CHEMHons	5	2.80	2.51	-.89	.29	-1.50	-.62	.66	-.94	.4168	18	CS2
UNKNOWN	11	2.09	1.93	-.89	.16	-1.22	-.34	.44	-.77	.4609	18	CS2
CHEM1	23	2.43	2.63	-1.14	-.19	-.73	.40	.30	1.34	.1956	19	CS3
CHEM2	5	3.40	3.01	-1.14	.39	-2.17	-1.03	.76	-1.35	.2695	19	CS3
CHEM3	16	2.94	2.99	-1.14	-.05	-1.03	.11	.37	.29	.7787	19	CS3
CHEMHons	5	2.60	2.63	-1.14	-.03	-1.08	.06	.65	.09	.9333	19	CS3
UNKNOWN	11	2.36	2.05	-1.14	.31	-1.80	-.66	.44	-1.51	.1656	19	CS3
CHEM1	23	2.74	2.66	-1.21	.08	-1.38	-.17	.31	-.56	.5825	20	WDT
CHEM2	5	3.00	3.04	-1.21	-.04	-1.10	.11	.70	.15	.8887	20	WDT
CHEM3	16	3.13	3.02	-1.21	.11	-1.46	-.25	.39	-.64	.5295	20	WDT
CHEMHons	5	2.60	2.66	-1.21	-.06	-1.08	.13	.65	.20	.8522	20	WDT
UNKNOWN	11	1.82	2.08	-1.21	-.27	-.65	.55	.43	1.28	.2321	20	WDT
CHEM1	23	2.48	2.46	-.78	.02	-.82	-.05	.30	-.15	.8818	21	LPK1
CHEM2	5	2.80	2.87	-.78	-.07	-.62	.16	.68	.23	.8337	21	LPK1
CHEM3	16	2.94	2.82	-.78	.12	-1.03	-.25	.37	-.68	.5105	21	LPK1
CHEMHons	5	2.40	2.46	-.78	-.06	-.66	.12	.64	.19	.8636	21	LPK1
UNKNOWN	11	1.73	1.88	-.78	-.15	-.47	.31	.43	.72	.4889	21	LPK1
CHEM1	23	2.43	2.39	-.64	.05	-.73	-.09	.30	-.32	.7553	22	LPK2
CHEM2	5	2.60	2.81	-.64	-.21	-.17	.47	.67	.71	.5299	22	LPK2
CHEM3	16	2.75	2.76	-.64	-.01	-.64	.00	.36	.00	1.000	22	LPK2
CHEMHons	5	2.60	2.39	-.64	.21	-1.08	-.44	.65	-.67	.5485	22	LPK2
UNKNOWN	11	1.73	1.81	-.64	-.08	-.47	.17	.43	.40	.7013	22	LPK2
CHEM1	23	2.17	2.22	-.29	-.05	-.20	.10	.30	.32	.7522	23	LPK3
CHEM2	5	2.80	2.66	-.29	.14	-.62	-.33	.68	-.48	.6627	23	LPK3
CHEM3	16	2.81	2.59	-.29	.22	-.76	-.47	.36	-1.28	.2223	23	LPK3
CHEMHons	5	2.20	2.22	-.29	-.02	-.24	.05	.64	.08	.9435	23	LPK3
UNKNOWN	11	1.36	1.64	-.29	-.28	.26	.56	.43	1.30	.2252	23	LPK3
CHEM1	23	2.09	2.20	-.26	-.12	-.02	.24	.30	.80	.4325	24	CTS1
CHEM2	5	2.60	2.64	-.26	-.04	-.17	.09	.67	.14	.8984	24	CTS1
CHEM3	16	2.69	2.57	-.26	.11	-.50	-.24	.36	-.66	.5227	24	CTS1
CHEMHons	5	2.60	2.21	-.26	.39	-1.08	-.82	.65	-1.26	.2967	24	CTS1
UNKNOWN	11	1.55	1.62	-.26	-.08	-.10	.16	.43	.37	.7210	24	CTS1
CHEM1	23	2.22	2.14	-.12	.08	-.29	-.16	.30	-.55	.5861	25	CTS2
CHEM2	5	2.60	2.58	-.12	.02	-.17	-.04	.67	-.07	.9513	25	CTS2
CHEM3	16	2.56	2.51	-.12	.06	-.24	-.11	.36	-.32	.7554	25	CTS2
CHEMHons	5	2.00	2.14	-.12	-.14	.17	.29	.64	.45	.6810	25	CTS2
UNKNOWN	11	1.36	1.56	-.12	-.19	.26	.38	.43	.90	.3911	25	CTS2

Appendix 31 **Highest education qualification DIF table for the survey sample**

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TABLE 30.2 Final data file all items for DIF wit ZOU870WS.TXTt Mar 16 10:03 2016
INPUT: 60 PERSON  25 ITEM  REPORTED: 60 PERSON  25 ITEM  5 CATS  MINISTEP 3.81.0
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DIF class specification is: DIF=@HEQUAL
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PERSON CLASS	OBSERVATIONS COUNT	AVERAGE	BASELINE EXPECT	MEASURE	DIF SCORE	DIF MEASURE	DIF SIZE	DIF S.E.	DIF t	Prob.	ITEM Number	Name
BEd	12	1.42	1.22	1.65	.20	1.23	-.42	.42	-1.00	.3407	1	CK1.1
BEd Hons	5	1.80	1.74	1.65	.06	1.52	-.13	.64	-.20	.8563	1	CK1.1
MASTERS	4	2.00	2.08	1.65	-.08	1.81	.16	.73	.22	.8456	1	CK1.1
NO ED QUAL	15	1.00	1.07	1.65	-.07	1.81	.16	.38	.41	.6857	1	CK1.1
PGCE / HDE	21	1.33	1.36	1.65	-.03	1.71	.06	.32	.19	.8499	1	CK1.1
TEACH DIP	3	.67	.92	1.65	-.26	2.36	.71	1.01	.70	.6109	1	CK1.1
BEd	12	1.25	1.44	1.18	-.19	1.58	.40	.42	.94	.3675	2	CK1.2
BEd Hons	5	1.80	1.96	1.18	-.16	1.52	.34	.64	.52	.6373	2	CK1.2
MASTERS	4	1.50	2.30	1.18	-.80	2.84	1.66	.71	2.35	.1434	2	CK1.2
NO ED QUAL	15	1.40	1.29	1.18	.11	.97	-.22	.37	-.59	.5659	2	CK1.2
PGCE / HDE	21	1.76	1.57	1.18	.19	.78	-.40	.32	-1.27	.2198	2	CK1.2
TEACH DIP	3	1.33	1.12	1.18	.22	.72	-.46	.83	-.56	.6753	2	CK1.2
BEd	12	1.58	1.44	1.18	.15	.88	-.30	.42	-.73	.4833	3	CK1.3
BEd Hons	5	1.80	1.96	1.18	-.16	1.52	.34	.64	.52	.6373	3	CK1.3
MASTERS	4	1.75	2.30	1.18	-.55	2.33	1.15	.72	1.60	.2509	3	CK1.3
NO ED QUAL	15	1.47	1.29	1.18	.17	.83	-.35	.37	-.96	.3555	3	CK1.3
PGCE / HDE	21	1.38	1.57	1.18	-.19	1.61	.42	.32	1.30	.2093	3	CK1.3
TEACH DIP	3	2.00	1.12	1.18	.88	-.59	-1.77	.82	-2.17	.2745	3	CK1.3
BEd	12	1.17	1.32	1.43	-.15	1.77	.33	.43	.78	.4539	4	CK1.4
BEd Hons	5	1.60	1.84	1.43	-.24	1.94	.51	.65	.78	.4910	4	CK1.4
MASTERS	4	2.00	2.18	1.43	-.18	1.81	.38	.73	.52	.6561	4	CK1.4
NO ED QUAL	15	1.47	1.17	1.43	.29	.83	-.60	.37	-1.63	.1262	4	CK1.4
PGCE / HDE	21	1.43	1.46	1.43	-.03	1.50	.07	.32	.21	.8347	4	CK1.4
TEACH DIP	3	1.00	1.01	1.43	-.01	1.46	.02	.89	.03	.9834	4	CK1.4
BEd	12	1.25	1.39	1.29	-.14	1.58	.29	.42	.69	.5035	5	CK1.5
BEd Hons	5	1.80	1.91	1.29	-.11	1.52	.23	.64	.36	.7437	5	CK1.5
MASTERS	4	1.50	2.25	1.29	-.75	2.84	1.55	.71	2.20	.1591	5	CK1.5
NO ED QUAL	15	1.47	1.24	1.29	.22	.83	-.46	.37	-1.25	.2346	5	CK1.5
PGCE / HDE	21	1.48	1.52	1.29	-.05	1.40	.11	.32	.33	.7452	5	CK1.5
TEACH DIP	3	2.00	1.07	1.29	.93	-.59	-1.88	.82	-2.30	.2608	5	CK1.5
BEd	12	2.58	2.71	-1.43	-.12	-1.17	.26	.42	.63	.5438	6	CK2.1
BEd Hons	5	3.40	3.20	-1.43	.20	-1.97	-.54	.76	-.71	.5280	6	CK2.1
MASTERS	4	3.50	3.49	-1.43	.01	-1.47	-.04	.85	-.04	.9702	6	CK2.1
NO ED QUAL	15	2.47	2.56	-1.43	-.10	-1.22	.21	.38	.55	.5935	6	CK2.1
PGCE / HDE	21	2.76	2.80	-1.43	-.04	-1.34	.09	.33	.27	.7882	6	CK2.1
TEACH DIP	3	3.33	2.40	-1.43	.93	-3.70	-2.27	.97	-2.35	.2557	6	CK2.1
BEd	12	1.67	1.56	.94	.11	.71	-.23	.41	-.55	.5913	7	CK2.3
BEd Hons	5	2.00	2.08	.94	-.08	1.11	.17	.64	.26	.8109	7	CK2.3
MASTERS	4	2.00	2.41	.94	-.41	1.81	.87	.73	1.19	.3546	7	CK2.3
NO ED QUAL	15	1.47	1.41	.94	.05	.83	-.11	.37	-.29	.7750	7	CK2.3
PGCE / HDE	21	1.76	1.69	.94	.07	.78	-.16	.32	-.50	.6211	7	CK2.3
TEACH DIP	3	.67	1.23	.94	-.56	2.36	1.42	1.01	1.40	.3950	7	CK2.3
BEd	12	1.08	1.17	1.76	-.09	1.95	.19	.43	.44	.6672	8	CK2.4
BEd Hons	5	1.40	1.69	1.76	-.29	2.36	.60	.65	.92	.4233	8	CK2.4
MASTERS	4	2.25	2.02	1.76	.23	1.28	-.48	.73	-.66	.5777	8	CK2.4
NO ED QUAL	15	.93	1.02	1.76	-.09	1.96	.20	.39	.51	.6180	8	CK2.4
PGCE / HDE	21	1.48	1.31	1.76	.16	1.40	-.36	.32	-1.12	.2763	8	CK2.4
TEACH DIP	3	.67	.88	1.76	-.21	2.36	.60	1.01	.59	.6594	8	CK2.4
BEd	12	2.17	2.41	-.81	-.25	-.31	.51	.41	1.23	.2462	9	CK3.3
BEd Hons	5	3.20	2.93	-.81	.27	-1.44	-.62	.70	-.89	.4398	9	CK3.3
MASTERS	4	3.25	3.25	-.81	.00	-.81	.00	.76	.00	1.000	9	CK3.3
NO ED QUAL	15	2.13	2.27	-.81	-.14	-.52	.29	.37	.78	.4477	9	CK3.3
PGCE / HDE	21	2.62	2.52	-.81	.10	-1.03	-.21	.32	-.67	.5108	9	CK3.3
TEACH DIP	3	2.67	2.11	-.81	.55	-2.03	-1.22	.88	-1.38	.3996	9	CK3.3
BEd	12	1.92	1.92	.18	-.01	.18	.00	.41	.00	1.000	10	CK4.2
BEd Hons	5	2.40	2.45	.18	-.05	.29	.11	.64	.16	.8795	10	CK4.2
MASTERS	4	2.50	2.78	.18	-.28	.76	.57	.72	.80	.5074	10	CK4.2
NO ED QUAL	15	1.60	1.79	.18	-.19	.56	.38	.37	1.03	.3197	10	CK4.2
PGCE / HDE	21	2.24	2.04	.18	.20	-.22	-.41	.32	-1.30	.2098	10	CK4.2
TEACH DIP	3	1.67	1.60	.18	.06	.06	-.12	.80	-.15	.9045	10	CK4.2
BEd	12	1.75	1.97	.08	-.22	.54	.46	.41	1.11	.2941	11	CK4.3
BEd Hons	5	3.00	2.50	.08	.50	-.97	-1.05	.67	-1.57	.2140	11	CK4.3
MASTERS	4	3.25	2.83	.08	.42	-.82	-.90	.76	-1.18	.3591	11	CK4.3
NO ED QUAL	15	1.47	1.84	.08	-.37	.83	.75	.37	2.04	.0617	11	CK4.3
PGCE / HDE	21	2.33	2.09	.08	.24	-.42	-.51	.32	-1.60	.1251	11	CK4.3
TEACH DIP	3	1.33	1.66	.08	-.32	.72	.64	.83	.77	.5806	11	CK4.3
BEd	12	2.00	2.04	-.05	-.04	.03	.08	.41	.21	.8407	12	CK5.1
BEd Hons	5	2.00	2.57	-.05	-.57	1.11	1.16	.64	1.81	.1680	12	CK5.1
MASTERS	4	3.50	2.90	-.05	.60	-1.47	-1.41	.85	-1.65	.2404	12	CK5.1
NO ED QUAL	15	1.73	1.91	-.05	-.17	.30	.35	.37	.95	.3588	12	CK5.1
PGCE / HDE	21	2.29	2.16	-.05	.13	-.32	-.27	.32	-.86	.4022	12	CK5.1
TEACH DIP	3	2.00	1.73	-.05	.27	-.59	-.53	.82	-.65	.6309	12	CK5.1
BEd	12	1.83	1.51	1.04	.33	.37	-.67	.41	-1.64	.1325	13	CK5.2
BEd Hons	5	1.60	2.03	1.04	-.43	1.94	.89	.65	1.38	.2606	13	CK5.2
MASTERS	4	2.25	2.36	1.04	-.11	1.28	.24	.73	.32	.7762	13	CK5.2
NO ED QUAL	15	1.33	1.36	1.04	-.03	1.10	.06	.37	.16	.8751	13	CK5.2
PGCE / HDE	21	1.67	1.64	1.04	.03	.98	-.06	.32	-.19	.8521	13	CK5.2
TEACH DIP	3	.67	1.18	1.04	-.51	2.36	1.31	1.01	1.30	.4183	13	CK5.2

BEd	12	2.58	2.55	-1.10	.03	-1.17	-.07	.42	-.16	.8764	14 REP1
BEd Hons	5	3.40	3.06	-1.10	.34	-1.97	-.87	.76	-1.15	.3350	14 REP1
MASTERS	4	3.50	3.37	-1.10	.13	-1.47	-.37	.85	-.43	.7100	14 REP1
NO ED QUAL	15	2.60	2.41	-1.10	.19	-1.51	-.41	.38	-1.08	.2994	14 REP1
PGCE / HDE	21	2.43	2.65	-1.10	-.22	-.62	.48	.32	1.50	.1497	14 REP1
TEACH DIP	3	2.00	2.25	-1.10	-.25	-.59	.51	.82	.63	.6435	14 REP1
BEd	12	2.25	2.23	-.43	.02	-.48	-.05	.41	-.11	.9136	15 REP2
BEd Hons	5	3.20	2.75	-.43	.45	-1.44	-1.01	.70	-1.43	.2472	15 REP2
MASTERS	4	2.75	3.08	-.43	-.33	.25	.68	.71	.95	.4421	15 REP2
NO ED QUAL	15	2.13	2.09	-.43	.04	-.52	-.09	.37	-.25	.8086	15 REP2
PGCE / HDE	21	2.24	2.34	-.43	-.10	-.22	.21	.32	.65	.5209	15 REP2
TEACH DIP	3	2.00	1.92	-.43	.08	-.59	-.16	.82	-.19	.8791	15 REP2
BEd	12	2.58	2.31	-.60	.27	-1.17	-.56	.42	-1.34	.2096	16 REP3
BEd Hons	5	3.60	2.83	-.60	.77	-2.63	-2.02	.87	-2.33	.1023	16 REP3
MASTERS	4	3.25	3.16	-.60	.09	-.82	-.22	.76	-.28	.8045	16 REP3
NO ED QUAL	15	2.13	2.17	-.60	-.04	-.52	.08	.37	.22	.8305	16 REP3
PGCE / HDE	21	2.10	2.42	-.60	-.32	.07	.68	.32	2.15	.0448	16 REP3
TEACH DIP	3	2.00	2.01	-.60	-.01	-.60	.00	.82	.00	1.000	16 REP3
BEd	12	2.42	2.50	-.99	-.08	-.82	.17	.41	.42	.6857	17 CS1
BEd Hons	5	3.00	3.01	-.99	-.01	-.97	.02	.67	.03	.9760	17 CS1
MASTERS	4	3.25	3.32	-.99	-.07	-.82	.17	.76	.22	.8430	17 CS1
NO ED QUAL	15	2.67	2.36	-.99	.31	-1.65	-.66	.38	-1.74	.1056	17 CS1
PGCE / HDE	21	2.48	2.60	-.99	-.13	-.72	.27	.32	.84	.4101	17 CS1
TEACH DIP	3	2.00	2.20	-.99	-.20	-.59	.40	.82	.50	.7074	17 CS1
BEd	12	2.50	2.45	-.89	.05	-.99	-.11	.42	-.26	.8031	18 CS2
BEd Hons	5	3.00	2.96	-.89	.04	-.97	-.08	.67	-.13	.9072	18 CS2
MASTERS	4	3.25	3.28	-.89	-.03	-.82	.07	.76	.09	.9398	18 CS2
NO ED QUAL	15	2.53	2.31	-.89	.23	-1.37	-.48	.38	-1.27	.2252	18 CS2
PGCE / HDE	21	2.43	2.55	-.89	-.12	-.62	.26	.32	.82	.4201	18 CS2
TEACH DIP	3	1.67	2.15	-.89	-.48	.06	.95	.80	1.18	.4474	18 CS2
BEd	12	2.58	2.57	-1.14	.01	-1.17	-.03	.42	-.07	.9430	19 CS3
BEd Hons	5	3.00	3.07	-1.14	-.07	-.97	.17	.67	.25	.8206	19 CS3
MASTERS	4	3.25	3.38	-1.14	-.13	-.82	.32	.76	.41	.7197	19 CS3
NO ED QUAL	15	2.53	2.43	-1.14	.11	-1.37	-.23	.38	-.61	.5526	19 CS3
PGCE / HDE	21	2.62	2.67	-1.14	-.05	-1.03	.11	.32	.33	.7429	19 CS3
TEACH DIP	3	2.33	2.27	-1.14	.07	-1.28	-.14	.85	-.17	.8931	19 CS3
BEd	12	2.58	2.60	-1.21	-.02	-1.17	.04	.42	.10	.9223	20 WDT
BEd Hons	5	3.20	3.10	-1.21	.10	-1.44	-.23	.70	-.33	.7643	20 WDT
MASTERS	4	3.25	3.41	-1.21	-.16	-.82	.39	.76	.51	.6619	20 WDT
NO ED QUAL	15	2.40	2.46	-1.21	-.06	-1.08	.13	.38	.34	.7426	20 WDT
PGCE / HDE	21	2.81	2.70	-1.21	.11	-1.45	-.24	.33	-.73	.4739	20 WDT
TEACH DIP	3	2.00	2.30	-1.21	-.30	-.59	.62	.82	.76	.5861	20 WDT
BEd	12	2.42	2.40	-.78	.02	-.82	-.04	.41	-.10	.9256	21 LPK1
BEd Hons	5	3.00	2.91	-.78	.09	-.97	-.19	.67	-.28	.7944	21 LPK1
MASTERS	4	3.00	3.23	-.78	-.23	-.27	.51	.73	.70	.5548	21 LPK1
NO ED QUAL	15	2.27	2.26	-.78	.01	-.80	-.02	.37	-.06	.9537	21 LPK1
PGCE / HDE	21	2.52	2.50	-.78	.02	-.83	-.05	.32	-.15	.8860	21 LPK1
TEACH DIP	3	2.00	2.09	-.78	-.09	-.59	.19	.82	.23	.8534	21 LPK1
BEd	12	2.50	2.33	-.64	.17	-.99	-.35	.42	-.85	.4173	22 LPK2
BEd Hons	5	2.80	2.85	-.64	-.05	-.54	.10	.65	.16	.8831	22 LPK2
MASTERS	4	4.00	3.17	-.64	.83	-3.71>	-3.07	1.86	-1.65	.2399	22 LPK2
NO ED QUAL	15	2.07	2.19	-.64	-.12	-.39	.25	.37	.68	.5055	22 LPK2
PGCE / HDE	21	2.24	2.44	-.64	-.20	-.22	.41	.32	1.31	.2048	22 LPK2
TEACH DIP	3	2.33	2.03	-.64	.31	-1.28	-.64	.85	-.75	.5887	22 LPK2
BEd	12	2.25	2.16	-.29	.09	-.48	-.18	.41	-.45	.6656	23 LPK3
BEd Hons	5	2.60	2.68	-.29	-.08	-.12	.18	.64	.27	.8027	23 LPK3
MASTERS	4	3.25	3.01	-.29	.24	-.82	-.53	.76	-.69	.5622	23 LPK3
NO ED QUAL	15	1.80	2.02	-.29	-.22	.16	.45	.37	1.23	.2388	23 LPK3
PGCE / HDE	21	2.43	2.27	-.29	.16	-.62	-.33	.32	-1.04	.3095	23 LPK3
TEACH DIP	3	1.33	1.85	-.29	-.52	.72	1.02	.83	1.23	.4347	23 LPK3
BEd	12	2.25	2.14	-.26	.11	-.48	-.22	.41	-.53	.6087	24 CTS1
BEd Hons	5	2.40	2.67	-.26	-.27	.29	.55	.64	.86	.4526	24 CTS1
MASTERS	4	3.75	3.00	-.26	.75	-2.38	-2.12	1.10	-1.93	.1941	24 CTS1
NO ED QUAL	15	1.87	2.01	-.26	-.14	.02	.28	.37	.77	.4543	24 CTS1
PGCE / HDE	21	2.24	2.25	-.26	-.02	-.22	.03	.32	.11	.9142	24 CTS1
TEACH DIP	3	1.67	1.83	-.26	-.17	.06	.32	.80	.40	.7569	24 CTS1
BEd	12	1.83	2.08	-.12	-.24	.37	.49	.41	1.19	.2601	25 CTS2
BEd Hons	5	2.40	2.60	-.12	-.20	.29	.41	.64	.65	.5641	25 CTS2
MASTERS	4	3.75	2.93	-.12	.82	-2.38	-2.26	1.10	-2.05	.1769	25 CTS2
NO ED QUAL	15	1.93	1.94	-.12	-.01	-.12	.00	.37	.00	1.000	25 CTS2
PGCE / HDE	21	2.29	2.19	-.12	.10	-.32	-.20	.32	-.64	.5295	25 CTS2
TEACH DIP	3	1.33	1.76	-.12	-.43	.72	.84	.83	1.02	.4931	25 CTS2

Appendix 32 **Teaching experience DIF plot for the survey sample**

```
TABLE 30.2 Final data file all items for DIF wit ZOU870WS.TXTt Mar 16 10:03 2016
INPUT: 60 PERSON  25 ITEM  REPORTED: 60 PERSON  25 ITEM  5 CATS  MINISTEP 3.81.0
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DIF class specification is: DIF=@TEACHING EXPERIENCE
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PERSON	OBSERVATIONS		BASELINE		DIF	DIF	DIF	DIF	DIF		ITEM	
CLASS	COUNT	AVERAGE	EXPECT	MEASURE	SCORE	MEASURE	SIZE	S.E.	t	Prob.	Number	Name
0 YEARS	12	.92	.99	1.65	-.07	1.81	.16	.44	.37	.7174	1	CK1.1
1-3 YEARS	9	1.11	1.11	1.65	.00	1.65	.00	.49	.00	1.000	1	CK1.1
11-20 YEARS	13	1.15	1.34	1.65	-.19	2.08	.43	.43	1.01	.3329	1	CK1.1
21+ YEARS	14	1.93	1.70	1.65	.23	1.18	-.47	.38	-1.22	.2450	1	CK1.1
4-10 YEARS	12	1.33	1.34	1.65	.00	1.65	.00	.43	.00	1.000	1	CK1.1
0 YEARS	12	1.33	1.20	1.18	.13	.91	-.27	.41	-.66	.5261	2	CK1.2
1-3 YEARS	9	1.22	1.32	1.18	-.10	1.40	.22	.49	.45	.6693	2	CK1.2
11-20 YEARS	13	1.77	1.55	1.18	.22	.73	-.45	.40	-1.14	.2784	2	CK1.2
21+ YEARS	14	1.86	1.93	1.18	-.07	1.33	.14	.38	.37	.7184	2	CK1.2
4-10 YEARS	12	1.33	1.55	1.18	-.21	1.65	.47	.43	1.09	.3010	2	CK1.2
0 YEARS	12	1.25	1.20	1.18	.05	1.08	-.10	.42	-.24	.8153	3	CK1.3
1-3 YEARS	9	1.22	1.32	1.18	-.10	1.40	.22	.49	.45	.6693	3	CK1.3
11-20 YEARS	13	1.54	1.55	1.18	-.01	1.21	.03	.41	.07	.9418	3	CK1.3
21+ YEARS	14	1.71	1.93	1.18	-.21	1.62	.43	.38	1.14	.2771	3	CK1.3
4-10 YEARS	12	1.83	1.55	1.18	.29	.58	-.61	.42	-1.45	.1771	3	CK1.3
0 YEARS	12	1.17	1.09	1.43	.08	1.26	-.17	.42	-.41	.6881	4	CK1.4
1-3 YEARS	9	1.11	1.21	1.43	-.10	1.64	.21	.49	.43	.6826	4	CK1.4
11-20 YEARS	13	1.62	1.44	1.43	.18	1.05	-.38	.40	-.95	.3643	4	CK1.4
21+ YEARS	14	1.71	1.81	1.43	-.09	1.62	.19	.38	.49	.6345	4	CK1.4
4-10 YEARS	12	1.33	1.43	1.43	-.10	1.65	.22	.43	.51	.6178	4	CK1.4
0 YEARS	12	1.25	1.15	1.29	.10	1.08	-.21	.42	-.49	.6314	5	CK1.5
1-3 YEARS	9	1.11	1.27	1.29	-.16	1.64	.35	.49	.72	.4976	5	CK1.5
11-20 YEARS	13	1.62	1.50	1.29	.11	1.05	-.24	.40	-.59	.5650	5	CK1.5
21+ YEARS	14	1.86	1.87	1.29	-.02	1.33	.04	.38	.09	.9272	5	CK1.5
4-10 YEARS	12	1.42	1.50	1.29	-.08	1.47	.18	.43	.42	.6836	5	CK1.5
0 YEARS	12	2.25	2.47	-1.43	-.22	-.95	.48	.42	1.15	.2775	6	CK2.1
1-3 YEARS	9	2.56	2.59	-1.43	-.04	-1.35	.08	.48	.16	.8791	6	CK2.1
11-20 YEARS	13	3.00	2.79	-1.43	.21	-1.95	-.52	.44	-1.17	.2678	6	CK2.1
21+ YEARS	14	3.21	3.16	-1.43	.06	-1.56	-.13	.41	-.32	.7557	6	CK2.1
4-10 YEARS	12	2.75	2.78	-1.43	-.03	-1.35	.08	.43	.18	.8619	6	CK2.1
0 YEARS	12	1.75	1.32	.94	.43	.08	-.86	.41	-2.10	.0616	7	CK2.3
1-3 YEARS	9	1.00	1.44	.94	-.44	1.89	.95	.50	1.90	.0986	7	CK2.3
11-20 YEARS	13	1.54	1.67	.94	-.13	1.21	.27	.41	.68	.5125	7	CK2.3
21+ YEARS	14	2.21	2.04	.94	.17	.58	-.36	.39	-.92	.3743	7	CK2.3
4-10 YEARS	12	1.50	1.66	.94	-.16	1.29	.35	.43	.82	.4326	7	CK2.3
0 YEARS	12	1.00	.94	1.76	.06	1.62	-.14	.43	-.31	.7593	8	CK2.4
1-3 YEARS	9	.67	1.06	1.76	-.39	2.68	.92	.53	1.73	.1268	8	CK2.4
11-20 YEARS	13	1.15	1.29	1.76	-.14	2.08	.32	.43	.76	.4651	8	CK2.4
21+ YEARS	14	2.07	1.65	1.76	.43	.88	-.88	.39	-2.27	.0424	8	CK2.4
4-10 YEARS	12	1.17	1.29	1.76	-.12	2.03	.27	.44	.62	.5460	8	CK2.4
0 YEARS	12	2.00	2.19	-.81	-.19	-.43	.39	.41	.94	.3691	9	CK3.3
1-3 YEARS	9	1.78	2.29	-.81	-.51	.24	1.05	.48	2.20	.0638	9	CK3.3
11-20 YEARS	13	2.54	2.51	-.81	.02	-.87	-.05	.41	-.13	.9015	9	CK3.3
21+ YEARS	14	3.14	2.88	-.81	.26	-1.39	-.58	.41	-1.43	.1789	9	CK3.3
4-10 YEARS	12	2.75	2.50	-.81	.25	-1.35	-.54	.43	-1.25	.2408	9	CK3.3
0 YEARS	12	1.33	1.70	.18	-.36	.91	.73	.41	1.77	.1068	10	CK4.2
1-3 YEARS	9	1.89	1.80	.18	.09	.01	-.18	.48	-.37	.7233	10	CK4.2
11-20 YEARS	13	1.92	2.04	.18	-.11	.41	.23	.40	.58	.5749	10	CK4.2
21+ YEARS	14	2.71	2.40	.18	.31	-.46	-.65	.39	-1.67	.1208	10	CK4.2
4-10 YEARS	12	2.08	2.02	.18	.06	.06	-.13	.42	-.30	.7672	10	CK4.2
0 YEARS	12	1.17	1.75	.08	-.58	1.26	1.17	.42	2.83	.0178	11	CK4.3
1-3 YEARS	9	1.78	1.85	.08	-.08	.24	.15	.48	.32	.7558	11	CK4.3
11-20 YEARS	13	2.31	2.09	.08	.22	-.38	-.46	.40	-1.14	.2769	11	CK4.3
21+ YEARS	14	2.64	2.45	.08	.19	-.31	-.39	.39	-1.02	.3273	11	CK4.3
4-10 YEARS	12	2.25	2.07	.08	.18	-.29	-.37	.42	-.89	.3958	11	CK4.3
0 YEARS	12	1.50	1.82	-.05	-.32	.58	.63	.41	1.55	.1519	12	CK5.1
1-3 YEARS	9	1.89	1.92	-.05	-.03	.01	.06	.48	.13	.8988	12	CK5.1
11-20 YEARS	13	2.15	2.15	-.05	.00	-.05	.00	.40	.00	1.000	12	CK5.1
21+ YEARS	14	2.79	2.52	-.05	.27	-.61	-.56	.39	-1.44	.1762	12	CK5.1
4-10 YEARS	12	2.17	2.14	-.05	.03	-.11	-.06	.42	-.14	.8885	12	CK5.1
0 YEARS	12	1.08	1.27	1.04	-.19	1.44	.39	.43	.92	.3769	13	CK5.2
1-3 YEARS	9	1.78	1.39	1.04	.39	.24	-.81	.48	-1.69	.1355	13	CK5.2
11-20 YEARS	13	1.46	1.62	1.04	-.16	1.38	.34	.41	.82	.4283	13	CK5.2
21+ YEARS	14	2.00	1.99	1.04	.01	1.04	.00	.39	.00	1.000	13	CK5.2
4-10 YEARS	12	1.67	1.61	1.04	.05	.93	-.11	.42	-.27	.7907	13	CK5.2

0 YEARS	12	2.75	2.32	-1.10	.43	-2.04	-.94	.43	-2.17	.0550	14	REP1
1-3 YEARS	9	2.44	2.43	-1.10	.01	-1.12	-.03	.48	-.05	.9594	14	REP1
11-20 YEARS	13	2.46	2.64	-1.10	-.18	-.70	.40	.41	.98	.3461	14	REP1
21+ YEARS	14	2.79	3.01	-1.10	-.23	-.61	.49	.39	1.26	.2332	14	REP1
4-10 YEARS	12	2.67	2.64	-1.10	.03	-1.17	-.07	.43	-.16	.8756	14	REP1
0 YEARS	12	2.25	2.00	-.43	.25	-.95	-.52	.42	-1.23	.2477	15	REP2
1-3 YEARS	9	2.22	2.10	-.43	.12	-.67	-.24	.48	-.50	.6298	15	REP2
11-20 YEARS	13	2.46	2.33	-.43	.13	-.70	-.27	.41	-.66	.5210	15	REP2
21+ YEARS	14	2.43	2.70	-.43	-.27	.14	.57	.39	1.47	.1680	15	REP2
4-10 YEARS	12	2.17	2.32	-.43	-.15	-.11	.32	.42	.77	.4618	15	REP2
0 YEARS	12	2.17	2.09	-.60	.08	-.77	-.17	.42	-.40	.6981	16	REP3
1-3 YEARS	9	2.67	2.19	-.60	.48	-1.59	-.98	.48	-2.03	.0819	16	REP3
11-20 YEARS	13	2.54	2.42	-.60	.12	-.87	-.26	.41	-.64	.5353	16	REP3
21+ YEARS	14	2.50	2.78	-.60	-.28	-.01	.59	.39	1.53	.1520	16	REP3
4-10 YEARS	12	2.17	2.40	-.60	-.24	-.11	.49	.42	1.18	.2643	16	REP3
0 YEARS	12	2.75	2.27	-.99	.48	-2.04	-1.05	.43	-2.42	.0359	17	CS1
1-3 YEARS	9	2.56	2.38	-.99	.18	-1.35	-.36	.48	-.75	.4753	17	CS1
11-20 YEARS	13	2.46	2.60	-.99	-.13	-.70	.29	.41	.72	.4873	17	CS1
21+ YEARS	14	2.64	2.96	-.99	-.32	-.31	.68	.39	1.76	.1040	17	CS1
4-10 YEARS	12	2.50	2.59	-.99	-.09	-.81	.18	.42	.43	.6733	17	CS1
0 YEARS	12	2.50	2.22	-.89	.28	-1.49	-.60	.43	-1.41	.1897	18	CS2
1-3 YEARS	9	2.33	2.33	-.89	.01	-.89	.00	.48	.00	1.000	18	CS2
11-20 YEARS	13	2.54	2.55	-.89	-.01	-.89	.00	.41	.00	1.000	18	CS2
21+ YEARS	14	2.64	2.91	-.89	-.27	-.31	.57	.39	1.48	.1639	18	CS2
4-10 YEARS	12	2.58	2.54	-.89	.05	-.99	-.10	.42	-.24	.8143	18	CS2
0 YEARS	12	2.50	2.34	-1.14	.16	-1.49	-.35	.43	-.82	.4317	19	CS3
1-3 YEARS	9	2.89	2.45	-1.14	.44	-2.06	-.93	.50	-1.88	.1026	19	CS3
11-20 YEARS	13	2.69	2.66	-1.14	.03	-1.21	-.07	.42	-.17	.8656	19	CS3
21+ YEARS	14	2.64	3.03	-1.14	-.39	-.31	.82	.39	2.13	.0544	19	CS3
4-10 YEARS	12	2.58	2.65	-1.14	-.07	-.99	.15	.42	.35	.7333	19	CS3
0 YEARS	12	2.08	2.37	-1.21	-.29	-.60	.61	.42	1.47	.1725	20	WDT
1-3 YEARS	9	2.78	2.49	-1.21	.29	-1.82	-.61	.49	-1.26	.2491	20	WDT
11-20 YEARS	13	2.77	2.69	-1.21	.08	-1.38	-.18	.42	-.42	.6846	20	WDT
21+ YEARS	14	2.93	3.06	-1.21	-.13	-.92	.29	.39	.74	.4720	20	WDT
4-10 YEARS	12	2.83	2.68	-1.21	.15	-1.54	-.33	.44	-.76	.4637	20	WDT
0 YEARS	12	2.25	2.17	-.78	.08	-.95	-.17	.42	-.40	.6981	21	LPK1
1-3 YEARS	9	2.22	2.28	-.78	-.05	-.67	.11	.48	.23	.8263	21	LPK1
11-20 YEARS	13	2.38	2.50	-.78	-.11	-.54	.24	.40	.60	.5595	21	LPK1
21+ YEARS	14	2.93	2.86	-.78	.06	-.92	-.14	.39	-.35	.7324	21	LPK1
4-10 YEARS	12	2.50	2.49	-.78	.01	-.81	-.03	.42	-.07	.9447	21	LPK1
0 YEARS	12	2.17	2.10	-.64	.06	-.77	-.13	.42	-.32	.7585	22	LPK2
1-3 YEARS	9	2.22	2.21	-.64	.02	-.67	-.03	.48	-.07	.9488	22	LPK2
11-20 YEARS	13	2.31	2.43	-.64	-.13	-.38	.26	.40	.66	.5236	22	LPK2
21+ YEARS	14	2.79	2.80	-.64	-.01	-.61	.03	.39	.07	.9452	22	LPK2
4-10 YEARS	12	2.50	2.42	-.64	.08	-.81	-.17	.42	-.40	.6946	22	LPK2
0 YEARS	12	1.75	1.94	-.29	-.19	.08	.37	.41	.92	.3813	23	LPK3
1-3 YEARS	9	2.11	2.04	-.29	.07	-.44	-.15	.48	-.32	.7599	23	LPK3
11-20 YEARS	13	2.23	2.27	-.29	-.04	-.22	.08	.40	.19	.8490	23	LPK3
21+ YEARS	14	2.64	2.63	-.29	.01	-.29	.00	.39	.00	1.000	23	LPK3
4-10 YEARS	12	2.42	2.25	-.29	.16	-.63	-.34	.42	-.81	.4354	23	LPK3
0 YEARS	12	1.75	1.92	-.26	-.17	.08	.34	.41	.83	.4249	24	CTS1
1-3 YEARS	9	2.22	2.02	-.26	.20	-.67	-.41	.48	-.87	.4154	24	CTS1
11-20 YEARS	13	2.15	2.25	-.26	-.10	-.06	.20	.40	.51	.6216	24	CTS1
21+ YEARS	14	2.79	2.62	-.26	.17	-.61	-.35	.39	-.91	.3816	24	CTS1
4-10 YEARS	12	2.17	2.24	-.26	-.07	-.11	.15	.42	.35	.7330	24	CTS1
0 YEARS	12	1.75	1.85	-.12	-.10	.08	.20	.41	.50	.6304	25	CTS2
1-3 YEARS	9	1.67	1.95	-.12	-.29	.47	.59	.48	1.23	.2591	25	CTS2
11-20 YEARS	13	2.31	2.19	-.12	.12	-.38	-.25	.40	-.63	.5401	25	CTS2
21+ YEARS	14	2.71	2.55	-.12	.16	-.46	-.34	.39	-.88	.3979	25	CTS2
4-10 YEARS	12	2.17	2.17	-.12	.00	-.12	.00	.42	.00	1.000	25	CTS2

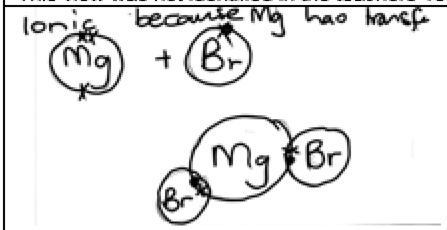
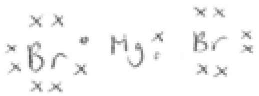
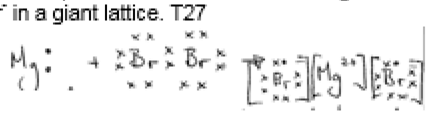
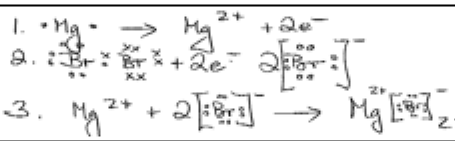
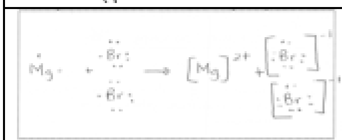
Appendix 33 **Explanatory framework analysis coding guidelines**

CK2.1 What is a chemical bond?	Comment	Code
It is a bond that exists between atoms to form molecules. T12 A chemical bond is the interaction between two atoms. T01 A force that keeps two or more atoms tightly together. T05	Formation of molecules Interaction between atoms Force between atoms	Atom
The link between two atoms that involve either sharing or donation of electrons between atoms. T08 Atoms coming together in the form of covalent bonding (sharing electrons) or ionic bonding (transfer-donate/accept).T15	Sharing or transfer of electrons	Octet
Interacting between atoms of elements to reach stability of the atoms resulting in a bond forming. T21	Stability or minimum energy	Minimum energy
An electrostatic force of attraction between the nucleus of one atom and the electron of another. T33	Electrostatic force	Electrostatic
This framework was not used.		Orbital

CK3.3 Describe the bonding in ammonia (polar bond)	Comment	Code
It is because nitrogen is a non-metal as well as hydrogen. T14 The diatomic molecule of nitrogen and hydrogen come into contact. T20	Bonding between two non-metals Interaction between atoms	Atom
The nitrogen atom has five valence electrons and the hydrogen has one valence electron. The nitrogen atom requires three electrons to complete its octet and the hydrogen requires one more to complete its outermost shell. T05 The N share its electrons with each H molecule. T06 Nitrogen has a valency of 3 because it has 5 valence electrons. It needs 3 electrons to complete the shell, 3 hydrogens will each donate 1 electron to fill in the three. T15 Nitrogen has 5 valence electrons. To obtain a stable noble gas electron structure it must gain 3 more. It does this by sharing with 3 hydrogen atoms. They in turn also gain a stable electron structure. T34	Full outer shell Bonding is sharing or transfer of electrons	Octet
Energy required to break single bond in H_2 Energy required to break triple bond in N_2. Energy released when covalent bonds are formed in NH_3. T38	Energy	Minimum energy
Enough energy was provided for the reaction to take place. Bonds formed between the N and H atoms through the sharing of e-, but this sharing is unequal, therefore polar covalent bond. N is more electronegative so it attracts the e- in the chemical bonds more strongly than the H does. T48	Difference in electronegativity	Electrostatic
Electrons are shared in N_2. Electrons are shared in H_2. Bonds break in N_2 and H_2. New bonds form in NH_3 between N and H, rearrangement of e- in molecular orbitals of lower energy. More stable product. Energy released. T09 The nitrogen atoms orbitals in its outermost energy are sp-hybridized and overlap with the 1s orbital of each H atom. The electrons are then shared between the H and N nuclei. Initially this sharing process begins with e`s attracted to the nuclei of the other atom. T28		Orbital

CK4.2 Describe metallic bonding	Comment	Code
It is the bond between the metals. T50	Bonding between metals	Atom
Electrons of the Al atoms are shared equally to form covalent bonds. Electrons are shared equally as there are no difference in electronegativity between Al atoms. T49 They share the electrons equally. T53	Electron are shared	Octet
Metallic bonding in a metal is a sea of delocalized electrons in between positive nuclei. T45 The valence electrons are delocalised in the atoms of the metallic, forming strong bonds between the atoms. T10 (does not mention where/what the bond is) A sea of electrons from the valence electrons of aluminium atoms surrounds the positive nuclei of the atoms T05 (does not identify the bond, only states that delocalised electrons and positive nuclei exist)	Metallic bond is a sea of delocalised electrons without identifying interaction as electrostatic	Limited electrostatic (coded as octet)

Each Al atom has 3 valence electrons. Valence electrons become delocalised, i.e. becomes part of the structure as a whole. The Al atoms are then left with a positive charge. The positive Al kernels attract the delocalised electrons to form a bond (strong force). T39 There is an electrostatic force between the positive atomic kernels and the delocalised electrons. T41	Electrostatic force between positive nuclei and negative delocalised electrons	Electrostatic
The densely packed atoms have the electron orbitals overlapping which creates an effect where electrons are not close to their own atoms and as such become delocalised. The force between the electrons and the now positive atoms creates a bond. T37	Orbital overlap is included	Orbital

CK5.1 Ionic Bonding	Comment	Code
This view was not identified in the teachers' responses.		Atom
 T06 One magnesium atom bonds with two bromine atoms to form magnesium bromide. T41  T41	Molecule formation as a result of electron transfer (no indication that a network structure is formed)	Octet
This view was not identified in the teachers' responses.		Minimum energy
The difference in electronegativity is 1.6 which is close to the cut off of 1.7. Hence assuming an ionic bond (supported by high melting point) T29  T29		Electrostatic
Ionic bond theory describes the transfer of the two valence electrons of Mg to the separated Br atoms. Unlike charges attract in a ratio of a Mg^{2+} to two Br^{-} in a giant lattice. T27  T27		
 T38		
 T59		
This view was not identified in the teachers' responses.		Orbital

REP Choosing representations, provide a reason for choice and explain how to use it in teaching	Comment	Code
It shows that there is a strong link between atoms during chemical bonding. T08	Interaction between atoms	Atom
I would explain the bond simply as something that result when two atoms share electrons. I would give example of H is always H_2 because the two Hs are sharing electrons. H-H. Thereafter I can go to atom and sharing of electrons. T06 Start with Bohr model/Lewis diagram of H. Discuss the idea of a 'full' outer shell. How would H[cross] get a full outer shell? Needs another e- -> what if it shared with another H×. That is why hydrogen is H_2 :-). Use other examples - Cl_2 O_2 N_2 H_2O CO_2 etc. T37	Electron sharing Full outer shell	Octet
Energy is a central concept in chemistry, especially in bonding and needs to be understood. Pupils find it difficult to understand that a release of energy leads to stability (cf. Release of heat during crystallisation) Parallels can be drawn. T38		Minimum energy
... I would talk about the electrostatic forces between the protons of one atom and the electrons of another atom, and also a repulsive force between the electrons of the two atoms, and between the protons of the two different atoms... T45 It represents the negative electron cloud. It shows the interference when clouds approach, It shows electrostatic forces (for explanations). It would use it in conjunction with representation no 6. I would use Coulomb's Law to explain the repulsion and attraction. T59		Electrostatic
Start off with 1 and use H• + ×H and explain about the different spins they must have - the e^- - Fig.1 Use Fig 2 and explain that these e^- are moving around the nucleus and must be properly orientated, for the bond to take place.T22	Quantum approach	Orbital

CS Choosing and sequencing big ideas	Comment	Code
Likely options A and K Why do atoms need to bond? Use water molecule as well as diatomic gases to explain covalent bonding (two non-metals). What now happens when a metal and a non-metal bonds? T42	Includes a metal – non-metal view	Atom
Likely options: A and K Electronic structure shows the position and number of valence electrons. Electron transfer, electron sharing or electrons being delocalized determines the type of bond. T04 I believe learners must know why reactions take place. A and K - I always start with covalent, sharing of e- and then explain to learners that there are instances where electrons are given away and taken by certain elements - metals and non-metals. T22 Learners must know what a chemical bond is and then types of these bonding. After explaining all types of bonds and properties, you teach application and that these substances can be molecules or networks e.g. diamond and salts. T10		Octet
I will start with E so that the learners understand what dictates which bonds can form. Then D [energy is required to break bonds and energy is released when bonds are formed] and G [Chemical bonds are formed to create stability] will be taught quite close to each other to give the students a good grasp of energy in bonds, and systems tendency to settle to a state of lowest potential energy. This idea transcends chemical bonding, and an idea which students would do well to grasp. T57	Includes views on stability	Minimum energy
I start with C because the learners already know about electrostatic forces so I start there and then talk about bonding. In Grade 10 they do electrostatic forces and Grade 11 they talk about Newton's Law of Gravitation, and these are linked, so when I teach about bonding I bring it in and link it to the energy involved. T45		Electrostatic
This view was not identified in the teachers' responses.		Orbital

LPK3 Choosing and sequencing big ideas	Comment	Code
This view was not identified in the teachers' responses.		Atom
Not attracted by a bond, rather ionic forces defied by Na+ and Cl-. Covalent forces between the NaCl molecules cause the crystal lattice structure of a salt crystal. T56 There is not just a donation of an electron there is also the formation of a NaCl molecule. T56 The problem in the statement is the use of force. Other ions are not bonded by force, but they are stable or filled their shells. T24 The 'bond' is between a positive ion and negative ion. The process of donating an e- forms ions when allow ionic bonding to take place. T37		Octet
... [The] fundamental reason is to minimise energy and once the shells are full they are no longer outer -> they are actually core e's with no e-s in an outer shell. T28		Minimum energy
Student does not know about the electrostatic force of attraction between ions. Ionic substances do not form molecules but rather 'formula units'. T31 Each chloride ion is attracted to six sodium ions by electrostatic forces. The electrostatic forces, together with the forces of repulsion which occur in the lattice, constitute a bond. T27		Electrostatic
This view was not identified in the teachers' responses.		Orbital

CTS1 Choosing and sequencing big ideas	Comment	Code
The metal non-metal rule is a general rule but does not apply to all cases. Be, being small can break this rule. T17	View include atoms combine to form compounds, or non-metals and non-metals for covalent compounds/ metals and non-metals from ionic compounds	Atom
The distinction between covalent and ionic bonding is closely linked. I would firstly focus on the electronic structure of beryllium. Teach about its atomic structure, shell casing and how that determines its reactivity towards non-metals. T17 This is an exception to the rule. Stick to metal and non-metal = ionic bond. Also in group 17 (VII) only one e- to fill up highest energy level. Be --> needs 6 e- to fill last energy level and would be too much energy to get these 6e- and rather give 2e- away.T22	Views include a focus on electron sharing/transfer and the filling of energy levels	Octet
This view was not identified in the teachers' responses.	Teachers did mention minimising energy, but in all these cases they used a more advanced view (e.g. electrostatic)	Minimum energy
It would be important to begin this lesson by highlighting the idea chemical bonds form to create stability. The type of bond that forms will depend on the electronegativity difference which is 2.1 for an ionic bond. It is important for learners to realize that there is a spectrum of bonding (for covalent). Although beryllium is a metal with two valence electrons, and these are closer to the nucleus and the force of attraction between the nucleus and valence electrons is stronger, hence the higher its electronegativity. When teaching this it would be important to confront what they learner has read but bring the explanation to electronegativity. T26	Views include explanations using electronegativity and the bonding continuum as opposed to a bonding dichotomy)	Electrostatic
Identify electronegativity difference and look at electronic structure. Which e- are involved (s, p, d). Shape of molecule. No. of bonds formed. ... A picture/drawing is absolutely necessary, of shape of orbitals, find shape of orbitals. Energy involvement must be included. Stability of new compound. T09	Here multiple frameworks are used, but the response is classified under the most complex framework used, namely an orbital view.	Orbital

Appendix 34 **Explanatory framework moderation**

ReCal 0.1 Alpha for 2 Coders
results for file "Explanatory framework analysis moderation.csv"

File size:	120 bytes
N columns:	2
N variables:	1
N coders per variable:	2

	Percent Agreement	Scott's Pi	Cohen's Kappa	Krippendorff's Alpha (nominal)	N Agreements	N Disagreements	N Cases	N Decisions
Variable 1 (cols 1 & 2)	87.5%	0.817	0.818	0.821	21	3	24	48

Source: http://dfreelon.org/recal/recal2.php

Appendix 35 **Rules for covalent and ionic bonding**

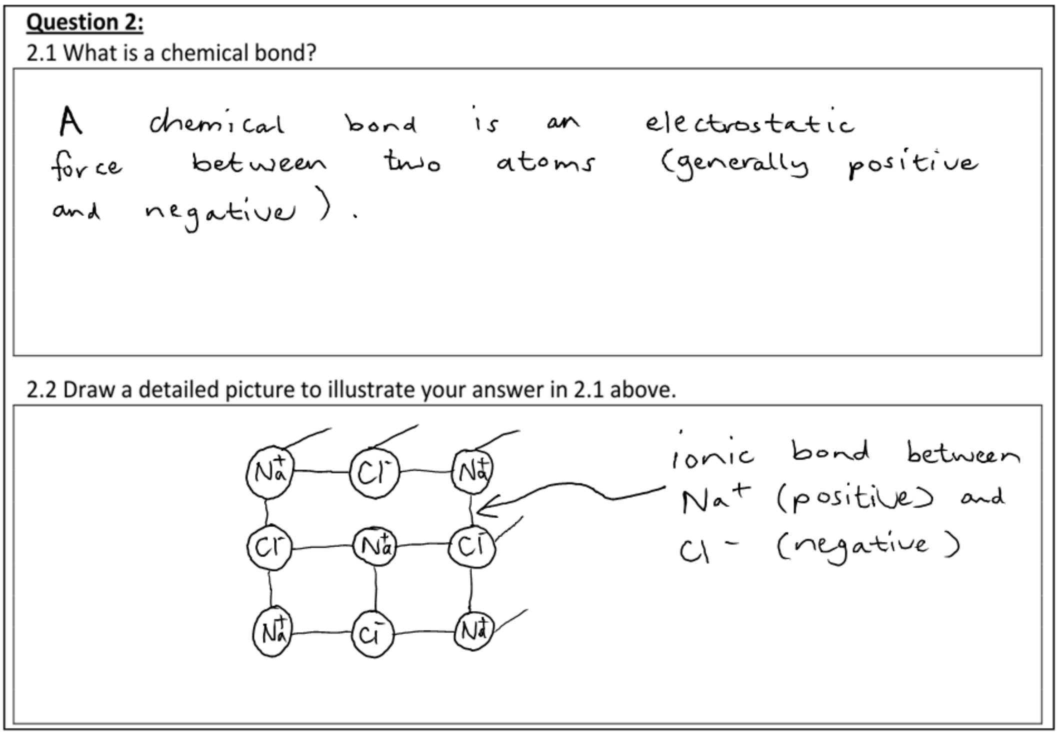
Extract from the CAPS document (DBE, 2011, p.70)

Compare the polarity of chemical bonds using a table of electronegativities:

- With an electronegativity difference $\Delta EN > 2.1$ electron transfer will take place and the bond would be ionic
- With an electronegativity difference $\Delta EN > 1$ the bond will be covalent and polar
- With an electronegativity difference $\Delta EN < 1$ the bond will be covalent and very weakly polar
- With an electronegativity difference $\Delta EN = 0$ the bond will be covalent and nonpolar

Appendix 36 **Explanatory framework analysis procedures**

An explanatory framework analysis was performed to gain insight into the teachers' choices of frameworks for explaining chemical bonding concepts and the teaching of chemical bonding. To illustrate how the analysis was done, the responses from one teacher, T41, is discussed in detail below. She was given a pseudonym, Stephanie, for this study. Figure A36.7 shows Stephanie's responses to the question on what a chemical bond is (CK2.1). The item includes a definition under 2.1 in the figure, as well as a diagram under 2.2. In CK 2.1 Stephanie described a bond as an electrostatic force, and although she used the term 'atom', she identified the force acting between positive and negative entities. The diagram she included confirmed that she does not have an ion-pair view of the crystal structure. Her response was classified as using an *electrostatic* explanatory principle. If Stephanie had only said that it was a force between atoms, it would have been labelled as an *atomic* view.


Question 2:

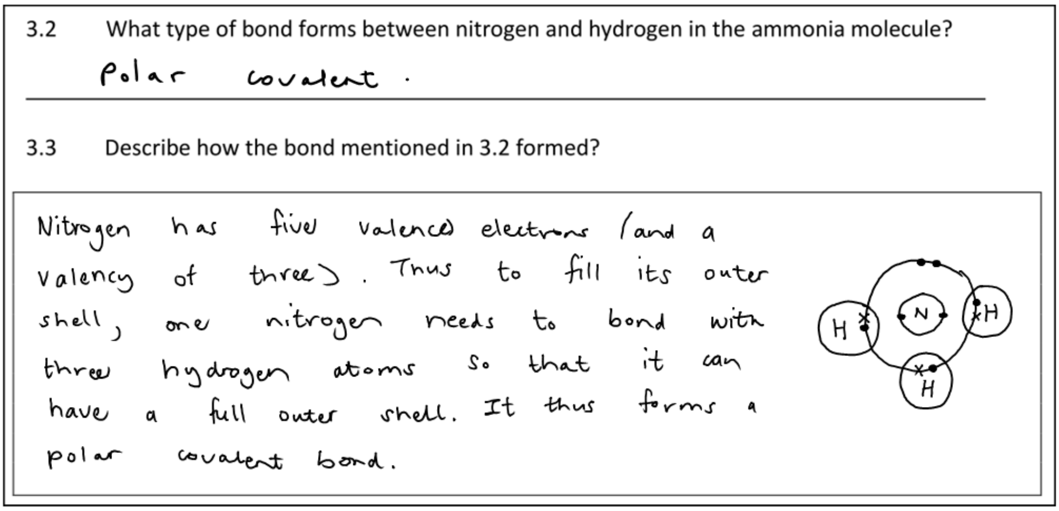
2.1 What is a chemical bond?

A chemical bond is an electrostatic force between two atoms (generally positive and negative).

2.2 Draw a detailed picture to illustrate your answer in 2.1 above.

Figure A36.7 Stephanie's response to item CK2.1

When she was asked to explain the bonding found between nitrogen and hydrogen in ammonia, she used the octet framework. Her response is included in Figure A36.8. She explained that bonds between hydrogen and nitrogen form because of nitrogen's 'need' to fill the outer shell. Nitrogen achieves a full shell by bonding with three hydrogen atoms. Her response is categorised as using the *octet* explanatory principle.



3.2 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

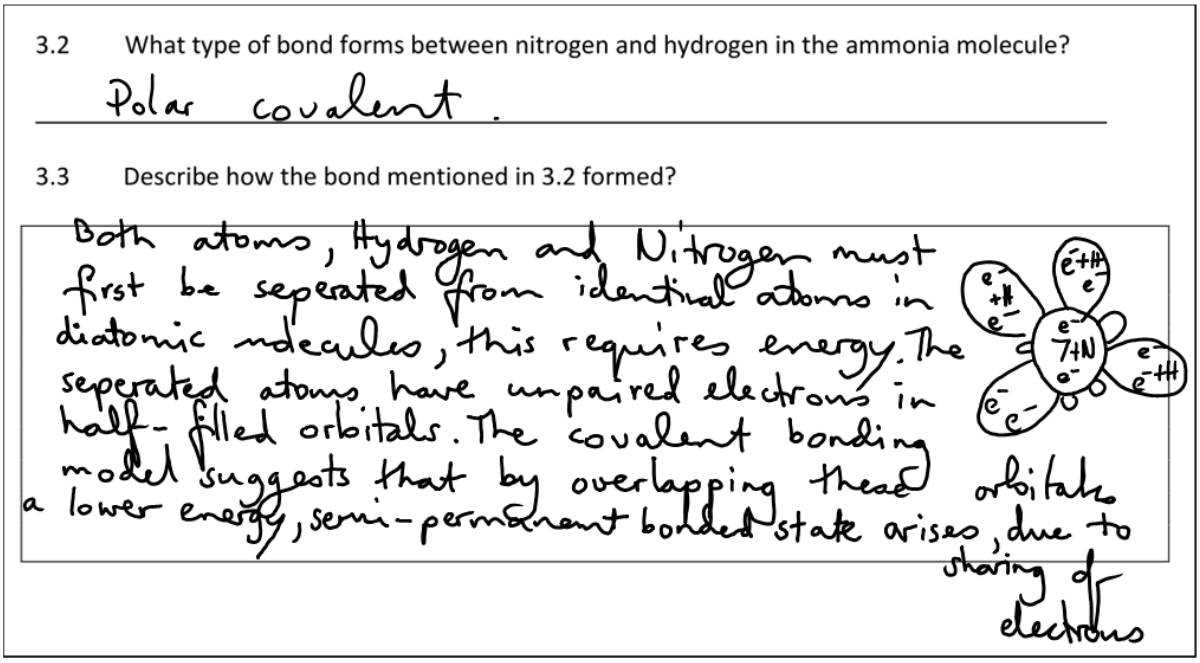
Polar covalent.

3.3 Describe how the bond mentioned in 3.2 formed?

Nitrogen has five valence electrons (and a valency of three). Thus to fill its outer shell, one nitrogen needs to bond with three hydrogen atoms so that it can have a full outer shell. It thus forms a polar covalent bond.

Figure A36.8 Stephanie's response to item CK3.3

To show how teachers have used other frameworks, two more responses are included. Teacher T27's response in Figure A36.9 was classified as an *orbital* view. He explained that bonding takes place to minimise energy, and that the system does so by overlapping atomic orbitals. He included a diagram showing sp^3 hybrid orbitals.



3.2 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

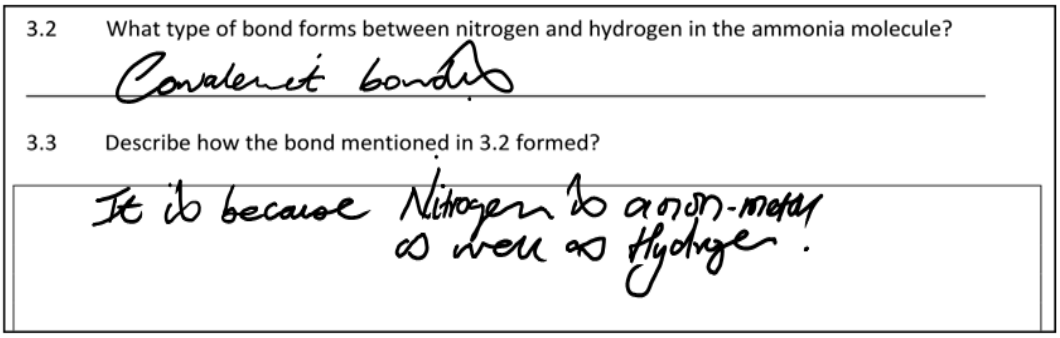
Polar covalent.

3.3 Describe how the bond mentioned in 3.2 formed?

Both atoms, Hydrogen and Nitrogen must first be seperated from identical atoms in diatomic molecules, this requires energy. The seperated atoms have unpaired electrons in half-filled orbitals. The covalent bonding model suggests that by overlapping these orbitals a lower energy, semi-permanent bonded state arises, due to sharing of electrons

Figure A36.9 Teacher T27's response to item CK3.3

Teacher T14, on the other hand, used an atomic view when he described the bond as the interaction between two non-metals: 'It is because nitrogen is a non-metal as well as hydrogen' (T14) (see Figure A36.10).



3.2 What type of bond forms between nitrogen and hydrogen in the ammonia molecule?

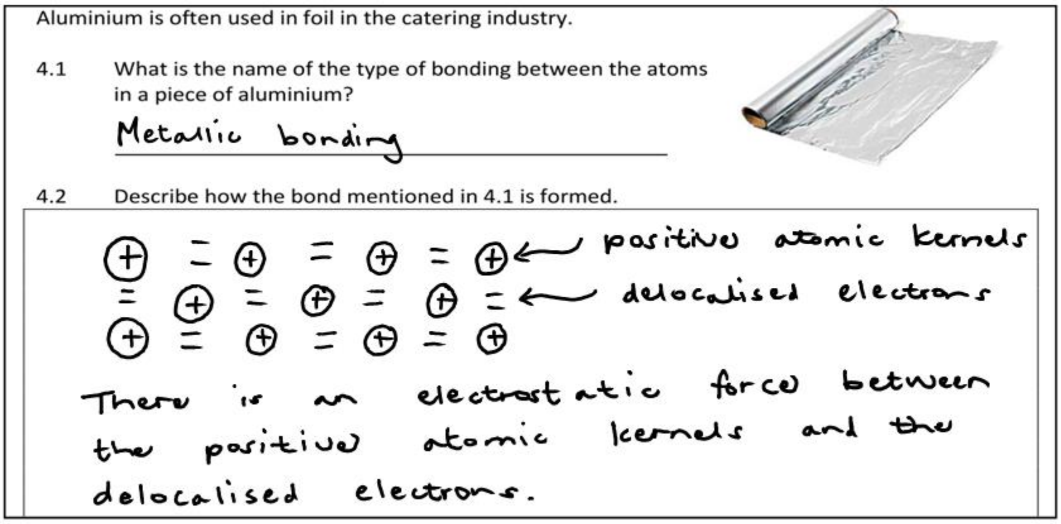
Covalent bonds

3.3 Describe how the bond mentioned in 3.2 formed?

It is because Nitrogen is a non-metal as well as Hydrogen.

Figure A36.10 Teacher T14's response to item CK3.3

For the question on metallic bonding (CK4), Stephanie used an electrostatic explanatory principle. She clearly identified the bond as an electrostatic force between positive atomic kernels and delocalised electrons. In her diagram she also indicated that a continous structure exists. She did not mention any 'need' for filled shells (octet view), or any orbital overlap (orbital view). Her response can be seen in Figure A36.11.



Aluminium is often used in foil in the catering industry.

4.1 What is the name of the type of bonding between the atoms in a piece of aluminium?

Metallic bonding

4.2 Describe how the bond mentioned in 4.1 is formed.

positive atomic kernels

delocalised electrons

There is an electrostatic force between the positive atomic kernels and the delocalised electrons.

Figure A36.11 Stephanie's response to item CK4.2

In the next CK item, CK5.1, teachers were asked to identify an ionic bond in magnesium bromide, as well as to provide a description of the bonding model. Stephanie identified the bond as polar covalent based on the difference in electronegativity (see Figure A36.12). A rule was used which states that bonds with an electronegativity difference less than a certain number ('cut-off' value) is polar covalent. (See Appendix 35 for a summary of the rules.) The Lewis diagram she drew showed the bond as a sharing of electrons between one magnesium atom and two bromine atoms. Since the bonding type, regardless of whether it was correctly identified or not, is described using electron sharing showing the octet structure, the response is classified as employing an *octet* explanatory principle.

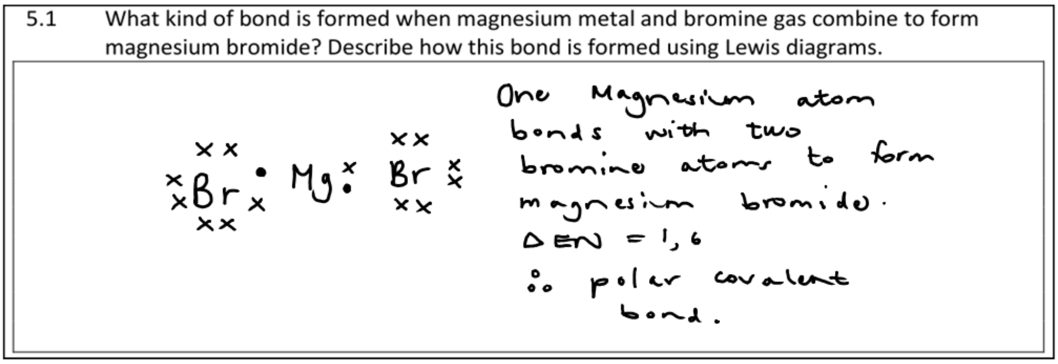


Figure A36.12 Stephanie's response to item CK5.1

The first TSPCK item provided the teachers with six representations, and they had to identify strengths and weaknesses for each. Stephanie was able to use five different views, as can be seen in Figure A36.13 on the next page.

She identified representation 1 as focussing on the sharing of electrons (octet view), representation 2 and 3 as showing orbital overlap (orbital view), representation 4 as sharing of electrons and atoms being 'happy' (octet view), representation 5 as the interaction between atoms as represented by people (atomic view), and representation 6 as having an energy focus as the driving force for bonding (minimum energy view). Stephanie was able to identify a variety of explanatory frameworks, providing her with a large repertoire to choose from. This part of the question was not used in the explanatory framework analysis, but is included here to show that Stephanie was able to reason from different views.

The second half of the question asked teachers to choose the representation they liked most, and to explain how they would use it in their teaching. Stephanie chose representation 1, the Lewis diagram, to use in her lesson (see Figure A36.14 on page 317). She explained how she would use valency and group number to explain the process of sharing electrons. Her response was classified as using the *octet explanatory principle*, as the focus was on obtaining a full octet structure. She wrote 'remind them that hydrogen only *needs* two electrons to fill its outer shell'. This approach could be considered appropriate for a Grade 10 group, but perhaps too limited for a Grade 11 class.

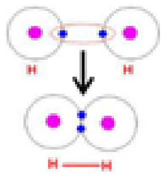
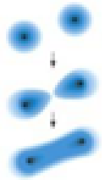
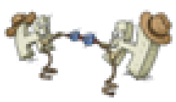
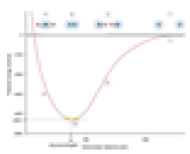
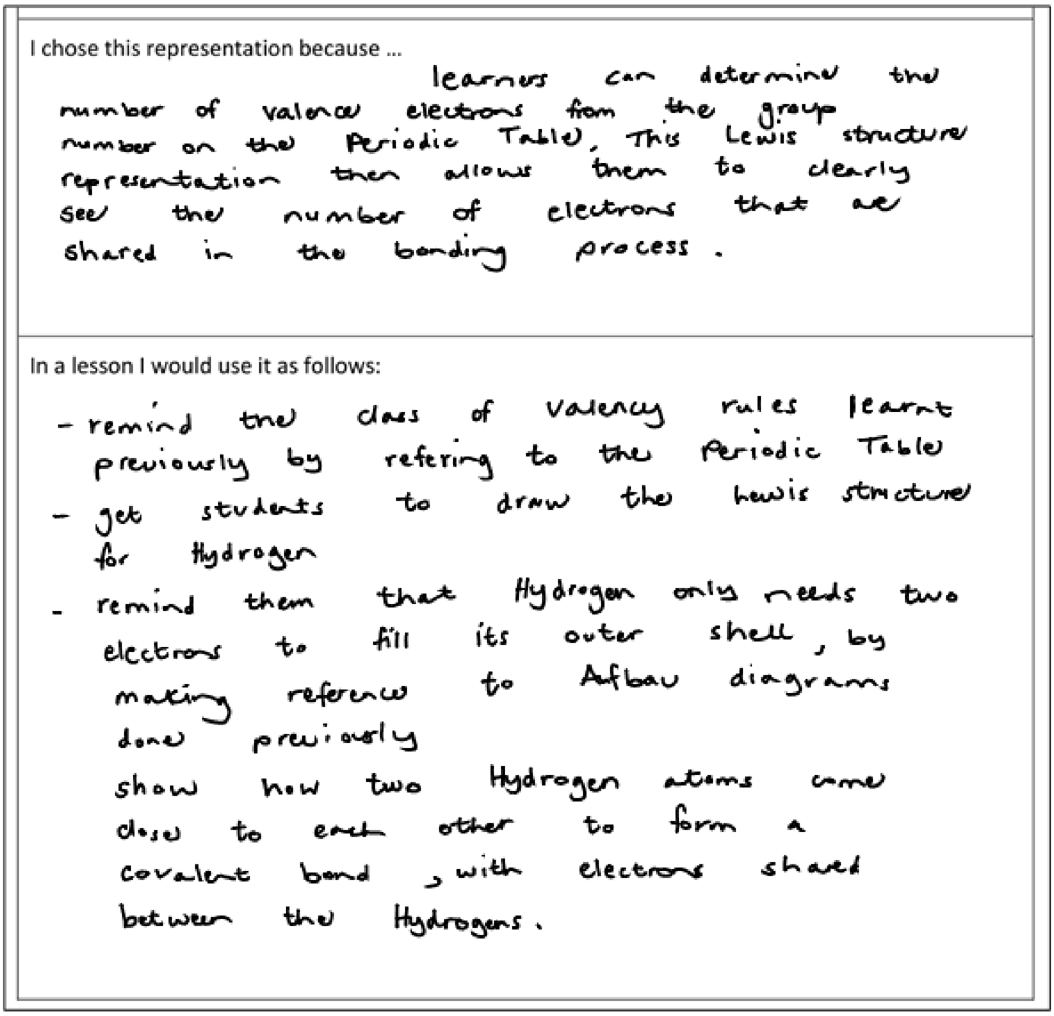
	What I **like** and **why** (Strengths of the representation)	What I **don't like** and **why** (Weaknesses of the representation)
Representation 1 	Clearly shows the number of electrons involved in the bonding process.	(No representation of the orbitals given.)
Representation 2 	Students can see the orbitals overlapping as electrons are shared.	Students need to understand orbitals first to understand bonding
Representation 3 	Shows s-orbitals overlapping.	The sharing of the electrons is not clearly shown
Representation 4 	Shows the two hydrogens are happy with sharing their electrons.	A very simple representation
Representation 5 	The learners can learn about the optimal distance between two atoms for bonding to occur, by extending their arms.	The learners are all different (while the H's are identical). This representation with two arms being held, looks like a double bond.
Representation 6 	This representation shows the ideal bonding distance between two atoms, but that atoms can be forced closer together too.	Students struggle to understand the E_p on the y-axis, and that it can have a negative value.

Figure A36.13 Stephanie's response to the items on strengths and weaknesses of representations



I chose this representation because ... learners can determine the number of valence electrons from the group number on the Periodic Table, This Lewis structure representation then allows them to clearly see the number of electrons that are shared in the bonding process.

In a lesson I would use it as follows:

- remind the class of Valency rules learnt previously by refering to the Periodic Table
- get students to draw the Lewis structure for Hydrogen
- remind them that Hydrogen only needs two electrons to fill its outer shell, by making reference to Afbau diagrams done previously
  show how two Hydrogen atoms come close to each other to form a covalent bond, with electrons shared between the Hydrogens.

Figure A36.14 Stephanie's response to the representation items

The item on curricular saliency (CS1) included a list of big and sub-ordinate ideas, some focussing on an octet view (for example choices A and K), some an energy view (for example choices D and G), and some an electrostatic view (for example choice C). Teachers had to choose the big ideas for teaching and provide a rationale for a teaching sequence. Their answers were classified according to the predominant view displayed. Stephanie's predominant view was using the *octet* explanatory principle (see Figure A36.15). Her choice of big ideas included a focus on the element's position on the periodic table, and the link to electron structure. She then moved to stability, but links it to an octet view as opposed to an energy focus (atoms being in a lower energy state when their outer shells are filled). Lastly, she included a spectrum of electron sharing, and used an electrostatic view.

2.2 Using the three ideas in **2.1**, give the sequence you would teach them in, and your reasons for doing so.

<table>
<tr><th>Order of teaching
(put the first concept you will teach next to the 1, the second next to the 2, etc.)</th><th>Reasons for order of teaching the Big Ideas chosen:</th></tr>
<tr><td>1: E</td><td rowspan="3">Students need to know something about electronic structure first. We teach this when looking at its (the element) position on the Periodic Table (rows and periods) as well as when we teach Aufbau diagrams
Students can then learn why atoms would want to bond, by understanding that they want a full outer shell (generally 8 electrons).
It is then good to explain that ionic and covalent bonding occurs over a spectrum.</td></tr>
<tr><td>2: G</td></tr>
<tr><td>3: I</td></tr>
</table>

Figure A36.15 Stephanie's response to the curricular saliency items

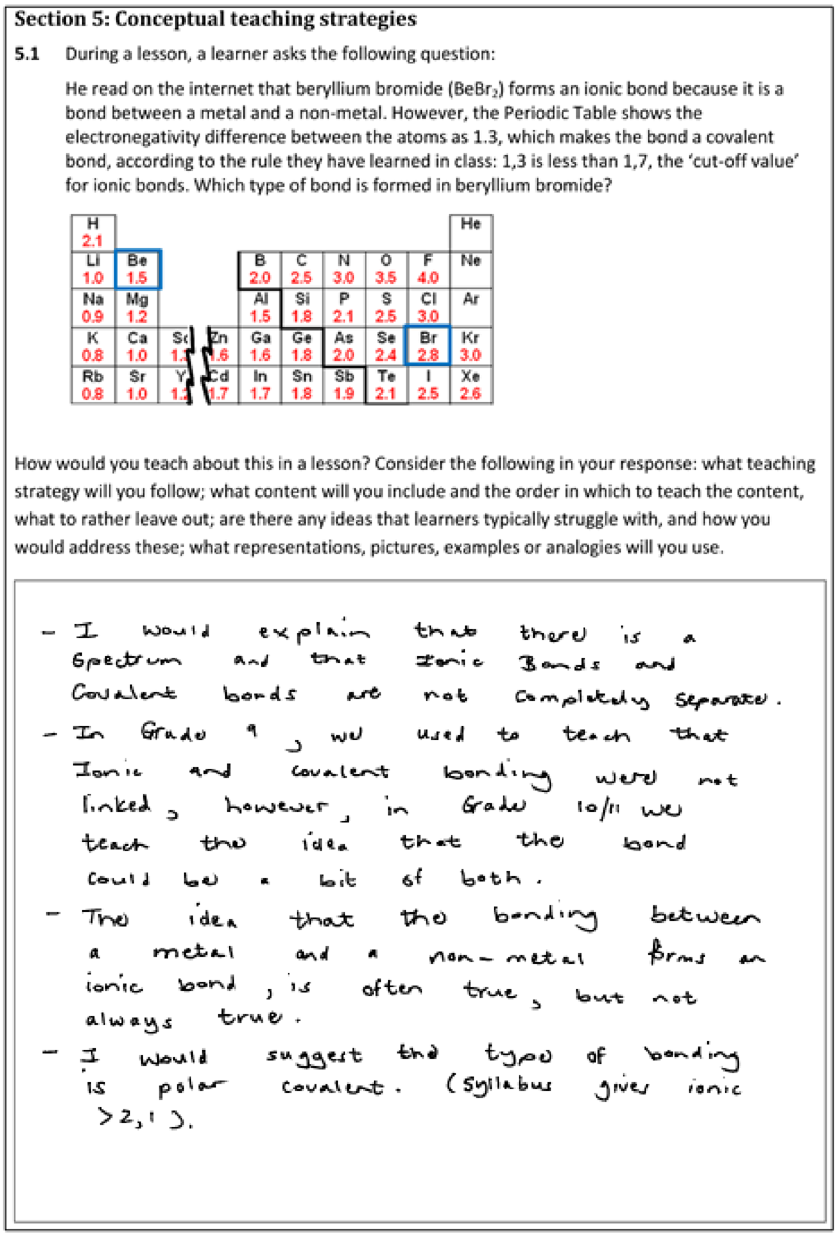
LPK3 was analysed to identify which explanatory principles teachers used to explain the problem with students' statements containing alternative conceptions. Stephanie's response is included in Figure A36.16. She identified the 'just forces' part of the statement as problematic, and explained that there should be a force acting, but she did not state that this force *is the bond* and acts throughout the structure. She also identified that there should be a ratio of one sodium to one chlorine (and not five as indicated in the statement). This is characteristic of an ion-pair view, which forms part of the *octet* explanatory principle.

Statement from the learner	Identify and explain the problem with each statement.
A chloride ion is attracted to one sodium ion by a bond and is attracted to up to five other sodium ions just by forces.	Problem: 'just by forces'. No explanation is given of the electrostatic force occurring between the sodium ion and the chloride ion. Also, the ratio is one sodium ion to one chloride ion

Figure A36.16 Stephanie's response to one of the student prior knowledge items

The last item that was analysed was CTS1, in which teachers had to explain a teaching strategy they would use for teaching about the bonding dichotomy. Stephanie's response is included in Figure A36.17.

Stephanie used an *electrostatic* explanatory principle in her description. She recognised that ionic and covalent bonding are 'not completely separate', and therefore not dichotomous. She explained that she used a basic understanding of bonding in Grade 9 (covalent and ionic bonding are not linked), but in Grade 10 and 11 she expected her students to expand their understanding to include a broader view of ionic and covalent bonds. Stephanie built a conceptual progression into her planning to teach this section.



Section 5: Conceptual teaching strategies

5.1 During a lesson, a learner asks the following question:

He read on the internet that beryllium bromide ($BeBr_2$) forms an ionic bond because it is a bond between a metal and a non-metal. However, the Periodic Table shows the electronegativity difference between the atoms as 1.3, which makes the bond a covalent bond, according to the rule they have learned in class: 1,3 is less than 1,7, the 'cut-off value' for ionic bonds. Which type of bond is formed in beryllium bromide?

H 2.1										He
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0		Ne
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0		Ar
K 0.8	Ca 1.0	Sc 1.	Zn .6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8		Kr 3.0
Rb 0.8	Sr 1.0	Y 1.	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5		Xe 2.6

How would you teach about this in a lesson? Consider the following in your response: what teaching strategy will you follow; what content will you include and the order in which to teach the content, what to rather leave out; are there any ideas that learners typically struggle with, and how you would address these; what representations, pictures, examples or analogies will you use.

- I would explain that there is a spectrum and that Ionic Bonds and Covalent bonds are not completely separate.
- In Grade 9, we used to teach that Ionic and covalent bonding were not linked, however, in Grade 10/11 we teach the idea that the bond could be a bit of both.
- The idea that the bonding between a metal and a non-metal forms an ionic bond, is often true, but not always true.
- I would suggest the type of bonding is polar covalent. (Syllabus gives ionic >2,1).

Figure A36.17 Stephanie's response to the first conceptual teaching strategy item

Appendix 37 **Simon's responses the instrument to show an electrostatic view**

Simon's reason for choosing a representation

I chose this representation because …

Personally, I feel that each representation is useful and can be used when teaching about chemical bonding. However, I like 4 the most as it can be used to introduce the learners to the big idea that a chemical bond is an electrostatic force between negative and positive charges in the atoms. The other representations (except 5) represent the fact that a chemical bond (in this case between two hydrogen atoms) involves a sharing of electrons. It provides a useful link that learners are familiar with (tug-o-war) that the chemical bond is actually a force.

Simon's choices of big ideas for teaching chemical bonding

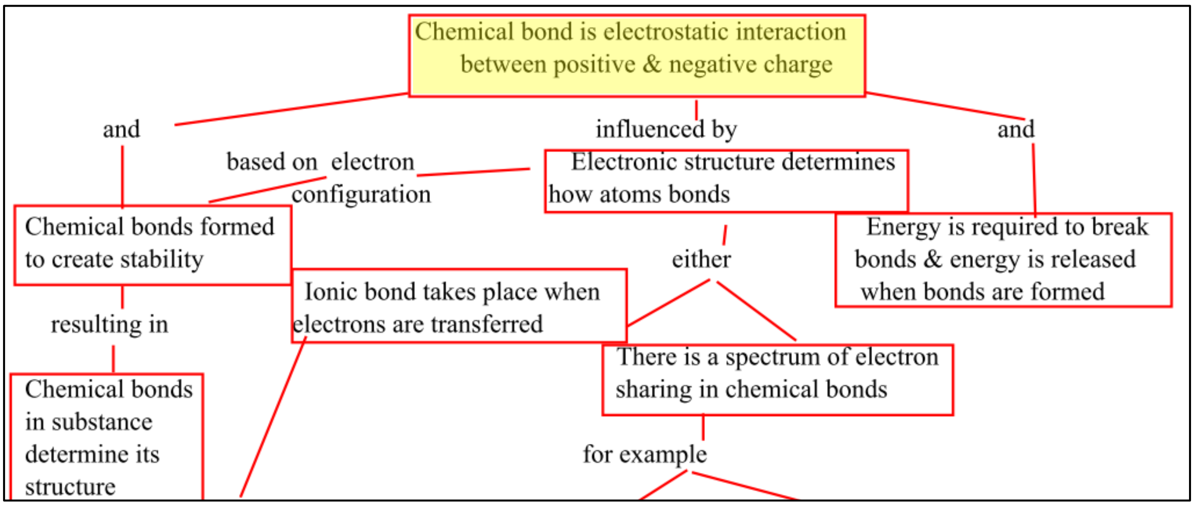
2.1 Select <u>three</u> ideas which you consider to be the **Big Ideas** in chemical bonding.

Idea 1: Chemical bond is an electrostatic interaction between charges (C)

Idea 2: Chemical bonds are formed to create stability (G)

Idea 3: Energy is required to break bonds/released when bonds are formed (D)

An extract from Simon's mind map for big and sub-ordinate ideas



Appendix 38 **Turnitin report**

trnren001:Thesis_Turnitin_Final.docx

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This project formed part of a national PCK project at the University of the Witwatersrand.

THE END