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INVESTIGATING THE EFFECT OF AN INTERVENTION ON NOVICE SCIENCE TEACHERS TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE

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A thesis submitted to the Wits School of Education, Faculty of Humanities, University of the Witwatersrand, in fulfilment of the requirements of the degree of Doctor of Philosophy.

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Abstract

The lack of teaching experience in uncertified teachers leaves them with little or no understanding of the transformation of Content Knowledge (CK) at their disposal. This transformation of CK is termed Pedagogical Content Knowledge (PCK) and it is known to develop through practice. Therefore, reflective analysis of lessons taught by these teachers is important. Research has also shown that they are often not supported as they embark on their teaching career. Therefore, the study investigated the influence of an intervention on novice unqualified graduate teachers' (NUGTs) Topic Specific Pedagogical Content Knowledge within a specific topic – the particulate nature of matter. The construct, Topic Specific PCK was the theoretical framework of my study and it consists of five topic specific categories that collectively enable transformation of content knowledge. The categories are: (1) *learner prior knowledge* (2) *curricular Saliency* (3) *what is difficult to teach* (4) *representations* and (5) *conceptual teaching strategies*. For measuring the quality of Topic Specific PCK, a new tool based on the topic of the particulate nature of matter was developed. The Topic Specific PCK tool was then validated using a group of 11 practising science teachers. The tool was scored using a rubric that is in line with the five categories, which are rated on a four point scale, where 1 stands for limited PCK and 4 is exemplary PCK.

The research design followed in my study was mixed-methods research (MM). The study involved 16 novice teachers recruited by Teach South Africa working together with the Department of Education. The teachers hold university degrees, have done chemistry for a minimum of one year during the course of their degree and have no teaching qualifications. Four of the teachers who taught the particulate nature of matter were selected as case study teachers.

Data was collected through a number of tools, including the newly designed Topic Specific PCK test on particulate nature of matter, a CK test and Content Representations (CoRes) which were all adapted from existing tools and thus considered validated. The case study teachers were observed while teaching particulate nature of matter and their lessons were analysed. All the teachers were tested before and after the professional development intervention (PDI).

The findings show that the quality of Topic Specific PCK and CK in particulate nature of matter was improved in all NUGTs. The greatest improvement was observed in the NUGTs who taught the topic directly. This improvement was attributed to the experience of teaching the topic directly or teaching related concepts that need understanding of it. The improvement was observed in all the NUGTs, showing the effect of indirect experience. This can be deduced from their improved CoRe which forced the NUGTs to engage with the construct and also through the positive significant improvement in CK and Topic Specific PCK results.

Finally, I suggest that although interventions like PDI have the potential to produce science teachers, care should be exercised in making assumptions about their CK and knowledge for teaching, and training programmes need to pay attention to both CK and Topic Specific PCK.

Keywords
Topic Specific PCK, Content Knowledge, Particulate Nature of Matter, Transformation of Content Knowledge.

Declaration

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

_____

(Signature of candidate)

_____day of_____2014

Dedication

To my beloved husband Mpho Mosabala for being my rock throughout this journey. My precious sons, Kata, Toka and Molupe, I hope that this achievement encourages you. My cousins' daughter Ishah Mpati, thanks for assisting me at home with all the duties-much appreciated. To my parents: Late Alpheus Kata Pitjeng and living Flora Kgadi Pitjeng who instilled in me the values of good education.

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Abbreviations

CK	Content Knowledge
PCK	Pedagogical Content Knowledge
SMK	Subject Matter Knowledge
NUGTs	Novice Unqualified Graduate Teachers
PDI	Professional Development Intervention
CoRe	Content Representation
PaP-eRs	Pedagogical and Professional experience Repertoires
SCK	Specialized Content Knowledge
MPCK	Mathematics teachers' pedagogical content knowledge
KCS	Knowledge of Content and Students
CAPS	Curriculum and Assessment Policy Statement
GET	General Education and Training
FET	Further Education and Training
DoE	Department of Basic Education
TFA	Teach for America

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CHAPTER 1

1. INTRODUCTION TO THE STUDY

This chapter gives an overview of the study. It provides a justification of why the study was conducted as well as the purpose. I also allude to the theoretical framework used in the study as well as the research questions which are framed conceptually. The chapter concludes with a description of the researcher's positionality and the order of the chapters.

1.1 Introduction

How certain are we that science graduates with no formal teaching qualifications i) can become effective science teachers, ii) do possess quality Content Knowledge (CK) and iii) can actually transform the CK for teaching purposes effectively? Research conducted on beginning teachers shows that they are often left to succeed or fail within the confines of their classrooms and that they are faced with challenges that involves pedagogy (Davis, Debra Petish, & Smithey, 2006; Ingersoll & Smith, 2004). It was recommended that science topic specific induction or professional development needs to be in place for supporting beginning teachers. South African teachers in particular, face challenges with regard to knowledge of subject matter, which impacts negatively on its transformation. This thesis explores the knowledge of subject matter held by unqualified science graduate teachers and how transformation of this knowledge occurs in the first year of their teaching career.

1.2 Purpose of Research

My study is located within a larger PCK project. In this larger project, there is already an existing study on the effectiveness of a targeted methodology course in an intervention involving pre-service teachers. The purpose of my study is to explore the impact of assisting novice unqualified high school chemistry teachers to transform CK through a Professional Development Intervention (PDI). Shulman (1986) termed this transformed knowledge Pedagogical Content Knowledge (PCK) and defined it as the ways of representing and formulating the subject that makes it comprehensible to others (p.9). The representation and transformation of CK were found to be the most challenging issues facing novice teachers. When teachers begin to engage with learners, they begin to actively construct their PCK. My study thus investigates the effect of a PDI when teaching the particulate nature of matter by Novice Unqualified Graduate Teachers (NUGTs). The findings gathered from my study will contribute to the literature on PCK development, particularly on uncertified science graduate

teachers. As recommended by Mavhunga (2012) that more tools for measuring the quality of PCK within more topics in science need to be developed, another purpose of the study is also the development of the particulate nature of matter tool.

1.3 Rationale

Based on what was indicated above, PCK is a construct that teachers need to develop in order to teach effectively. van Driel et al. (1998) argue that there is general agreement amongst researchers that PCK is developed through classroom practice. This implies that new teachers usually have little or no PCK at their disposal. Taking that into account in my study, I envisage that NUGTs would have little or no PCK since they have not been engaged in any kind of teaching. However, Kind (2009) indicates that researchers have found that even some experienced teachers are not necessarily experts. It also appears that even teachers with strong CK may not have sound PCK. Luft (2009) suggested four different types of induction programmes that could be put in place to support beginning teachers. She further compared these programmes to find out which showed the greatest gains in beginning teachers' PCK. The findings revealed that in science-specific and e-mentoring programmes teachers who were assisted to apply inquiry instruction eventually strengthened their PCK. An inquiry method of teaching uses investigation as an approach. Luft's finding on the impact of induction programmes in beginning teachers supports the idea of early career support, which currently does not exist in South Africa. My study has put in place a PDI that is science topic-specific that anticipates assisting NUGTs in developing their PCK of particulate nature of matter in line with the grade 10 Curriculum and Assessment Policy Statement (CAPS) document. This was done because in South Africa there is no tradition of such interventions to assist novice science teachers. The particulate nature of matter was chosen because it underpins most chemistry content and incorporates macroscopic, sub-microscopic and symbolic representations. I am hoping that this research will provide findings that will share some insight on how novice teachers' PCK may be developed. In a way, the findings will also suggest ways to reduce the frustrations novice teachers are faced with in their classroom situations. I am also anticipating that the findings of my study would break the silence of the 'National Policy Framework for Teacher Education and Development in South Africa (Department of Education, 2006) about the challenges faced by teacher development and that this model might eventually be embraced nationally.

1.4 Research Problem and Research Questions

The state of mathematics and science education in South Africa is a cause for concern. Botsis and Cronje (2006/2007) report that about 1700 South African science teachers are not qualified to teach physical science. This implies that South Africa has a shortage of qualified physical science teachers leading to the deployment of teachers not qualified to teach the subjects. Kriek and Grayson (2009) argue that this limited knowledge of subject matter leads to ineffective teaching approaches. The authors further report that the number of Grade 12 learners who pass physical science higher grade, a recommended subject to enter to enter into science-based studies at university, remains very low. This is the reason why a South African based organisation-Teach South Africa recruits the Novice Unqualified Graduate Teachers (NUGTs), a model similar to that of Teach America (Xu, Hannaway, & Taylor, 2011). This kind of intervention is meant to improve the state of mathematics and science in South African high schools

It is important to emphasise that I am referring to these teachers as novices in my study because they are non-certified, implying that they are a group of teachers who begin teaching with a university degree but with no teaching qualification and no teaching experience. However, literature on PCK of beginning, as well as pre-service teachers, will be relevant in this case. Luft (2009) described beginning teachers as qualified teachers with a bachelor's degree, who are in their first years of teaching. It is for this reason that I do not classify novice teachers as beginning teachers. Beginning certified teachers are more experienced than uncertified novice teachers, in that they have had some exposure to school experience during their studies towards their teaching qualification. However, the commonality between novice and beginning teachers is that they are all new in the teaching profession with little or no teaching experience. Hence they are not yet experts. Therefore, the literature on beginning teachers might also apply to novice teachers and it is for this reason that, in the reviewed literature in Chapter two both terms are used interchangeably.

The main purpose of my study is to investigate the extent to which the NUGTs' Topic Specific PCK and CK are influenced by the PDI. The main research question in my study is: How and to what degree is the development of Novice Unqualified Graduate Teachers' (NUGTs) PCK of the particulate nature of matter influenced by the PDI? The sub-questions which are answered in Chapter eight were articulated as follows:

1. How can NUGTs' Topic Specific PCK, with regard to the particulate nature of matter, be measured?
2. What effect does a targeted PDI have on the NUGTs' CK for the particulate nature of matter?
3. To what degree does the PDI influence the development of NUGTs' Topic Specific PCK?
4. What is the relationship between NUGTs' CK and Topic Specific PCK of particulate nature of matter?

1.5 Conceptual Framework

The study is guided by the notion of the PCK construct (Shulman, 1986). I adopted the model of Topic Specific PCK construct by Mavhunga (2012) as a theoretical framework. The reason for using the model is because it has combined and utilised CK and PCK in a theoretical framework. Therefore, acknowledging the importance of transformation of CK is a key element in establishing PCK. In Chapter two, I elaborate on the description of this notion, including how its understanding and descriptions have evolved over nearly 28 years.

1.6 The Researcher and Positionality

I am currently living in Johannesburg, South Africa but originally from Ga-Matlala Mahoai, a small village in Limpopo province, near Polokwane. After completing my grade 12 in 1995, I studied at the East Rand College of Education, one of the education colleges most disadvantaged by the apartheid system, where I graduated with a teaching diploma. Pedagogical skills were the only strong focus in these disadvantaged education colleges; knowledge of subject matter was seriously neglected and weak. This, I realised, let me down over my teaching career and prompted me to further study to obtain a further degree in Education.

I taught in two different former white Johannesburg city schools, which now have a majority of black students, over a period of 8 years as a physical and natural science educator. Prior to the introduction of the new curriculum in grade 10, I registered for a BSc honours degree at the University of the Witwatersrand, in the School of Education in 2006, where I engaged extensively with CK issues, and interacted with senior CK and PCK experts with the aim of becoming an expert in science education. In 2008 I was employed at the RADMASTE Centre, University of the Witwatersrand, where I developed microscience teaching materials,

and trained teachers and learners in rural and urban areas. Later in that year I obtained my MSc degree in Science Education. In 2010 I joined the Gauteng Department of Education science centre (Sci-Bono Discovery Centre), working in the teacher development unit as a project officer. I also interacted with teaching from all the Gauteng districts with matters regarding science CK.

Throughout my career as an educator and teachers trainer, I had realised and believed that what constitutes good teaching is how teachers transform the CK they possess into ways that can enable learners' understand. For this to be a success, better understanding of the CK in a particular topic is crucial, as this may allow flexibility in teaching, which may result in better conceptual teaching strategies. This journey has motivated me to embark on research about science teachers' CK and PCK.

1.7 The Structure of the Thesis

My thesis consists of eight chapters, beginning with the overview of the introduction to the study (research), which includes the rationale for the study, a summary of the purpose and a statement of the problem of the study, as well as the research questions. In Chapter two I review literature relevant to the study. Here, I selectively review literature about the development of PCK in beginning teachers and the topic under consideration (the particulate nature of matter). The description and understanding of PCK have evolved, so literature on previous studies about PCK is included. This is followed by a discussion on the theoretical framework that informed the study. Chapter three describes my research methodology, which includes mixed-methods (MM) and case study design, my research instruments and how the data was collected, as well as issues of ethical consideration. In addition, it addresses matters of rigour in terms of the validity and reliability of the study. Chapter four describes in detail the development of the Topic Specific PCK test. This includes the process of both validation and the pilot phase. Chapter five provides greater detail about the PDI, including the sequence of delivery of the PDI. In chapter five, the first of the findings' chapters, is about the establishment of the NUGTs' knowledge about the particulate nature of matter through the analysis of Content Representations (CoRes), pre and post observation interviews and case study teachers' lessons. Chapter six provides the findings of the analysis on the effect of the PDI on NUGTs' CK. The findings of the two methods of analysis were compared. Chapter seven shows the analysis and findings on the effect of the PDI on NUGTs' Topic Specific PCK. As with Chapter six, data was analysed both quantitatively and qualitatively

for comparison. The findings were triangulated from case study teachers' observation, interviews and tests. Chapter eight summarises and consolidates the main findings from the analysis chapters (chapters five to seven), relating them to the literature on PCK. The research questions set out in Chapter one are answered. The chapter concludes with the discussions about the implications and recommendations for future research, while giving critical reflections on the study.

CHAPTER 2

2. LITERATURE REVIEW

In this chapter I review a selection of the literature related to development of PCK. This includes its origin, nature and the measurement. The literature regarding the relationship between CK and PCK is reviewed as well as that of PCK, in particular of novice/beginning teachers. In the light of this review I then present a theoretical framework on Topic Specific PCK, which underpins the study. As my study is topic related, I also review the literature related to the teaching and learning of the particulate nature of matter. I conclude this chapter by highlighting kinds of professional development utilised in various literature.

2.1 Introduction

This research study draws upon the theoretical idea of PCK (Shulman, 1986; Shulman, 1987). Nearly 28 years ago, Shulman (1986, p. 7) argued that there was a '*missing paradigm'* in the literature of research on teaching. He pointed out that research on teaching done at that time emphasised how teachers manage their classroom, organise activities, allocate time and turns, structure assignments, plan lessons and judge general student understanding. However, he noted important omissions, such as the content of the lessons taught, the questions asked and the explanations given. From the perspective of teacher development, he found little research on where teachers' explanations come from, how they decide what to teach, how they represent what they teach, how they question learners about the material and how they deal with problems of misunderstanding. However, Shulman (1986) acknowledged that the cognitive psychology of learning had taken into account some of these questions, but strictly from the perspective of learners. He claimed that research on teaching had ignored these questions from the teachers' point of view. Hence the notion of PCK emerged and Shulman (1987, p. 8) defined it as:

> *'the distinctive body of knowledge for teaching that represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interest and abilities of learners, and presented for instruction'*

Shulman's proposal created responses and different researchers have interpreted them in different ways through transformative and integrative models (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). The manner in which Shulman's proposal was extended by

different researchers is discussed in the next section of conceptions of PCK. I should indicate that in this chapter, Subject Matter Knowledge (SMK) is to be read as synonymous with Content Knowledge (CK). This is because some researchers used the term SMK when referring to CK and vice versa.

2.2 Conceptions of PCK

Shulman (1987) included PCK in what he termed the knowledge base for teaching, which consists of seven categories. The other categories are content knowledge, general pedagogical knowledge, curriculum knowledge, knowledge of learners and their characteristics, knowledge of educational context and knowledge of educational ends, purposes, values, philosophical and historical grounds. However, among these categories, PCK turned out to be of special interest. A large number of researchers began showing interest and refined the concept by modifying Shulman's conception. Cochran, DeRuiter and King's (1993, p. 263) version of PCK emphasised "the importance of teachers' knowing about the learning of their students and the environmental context in which learning and teaching occurs". Geddis and Wood (1997, p. 612) defined PCK "as a broad category of those kinds of knowledge involved in pedagogical transformations of subject matter". Grossman (1990) argued that PCK is the knowledge that teachers draw upon, that is specific to teaching particular subject matter. Other researchers, however, have further conceptualised PCK by classifying categories, and view PCK as an integration of those categories. Grossman (1990) expanded the notion of PCK as composed of four central categories 1) knowledge and beliefs about the purposes for teaching a subject 2) knowledge of students' understanding, conceptions, and misconceptions of particular topics in a subject matter 3) knowledge of curriculum material and 4) knowledge of instructional strategies and representations for teaching a particular topic. Magnusson, Krajcik and Borko (1999) further built upon Grossman's (1990) work by broadening categories of PCK, including orientations toward science teaching and knowledge and beliefs about assessment in science. Later, Park and Oliver (2008) also included knowledge of assessments of students' understanding, using Grossman's (1990) conceptualisation. Taking into account the conceptualisation of PCK above, it is argued that, although the PCK categories among researchers are different, there is some kind of commonality with Shulman's (1986) two key categories (Park, Jang, Chen, & Jung, 2011). The two key categories are knowledge of instructional strategies, which incorporate representations of subject matter and understanding of specific learning difficulties. van Driel et al. (1998, p. 675) acknowledge the idea that instructional strategies and students' conceptions are

interlinked and therefore should be used in a flexible manner -*"the more representations teachers have at their disposal and the better they recognize learning difficulties, the more effectively they can deploy their PCK"*. This is supported by a study done by Halim and Meerah (2002) in an attempt to explore science trainee teachers' awareness of learners' misconceptions, and strategies and representations used in selected physics concepts. They found that trainee teachers were less likely to be aware of learners' misconceptions due to incorrect scientific answers they have given the learners, and were also unable to create representations that convey the scientifically correct answers. This may implies that teachers were unable to transform the subject matter due to their own poor content knowledge. Even though different scholars have modified Shulman's (1986) definition of PCK, they all agree that the transformation of subject matter knowledge for the purpose of teaching is the heart of PCK (Park et al., 2011). However, researchers differ on how they perceive PCK. Abell (2007) argues that research on PCK does not demonstrate agreement on what constitutes PCK. Hence the discussion in section 2.3, that reviews the literature on the nature of PCK. Some of the questions asked in the PCK summit explained in detail in section 2.7 relate to the nature of PCK and whether it is tacit or explicit (http://pcksummit.bscs.org). The nature of PCK is explored further in the discussion below.

2.3 The nature of PCK

The nature of PCK has been described differently by different researchers. It has an elusive nature which is described as tacit and hidden (Kind, 2009). This is partially because it has not yet been used as a conceptual tool explicitly by teachers. Kind (2009) supports the idea that when preparing lessons, for example, teachers think pragmatically: 'I am preparing a lesson', not: 'I am using my PCK' (p.170). Padilla, Ponce-de-León, Rembado, and Garritz (2008) acknowledged that attempting to understand how PCK develops can be difficult, as teachers do not easily articulate their knowledge as practitioners. Cohen and Yarden (2009) also point out that the difficulty in investigating PCK in practice is linked to the fact that teachers cannot be studied within the confines of one lesson of teaching experience. They further highlight that PCK is an internal construct, in the sense that even if teachers are observed over a long period, only limited insight into their PCK can be obtained.

Tools used to portray a clearer picture of PCK have been developed. Mortimer and El-Hani (2014) and Loughran, Berry and Mulhall (2004) developed ways in which one can gain access to this tacit nature of PCK. Mortimer and El-Hani (2014) came up with a Conceptual

Profile Model (CPM) to describe learner thinking and different ways of explaining a concept. According to the authors, the use of the conceptual profile makes it possible to deal with conceptual evolution in the classroom. For example, Mortimer and El-Hani (2014) argue that in exploring the zone that constitutes a conceptual profile of a molecule, drawing on the history of science is necessary. This is because 'all zones in the profile can be identified based on the historical development' (Mortimer & El-Hani, 2014, p. 104). More importantly, the historical facts are looked at in order to illustrate the genesis of categories that constitute the profile model. In terms of teaching, the authors highlighted that the discursive interactions are important in that they are inherent in the process of forming and developing concepts. Ultimately, the transitions between dialogic and authoritative discourses yield the teaching strategy that makes possible the following, as indicated by Mortimer & El-Hani (2014, p. 258):

- The evoking and discussion of the prescientific zones of the concepts and its understanding of aspects including limitations and gaps
- The introduction and strengthening of new zones of the conceptual profile in the context of the relevant task
- The awareness of different zones of the conceptual profile in order to prevent their meanings being used without distinction or in a mixed way

Loughran et al. (2004) came up with two complementary elements for capturing and representing one's PCK in meaningful ways, called Content Representation (CoRe) and Pedagogical and Professional experience Repertoires (PaP-eRs). According to Loughran (2004), the CoRe can be used as both a research tool for accessing science teachers' understanding of the content and as a way of representing this knowledge. The CoRe sets out and discusses teachers' understanding of particular aspects of PCK (Loughran et al., 2004, p. 376). Examples of these aspects of PCK include: an overview of main ideas, knowledge of alternative conceptions, insightful ways of testing for understanding, known points of confusion, effective sequencing and important approaches to the framing of ideas. These examples are encapsulated in the CoRe prompts, which are described fully in chapter three.

PaP-eRs emerge from the teachers' practice, illustrating aspects of the CoRes. This may come from comments made by the teacher during interviews, teaching journals, lesson plans, teacher analysis of learners' work and observers' voice (Loughran et al., 2004). All the PaP-eRs focus on teachers' pedagogical reasoning behind a particular teaching decision

(Loughran et al., 2004). This explains the different types of strategies used and how they were enacted during practice. Despite PCK's tacit nature, still difficult to pin down theoretically, it is clear that this knowledge of science teaching represents a class of knowledge that is central to science teachers' work (Lee & Luft, 2008).

2.4 Content Knowledge (CK) and its nature

Generally, the terms CK and SMK in the literature are used interchangeably. Cochran and Jones (1998) indicate that science education scholars view CK (considered as the facts and concepts of SMK) as one of the four categories that falls under SMK. The authors described the other three categories as substantive knowledge (explanatory structures or paradigms of the field), syntactic knowledge (methods and processes of generating new knowledge in the field) and beliefs about the subject matter. In mathematics education, Ball, Thames and Phelps (2008) interpret CK as knowledge of the subject and its organising structure. Abell (2007) chooses to conflate substantive and content knowledge. In my study, I view CK as facts and concepts of subject matter (Cochran & Jones, 1998). The syntactic knowledge and beliefs about science are not considered, as the focus is on NUGTs' understanding of "central ideas, relationships, elaborated knowledge and reasoning ability" (Abell, 2007, p. 1110). Thus in my study, the facts and concepts of the topic- the particulate nature of matter, are under consideration in the CK test and in the knowledge unpacked through big ideas (explained in detail in chapter 3 and 5) in the teaching of the topic.

Kind (2009) argues that "good CK confers a sense of security, which supports a teacher in devising appropriate PCK" (p.191). Child and McNicholl (2007) share the same sentiment saying that when a teacher possesses a specialist CK background, this instills confidence, which in turn, provides a basis to interact with learners. However, Kind (2009) acknowledges that a teacher's over-confidence in CK might result in poor quality lessons. This could be influenced by the fact that a teacher might be more focused on the idea of showing his/her knowledge and may neglect the most influential part of presenting a lesson appropriately, for the learners' benefit. Kind (2009) further argues that even the confidence of an experienced teacher might show signs of vulnerability, when faced with the teaching of unfamiliar content. This is mainly because the teacher might not realise what he/she does not know. When a teacher's confidence is low, this impacts negatively on his/her development, and hence, PCK may be affected negatively too.

2.5 The relationship between PCK and CK

Logically a teacher cannot teach what he/she does not know. Therefore CK is considered a pre requisite for PCK. The starting point of looking at the relationship between PCK and CK is to first acknowledge the different views about the two constructs held by different researchers. Kind (2009) highlighted some disagreement amongst researchers about the extent to which CK and PCK should be viewed as separate categories of teacher knowledge. This implies that some researchers view CK and PCK as separate knowledge base categories whilst others regard them as integrated. Studies that show PCK and CK as separate categories were conducted by many researchers (Grossman, 1990; Magnusson et al., 1999). My study follows the principle of transforming CK, where a combination of knowledge categories is used in creating PCK and CK contributing to PCK.

The novice/beginning teachers, teachers teaching outside subject specialism and experienced teachers with less confidence were unable to transform CK effectively to learners (Childs & McNicholl, 2007; Geddis, Onslow, Beynon, & Oesch, 1993; Rollnick, Bennett, Dharsey, & Ndlovu, 2008). This has impacted negatively on their PCK due to their weakness in CK. The same authors also found in the case of teachers teaching within their specialism, experienced teachers with stronger CK were able to confidently and successfully transform the CK to learners. This suggests that one's knowledge about a particular subject has a significant impact in terms of how that content is instructed.

Most studies focusing on the relationship between PCK and CK have shown a strong relationship between the two. According to Jüttner, Boone, Park, & Neuhaus (2013) this suggests that teachers' professional knowledge is presented by overlapping of PCK and CK constructs. However, research showed teaching experience does not necessarily result in increased PCK. This was evident in the study conducted by Rollnick et al. (2008) where qualified and experienced teachers were constrained in their teaching due to poor understanding of the concepts when teaching about the amount of substance and chemical equilibrium. This has impacted negatively on their PCK. Furthermore, in her review Kind (2009) found that even content specialists struggle to put together relevant information required for effective teaching. This is due to lack of teaching expertise and the perceived possession of good CK, which causes overconfidence and which results in weaker PCK.

There is a general agreement amongst researchers that CK influences teachers' classroom practice. Rollnick et al. (2008) explored the influence of CK on PCK by observing two

teachers teaching chemical equilibrium. They found that one teacher was able to demonstrate more powerful PCK, particularly where his CK was '*nuanced'* (p. 1383), allowing him to be flexible, and therefore producing innovative approaches. A study conducted by Halim and Meerah (2002) on PCK of trainee teachers on a one year post-graduate course on selected physics topics found that the majority of teachers had problems in understanding the scientific ideas themselves. It was also discovered that teachers created analogies that embodied misconceptions. This implies these teachers do not know what they are talking about. When teaching, teachers were unable to transform the subject matter appropriately for pupils because of their own poor CK (Halim & Meerah, 2002). It was thus argued that trainees' knowledge of the categories of PCK depended on their CK.

2.6 PCK in practice - novice teachers

Uncertified novice teachers are faced with teaching challenges in the beginning of their teaching career. However, Darling-Hammond and Young (2002, p. 13) argue that i) teacher education and certification are not related to teacher effectiveness ii) verbal ability and subject matter knowledge are the most important categories of teacher effectiveness iii) teachers who have completed teacher education programmes are academically weak and are underprepared for their jobs and iv) alternative certification programmes have academically stronger recruits who are highly effective and have high rates of teacher retention (p.13). This suggests that teacher training may not be essential for good teaching. However, it is worth looking into the challenges that novice teachers are confronted with when beginning to teach. It is also worth noting that, although Darling-Hammond and Young were referring to the US context, their observations also have resonance in South Africa.

Davis et al. (2006) argue that new science teachers are faced with significant difficulties. The challenges reviewed are related to their understanding of the following five areas: the content and discipline of science, learners, instruction, learning environments and professionalism. Adams and Krockover (1997) analysed concerns and perceptions held by beginning secondary science teachers. One of the implications they highlighted was that *'the teachers have a need to not only develop content knowledge but pedagogical content knowledge'* (p. 48). Kind (2009) further added that a better understanding of PCK will better prepare beginning teachers for working full-time in schools. De Jong and van Driel (2004) explored the development of eight pre-service teachers' PCK during the teaching of chemistry topics that involved macroscopic, microscopic and symbolic meaning. They found that during the

pre-lesson interviews, only three teachers reported expectations of teaching difficulties they might experience. The manner in which they expressed these difficulties was unclear, as they used short statements. The remaining five student teachers indicated that they were not anticipating significant difficulties. However, the results of post-lesson interviews revealed that all student teachers reported teaching difficulties in an extensive and detailed manner. Student teachers now realised that when teaching, they moved between macro and micro meanings without mediation leading them to jump from one meaning to another, and that their reasoning was mainly unconscious. It was also found that the three pre-service teachers who did anticipate students' difficulties in the pre-lesson interview were able to elaborate further on these difficulties afterwards. The authors report that university-based- workshops and mentoring made student teachers more aware of learners' needs when preparing teaching strategies and their PCK developed further. Geddis, Onslow, Beynon, and Oesch (1993) compared the PCK of an 'expert' teacher and novice chemistry teachers teaching about chemical isotopes. They found that the two novice teachers adopted a transmission model of teaching. Novice teachers spent time on doing mathematical calculations, which most students struggled with, and therefore did not understand the essential ideas, which they thought students would find relatively simple. On the other hand, an experienced teacher developed a step-wise strategy that took students gradually towards the concept he intended them to learn. Unlike the novice teachers, the experienced teacher focused more on the development of conceptual knowledge, rather than procedural knowledge. The transformation of his CK was evident and benefitted students. Geddis et al. (1993) concluded that, in order for teachers to transform their CK successfully for learners, knowledge of learners' prior knowledge, effective teaching strategies that take learner knowledge into account, alternative representations and curricular saliency should be evident. They identified these four categories as essential categories of PCK, and, as such, they play an important role in transforming CK into forms that are accessible to students.

Williams, Eames, Hume, and Lockley (2012) conducted a study to examine whether CoRes done by pre-service teachers, content experts and pedagogy specialist can enhance PCK of the pre-service teachers. Their findings revealed that CoRes developed through a collaborative process, assisting the pre-service teachers to focus on the big picture of the topic and to consider alternative ways of planning for their teaching. This finding supports a recommendation made by Bertram and Loughran (2012) that the CoRe tool could be explored in enhancing pedagogical models that might assist not only experienced science

teachers but also pre-service and beginning science teachers. Hynes (2012) investigated six middle school novice teachers without engineering degrees. It was found that the teachers portrayed some budding PCK for teaching the engineering design process. This was evident from the use of examples or analogies their students could relate to.

Jones, Carter and Rua (1999) investigated the role that primary learners' science concepts play in developing trainee teachers' pedagogical practices in sound, light and electricity. Through comparison between pre- and post-concept maps, they claim that trainee teachers grew both from pedagogical and conceptual perspectives. The analysis showed that learners' science concepts worked as effective tools in promoting trainees' development. The authors also reported that as trainee teachers examined how learners developed these concepts, they became aware of their own lack of CK. This had led to trainee teachers' pedagogical strategies changing, which resulted in a shift in their view of teaching and learning. The results of my study show that teaching experience is crucial in improving one's teaching. In supporting beginning science teachers in a two-year induction programme, Luft et al. (2011) indicated that the PCK of beginning teachers tend to build more on their specific discipline or at topic PCK level. However, she emphasised that more understanding on how beginning teachers construct their general, discipline or topic-specific PCK needs to be built.

From all the literature on PCK reviewed above, none looks at the teachers who are graduates but not qualified certified. My study fills the gap in that it investigates the transformation of content for this particular group of teachers.

2.7 Theoretical Framework

My study investigates novice teachers' ability to articulate transformation of CK. Shulman (1987) considered seven categories as the foundation of the teachers' knowledge base needed to effect learners' comprehension. Shulman's seven categories considered as prerequisite, extracted from Shulman (1986, 1987) include:

Content knowledge

Content Knowledge (CK) as described by Shulman (1986) refers to 'the amount and organisation of knowledge per se in the mind of the teacher' (p.9). However, Shulman emphasised that the CK requires "going beyond knowledge of the facts or concepts of a domain" (p.9).

General Pedagogic Knowledge

General pedagogical knowledge is defined as the "broad principles and strategies of classroom management and organisation that appear to transcend subject matter" (Shulman, 1986, p.8). Such knowledge includes ways of maintaining appropriate discipline, using class time efficiently, and communicating instructions and expectations clearly.

Curricular Knowledge

Shulman (1986, p.10) maintains that curriculum knowledge and its associated materials provide the pharmacopoeia from which the teacher draws those tools of teaching that present or exemplify particular content and remediate or evaluate the adequacy of student accomplishments"

Pedagogical Content Knowledge (PCK)

Shulman (1986) describes pedagogical content knowledge (PCK) as "subject matter knowledge for teaching" (p.9). He argues that knowledge of subject matter alone does not make one a teacher. The difference between teachers and subject specialists is that teachers need to know the subject matter, as well as how this content knowledge can be transformed into representations that are comprehensible to a group of learners with diverse interests and abilities (Shulman, 1987, p.8). Shulman defines PCK as a 'blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners and presented for instruction" (Shulman, 1987, p.8)

Knowledge of the learners

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

Knowledge of educational contexts

Shulman (1987) suggests that educational contexts range from "the workings of the group or classroom, the governance and financing of school districts, to the character and communities of culture" (p.8).

Knowledge of educational ends, purposes, and values and their philosophical grounds

This category draws on values and purposes of education that communities possess. It also takes into account the effect of the historical background of the school or learning.

These categories are considered to be important requirements for teachers. Earlier, Shulman (1986) asserted that PCK is of special interest as it 'goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching' (p.9). In other words, Shulman considers PCK as another type of knowledge or subject matter knowledge for teaching.

For my study, a model of Topic Specific PCK as a conceptual construct was used. As shown in figure 2.1, the model makes explicit the topic specific categories of CK from which transformations emerge, which are drawn from Geddis and Wood (1997) and Ball, Thames and Phelps (2008). Geddis and Wood (1997) argue that, for subject matter transformation to emerge, a variety of different kinds of knowledge, which forms an amalgam, occurs. The different kinds of knowledge include:

- learners' prior knowledge, including the preconceptions about the topic
- effective teaching strategies
- alternative representations of subject matter
- importance of the topic to the overall chemistry curriculum - 'curricular saliency'
- what makes the topic easy or difficult to understand

On the other hand, through empirical studies, Ball et al. (2008) worked on the notion of knowledge for teaching mathematics where they analysed the core activities of mathematics teaching of specific topics, such as multiplication, fractions and division. Their analysis revealed that mathematics teaching requires a 'specialised form of pure subject matter': '*Specialized Content Knowledge (SCK) is the mathematical knowledge and skill unique to teaching'* (Ball et al., 2008, p. 400). The kinds of knowledge identified by Ball et al. (2008) include:

- Error analysis
- Mathematical reasoning
- Mathematical language

- Common student conceptions and misconceptions about mathematical content
- Mathematical knowledge of the design of instruction
- Horizon knowledge

Both Geddis and Wood (1997) and Ball et al. (2008) identified various knowledge types which form an amalgam, which enables transformation for the purpose of teaching. However, unlike Mavhunga (2012) and Ball et al. (2008), Shulman has not given the amalgam of this different kind of knowledge a term or title. Mavhunga (2012) called the amalgam Topic Specific PCK which is the theoretical framework of my study. Mavhunga (2012, p. 30) defined Topic Specific PCK as: *a construct referring to the capability needed to transform teachers' own comprehension of a given topic into formats that are suitable for teaching*. The different knowledge types that form Topic Specific PCK (refer to figure 2.1 - Mavhunga model) are the common elements listed by both Geddis and Wood (1997) and Ball et al. (2008), which are:

- **Learner prior knowledge** - knowledge of learners' common misconceptions and alternative conceptions about specific content.
- **Curricular saliency** - understanding the order in which topics are addressed and the depth to which a topic should be covered.
- **What is difficult to teach** - the ability to identify gate keeping concepts, within a topic, that are difficult to understand.
- **Representations** - knowing a range of subject matter representations including examples and analogies.
- **Conceptual teaching strategies** - knowledge of effective instruction strategies for particular misconceptions, known areas of difficulty to learn and the educational purpose of available curriculum materials.

Mavhunga's (2012) model illustration was developed from the PCK model by Rollnick et al. (2008). This is possible because the latter's model makes CK explicit. In this model, PCK emerges from the amalgam of domains of teacher knowledge, which are underpinned by the beliefs (refer to the section on teaching beliefs). These domains are:

- Content Knowledge (CK) - the teacher's pure untransformed CK.
- Knowledge of students - appreciation of learners' prior knowledge, how they learn, their interests and aspirations, as well as a consideration of their linguistic abilities.

- Pedagogical knowledge - having an understanding of what constitutes good teaching, taking into consideration the best teaching approaches in a given context, which is informed by appropriate learning theories.
- Knowledge of context - all contextual factors influencing the teaching condition like resources, class size, learners' socio-economic background, curriculum, conditions in the classroom and availability of time for teaching and learning.

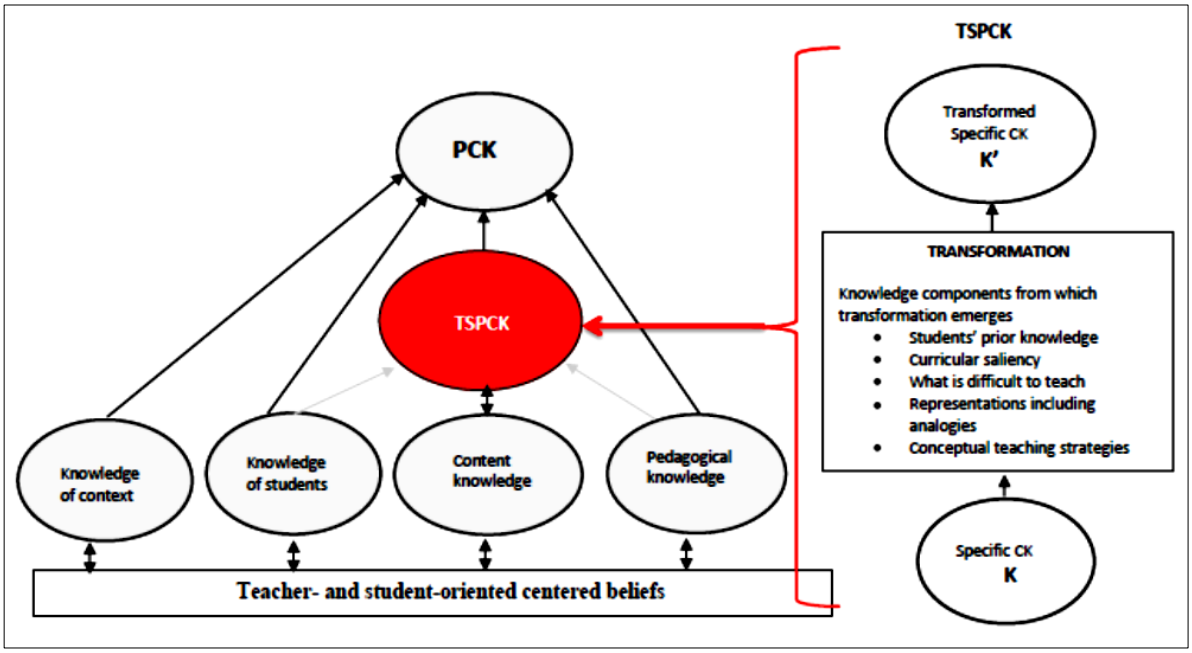


Figure 2.1: A model of Topic Specific PCK from Mavhunga (2012)

Mavhunga's main enhancement of Rollnick et al.'s model is the inclusion of Topic Specific PCK which is an intermediate stage in the transformation of CK. It is therefore a link between CK and PCK. According to Rollnick et al. (2008), the domain of student knowledge includes learners' prior knowledge, which is also identified by Geddis and Wood (1997) as one of the knowledge domains needed to effect transformation. It is for this reason that Mavhunga (2012) inserted a link between Topic Specific PCK and the domain of student knowledge, as it is not considered as important in the formation of Topic Specific PCK. However, it is worth mentioning that the author acknowledged that student knowledge does incorporate prior knowledge, which constitutes Topic Specific PCK under the category of misconceptions. Furthermore, these knowledge domains are influenced by the beliefs of the teacher and students about teaching science. However, my study did not incorporate the beliefs.

My study investigates how teachers' CK on the particulate nature of matter is transformed. The findings may have a positive impact on the concept of transformation and understanding of the knowledge needed, in order to transform CK. Shulman (1987) asserted that teaching starts with a teacher's understanding of what needs to be learned and how it is to be taught. In support of this, Shulman (1987) presented a theoretical framework derived from an empirical study of veteran high school teachers, called 'Pedagogical Reasoning and Action'. He suggested that teaching takes place in a cycle that involves Comprehension, Transformation, Instruction, Evaluation, Reflection and finally a New Comprehension. Shulman (1987) argued that the conception of pedagogical reasoning and action is crucial from teachers' points of view. This is because it allows teachers not only to comprehend the knowledge but also to make wise pedagogical decisions, such as effective instructions.

The Topic Specific PCK construct shares some similarities with the Topic Specific Professional Knowledge of the Consensus model for PCK (http://pcksummit.bscs.org) shown in figure 2.2. Both the Topic Specific Professional Knowledge and Topic Specific PCK are derived from a section of teacher domain and for a specific topic. The teacher domains are assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students and curricular knowledge. The consensus model provides a useful way of understanding the link between knowledge and practice. It provides a definition of PCK that highlights it as a topic, teacher and context specific and includes both *Reflection on Action and Reflection in Action (*http://pcksummit.bscs.org/). The model indicates teachers drawing on professional knowledge bases to produce topic specific professional knowledge.

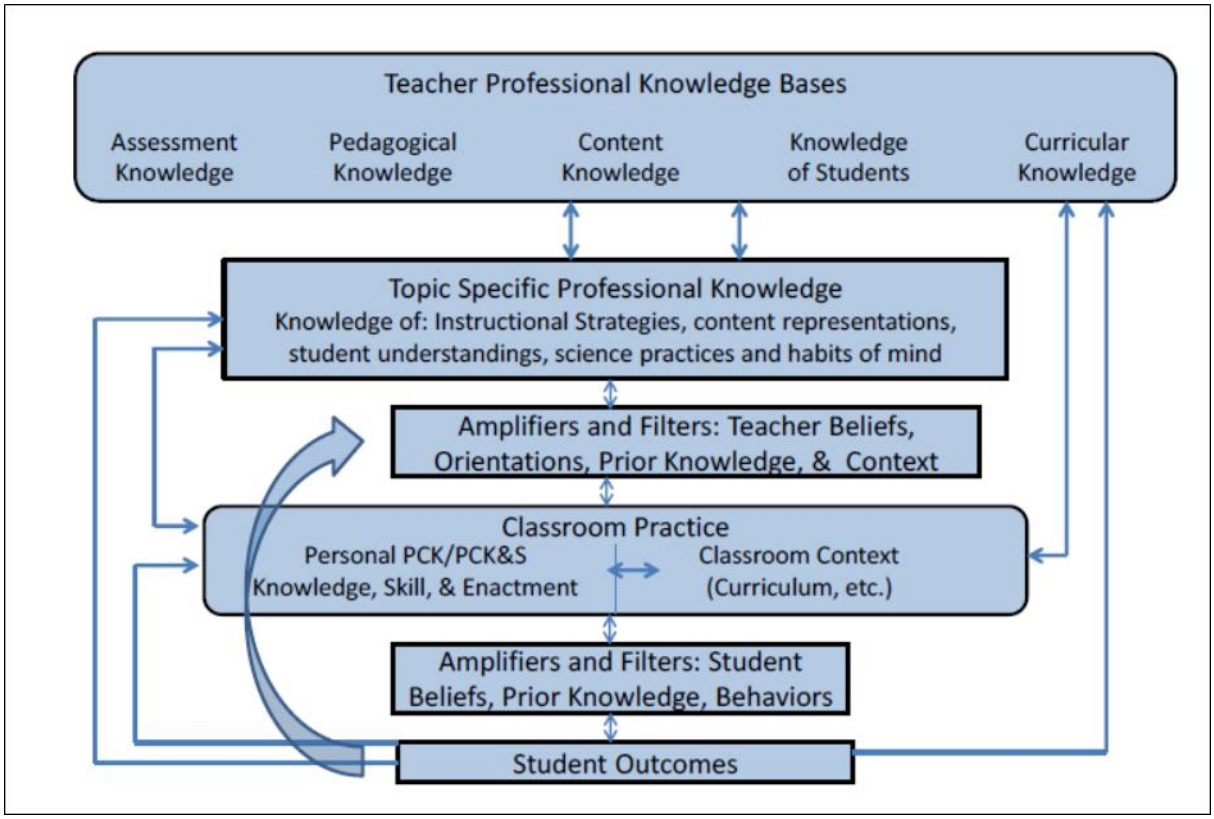


Figure 2.2: Consensus model for PCK (http://pcksummit.bscs.org/)

The model aligns closely with the construct of Topic Specific PCK which is knowledge rather than practice. Similar to the Topic Specific PCK (which has domains of teacher knowledge), the Consensus model for PCK also consists of the categories of knowledge in the domain of teacher professional knowledge bases. These categories of teacher knowledge (domains) for both models have been variously described by Shulman and other researchers. There are also some similarities in terms of types of knowledge, which are aligned with the Topic Specific PCK's five categories as articulated above; these include various forms of content representations, the links between instructional strategies and reasons for using them, learners' difficulties and misconceptions (http://pcksummit.bscs.org).

The consensus model for PCK shows that as knowledge is translated into practice, various effects operate in the form of amplifiers and filters. These are linked to beliefs and orientations and learning context. The double arrow between classroom practice and topic specific professional knowledge indicates that the two influence each other. To some extent, my study explores both the knowledge and practice of the NUGTs and, in particular, the case study teachers who have been exposed to the PDI on the teaching of the particulate nature of

matter. Therefore, it is envisaged that the Consensus Model for PCK may provide a useful way of investigating the interface between knowledge and practice in NUGTs.

2.8 Measuring PCK

Even though many researchers have elaborated on PCK, there are still challenges involved. Abell (2008) highlighted that there is still a need to find the relationship of PCK to teacher practice in terms of quality and quantity. This challenge might be caused by the tacit nature of PCK and points to the need for measurement. In that case, one needs to be explicit about exactly what needs to be measured. In the literature, most PCK tools have focused more on documenting PCK rather than measuring it. Hill, Ball and Schilling (2008) share the same sentiment that there is widespread evidence that effective teachers have unique knowledge of learners' mathematical ideas and thinking. However, few scholars conceptualise this domain, and fewer have focused on measuring this knowledge. Rowan, Schilling, Ball and Miller with Atkins, Camburn, Harrison and Phelps (2001) attempted to measure teachers' PCK in surveys where they developed a set of questionnaire items. The survey questions were developed to directly measure two critical domains of the elementary school curriculum - reading/language arts and mathematics. They intended to assess two dimensions of teachers' PCK, namely: teachers' knowledge of subject matter and teachers' knowledge of effective teaching practices in a given content area. In their initial pilot study, the authors have shown that there is a possibility of reliably measuring certain facets of teachers' PCK in very fine-grained areas of the school curriculum, with as few as 6-10 survey questionnaire items. Lim-Teo, Chua, Cheang and Yeo (2007) investigated Mathematics teachers' pedagogical content knowledge (MPCK) of pre-service teachers, where they developed a 16-item instrument to measure some aspects of the MPCK for teaching mathematics. The four broad content areas: whole numbers, fractions & decimals, geometry and measurement were covered as this was primary level mathematics. The instrument intended to explore the MPCK constructs on a teacher's: (a) own understanding of mathematical structure and connections, (b) knowledge of a range of alternative representations of concepts for the purpose of explanation, (c) ability to analyse the cognitive demands of mathematical tasks on learners and (d) ability to understand and take appropriate action for children's learning difficulties and misconceptions. This means that they implicitly consider these constructs to be aspects of PCK. The findings on pre- and post-tests revealed that there was significant improvement in some aspect of their MPCK on completion of the programme. However, the constructs of teachers' own knowledge of mathematical structure was found to be the weakest in both tests,

although there was improvement between the two tests. This implies that there is a room for pre-service teachers' MPCK level to improve, taking into account the post-test scores. Hill et al. (2008) gave a description of their effort to conceptualise and develop measures of teachers' combined knowledge of content and students, by analysing the result of practicing teachers' multiple-choice items. They termed this domain knowledge of content and students (KCS), which is defined as *"content knowledge intertwined with knowledge of how students think about, know, or learn this particular domain*" (p. 375). The findings from the KCS analysis showed that teachers do seem to hold "knowledge of content and students". This is because of the familiarity with aspects of students' thinking, such as common student errors which emerged and are important elements of the knowledge of teaching. They also found that the results from psychometric and validation analyses were ambiguous. They acknowledge that KCS remains under-conceptualised and understudied, even though most scholars, teachers and teacher educators feel strongly that teacher knowledge of learners' thinking in certain domains is likely to matter. Hill et al. (2008) further argue that what is yet to be understood is what constitutes such 'knowledge'. Park et al. (2011) investigated the correlation between teachers' PCK level, as measured by their PCK rubric, and the degree to which teachers' classroom is reform-oriented. The rubric was used as an instrument to measure the level of teachers' PCK from observation of teachers teaching and pre-/post-observation interviews. The authors acknowledged that the rubric focused on the measurement of two key categories, namely: knowledge of student understanding with respect to a certain subject matter and knowledge of instructional strategies and representations of subject matter among the five categories. The findings have shown that measuring teachers' PCK has proven to be reliable because the results revealed that the two categories are positively related to the reform orientedness of instruction. This may enhance teachers' transformation of CK.

In my study, a rubric developed by Mavhunga and Rollnick (2013) was used to score the developed PCK tool. Minor changes were made to the rubric, in order to be aligned with the particulate nature of matter test. The rubric corresponds to the five categories with each being rated on a four point scale from 1 "limited" to 4 "exemplary". Each category was scored singly as an item, so that the test comprised 5 items each with a maximum score of 4. The rubric's adaptation and scoring is explained in detail in chapter four.

2.9 Teaching and learning of the particulate nature of matter

To develop PCK, teachers need to gain a deeper understanding of learners' conceptions and difficulties concerning the topic involved (De Jong, Van Driel, & Verloop, 2005). Many researchers have conducted research on students' alternative conceptions and the implications attached to teaching and learning of the particulate nature of matter. The topic, particulate nature of matter in the grade 10 curriculum consists of the kinetic molecular theory, states of matter and the atom (models and structure). Hence the literature reviewed below incorporates some of these concepts.

2.9.1 Alternative conceptions and difficulty associated with the teaching and learning of the particulate nature of matter

The particulate nature of matter is a key basic concept and the literature suggests that learners from early schooling often have difficulties learning chemistry if they do not understand the scientific model for the particulate nature of matter. The ability to explain matter at the particulate level is crucial as far as the topic under consideration is concerned. The study done by Treagust, Chandrasegaran, Crowley, Yung, Cheong and Othman (2010) revealed that learners' responses to the test items showed that they have limited understanding of the particle theory concepts amongst the samples of learners from all four countries involved in the study. Based on this finding it is evident that the particulate nature of matter continues to pose challenges to the learners. Boz (2006) also indicated that many high school learners of all ages find difficulties in applying the particulate theory to explain phase changes despite science teaching. Griffiths and Preston (1992) identified the understanding of concepts such as atoms and molecules as important. This will enable learners to explain phenomena and other concepts such as chemical bonding, chemical reactions, ions, states of matter (Griffiths & Preston, 1992). Gabel, Samuel and Hunn (1987) also share the same sentiment in that matter at the particulate level is fundamental to the nature of chemistry itself and such understanding is essential to the learning of concepts such as gas laws, stoichiometry relationships and solution chemistry.

Taber (2001, p. 131) argues that 'one general problem that has widely been recognised in the learning of chemistry is the difficulty learners have with the relationship between the molecular and macroscopic' and Boz (2006) also argue that a common misconception among learners of all age groups was the attribution of macroscopic properties to particles. Taber

(2001) and Griffiths and Preston (1992) highlighted reasons attributed to the difficulty among others that:

- Learners have a primitive continuous matter outlook on the physical world as opposed to a particle model.
- Learners experience chemistry at the molar level while more of the theoretical structure of chemistry relies on entities that are at molecular scale.
- Many of the constructs used are abstract in nature with no direct evidence that learners can experience.
- Learners tend to transfer changes in macroscopic properties to the sub-microscopic level.
- Often textbooks present conflicting models of the atom which confuse many learners.

Taber (2001) argues that understanding chemical structure needs a theoretical level of description such as distinguishing elements, compounds, etc. However, distinguishing these fundamental concepts appears to be a cause for concern in the teaching of particulate nature of matter. In the study conducted by Gabel et al. (1987) about the particle nature of matter, the findings showed that even after being taught chemistry, students were unable to distinguish solids, liquids, gases or elements, mixtures and compounds. In addition to the macroscopic and sub-microscopic, Taber (2001) also suggests knowledge of quantum chemistry may be needed as part of understanding chemical structure. The study by Garnett, Garnett and Hackling (1995) found learners' conceptions to be located in areas such as: the nature and characteristics of particles, the spaces between particles and the way particles are arranged, molecules in different phases and changes of phase, as well as the effects of temperature.

Boz (2006) investigated Turkish learners' conceptions of the particulate nature of matter and found that learners of all age groups experienced difficulties in understanding the movement of particles in a solid substance. In addition to that, learners tend to think that if no phase change occurs in a substance, this implies that there is no change in the arrangement or movement of particles (Boz, 2006). Table 2.1 shows the students' alternative conceptions on the particulate nature of matter as summarised by Garnett et al. (1995, p. 73). Garnett et al. (1995) argue that some of these alternative conceptions arise because learners confuse the interpretation of everyday language with specific scientific language and have difficulties in

visualising matter in terms of a particulate model. This is supported by Ayas, Özmen, and Çalik (2010) who found that most learners, including students at the university level, had misconceptions and challenges in making sense of knowledge and linking their theoretical knowledge to daily phenomena. The authors suggest that this might be attributed to a lack of explanation from their teachers who might not have linked scientific learning to everyday life in their science lessons. For example, the word 'particle', which, in everyday usage, is a small but visible piece of a solid substance, while in chemistry, it is used at a submicroscopic level, intended to describe atoms, molecules or ions. The authors argue that the various ways of interpreting words may be a possible cause of misconceptions.

Table 2.1: Students' alternate conceptions of the nature of matter (Garnett et al., 1995)

The nature and characteristics of particles	The spaces between particles and the way particles are arranged	Molecules in different phases	Changes of phase and the effects of temperature
*Atoms are alive. They are alive because they move. *All atoms have the same weight. *Atoms and molecules have macroscopic properties e.g. expand when a substance is heated: freeze when a substance is frozen, malleable etc. *Matter is made up of particles which individually have the properties of the substance they constitute.	*Matter is continuous and there is no vacuum or space between particles. Matter exists between atoms *There is considerable space between molecules in a liquid. *Gas molecules are arranged in an orderly rather than disorderly fashion	*Atoms and molecules may have different sizes, shapes and weights depending on the phases. *Water in the solid phase has the largest and heaviest molecules *Molecules within a phase move at the same speed	*Temperature can affect the shape of molecules *Heat causes water molecules to expand. The size of a molecule depends on the temperature *When solids melt, water runs out *When water boils, air escapes.

Novick and Nussbaum (1978) also found the conceptions about 'empty spaces between particles' (vacuum concept), intrinsic motion (particle kinetics) and interaction between particles (chemical change) to be the least well assimilated by learners. In addition, Novick and Nussbaum (1981) further conducted a cross-age study on learners' understanding of the particulate nature of matter and still found that learners' inability to picture empty spaces in gaseous medium persisted.

When learning about atomic structure, Taber (2001) highlighted several areas where learners may have difficulty. Firstly, learners tend to confuse the various entities that are posited at molecular level, which leads to non-sensible comments (Taber, 2001). For example, describing atoms as 'a very small molecule' or describing both ion and molecule as 'part of an atom'. Secondly, learners believe that the nucleus of an atom must contain an equal number of neutrons as protons because the role of neutrons is to neutralize the protons.

According to Taber (2001) this is attributed to learners' inability to correctly identify the charge on the three main sub-atomic particles. Finally, some learners believe that orbiting electrons push on the protons in the nucleus in order to hold the nucleus together.

The relationship between the macroscopic and sub-microscopic does not only pose a challenge to the learners but also to the teachers. Chemists switch between the two levels during discussions (Taber, 2001) and yield many problems for novice learners. Davidowitz and Chittleborough (2009) found that students have difficulties translating between the macro and the sub-micro "levels of representation" of matter. The same was also discovered in novice teachers when reasoning about particles; they mix together macro and sub-micro-meaning (De Jong & Van Driel, 2004). De Jong et al. (2005) investigated PCK of pre-service teachers, using the particulate model in the teaching of chemistry. Their findings showed that almost all the pre-service teachers seemed to be aware of the learners' difficulties in understanding the invisibility of particles. The pre-service teachers highlighted the importance of using models of molecules and atoms to promote learners' understanding of the relationship between phenomena and entities, such as atoms and molecules. According to Boz and Boz (2008), prospective teachers showed that they preferred and utilised concrete objects and computer animations as teaching techniques when introducing the particulate theory. The study by Karacop and Doymus (2013) showed that the computer animation methods and jigsaw cooperative learning groups were more effective in improving learners' achievements in their understanding of chemical bonding as compared to the traditional teaching method.

2.10 Professional Development

Since my study incorporated the professional development which is discussed in detail in chapter 5, it is important to review what the literature says about it. According to Grigg, Kelly, Gamoran, and Borman (2013) professional development may take different forms, such as in-service training, mentoring, coaching and lesson study, amongst others. Zwiep and Benken (2013) argue that in the literature on professional development there are critical emphases, namely 1) the knowledge and perceptions of the teacher and 2) the role that rigorous content plays within teacher development. This is to some extent in line with the purpose of the professional development in my study where its impact on teachers' CK and PCK of the topic is investigated. This implies that the professional development attempts to expand teachers' CK, as well as their perceptions about that content. This is supported by

Supovitz and Turner (2000), who argue that high-quality professional development should focus both on subject-matter knowledge and deepen teachers' content skills and pedagogical content knowledge, and deepen their skills in teaching the subject (Hashweh, 1987). However, Hewson (2007) acknowledged that there are also practical difficulties associated with conducting research in the area of teacher professional development. The following were identified by the author:

- the number of categories involved,
- the length of time it takes for teaching practice to mature,
- the amount of detail,
- intensive research techniques required to provide understanding of what is happening at each stage of the process and
- the cost of effective research which can be substantial (Hewson, 2007).

Professional development encourages systemic and coordinated teacher learning, which may influence student achievement (Grigg et al., 2013; Hewson, 2007). Earl & Fullan (2003) highlighted that teachers' learning needs should be informed by evidence of learners' learning needs. When investigating core features that make professional development effective, Garet, Desimone, Birman, and Yoon (2001) argue that content focus, coherence, collective participation of teachers, activities in the form of workshops and duration of the activity, affect teacher learning significantly. The first core feature suggests the need for professional development to put emphasis on the activities that concentrate on CK. In addition, my study further extended the core by incorporating the transformation of CK.

The NUGTs in my study are similar to the participants of the Teach for America (TFA) model (Xu et al., 2011). The TFA model aimed at improving the teaching in both primary and high schools, particularly the quality of maths and science teachers. The model also intends to boost the number of these teachers in the lowest performing schools. Due to their similarity, it is worth describing the professional development process followed in the TFA model.

- The TFA participants who are called 'corps members' participate in an intensive five-week summer national institute and a two-week local orientation and induction programme prior to their first teaching assignment (Xu et al., 2011)

- The five week period includes coursework and student teaching, prior to the corps member's initial placement in the classroom (Glazerman, Mayer, & Decker, 2006)
- The corps members spend about 70 hours per week on training-related activities during the intensive five-week training (Glazerman et al., 2006)
- In addition to the TFA five-week training, corps members participate in a one- to two-week, TFA-led induction in their assigned region (Katz, 2007)
- As part of professional development, TFA has a regional support network that assists teachers throughout the two-year commitment. They receive ongoing support from TFA staff and faculty located in each community, as well as from TFA national staff (Xu et al., 2011)

The TFA model relates to my study with respect to the type of participants involved. They both recruit uncertified graduates to teach science and mathematics in underperforming high schools. A more detailed description of the NUGTs' PDI followed in my study is found in chapter five.

2.11 Summary

This chapter gives a description of research associated with the improvement of the quality of PCK. It began with a summary of the theoretical idea by Shulman. This was followed by the conceptions of PCK including descriptions of how different researchers extended the notion of it. As PCK is perceived as elusive, it was important to review its nature. Many researchers agree that CK is a pre-requisite to quality PCK. It is for this reason that a description of CK and its nature was reviewed in this chapter. In addition to that it was important to also look at findings that show its contribution to PCK as well as the relationship between them. Since my study involves measuring PCK of novice science teachers, findings related to PCK in novice/beginning/pre-service science teachers were reviewed. This included the review of existing literature on measuring PCK of both experienced and inexperienced science teachers.

The proposed theoretical framework of Topic Specific PCK adopted in my study was also described. This construct includes the five teacher knowledge categories that effect transformation of CK, identified as being: 'learners' prior knowledge; curricular saliency; aspects that are difficult to teach; representations and conceptual teaching strategies'. Since my study looks at both the knowledge and practice of NUGTs, it was important to show the similarities between the Topic Specific PCK and the Consensus model for PCK. According to Mavhunga (2012), the theoretical framework of Topic Specific PCK enables exploration of

pedagogical transformation topic by topic. For my study, the measurement and investigation of Topic Specific PCK takes place within a topic – the Particulate Nature of Matter. The literature related to both the teaching and learning of the particulate nature of matter was reviewed. The focus was on alternative conceptions as well as the difficulties associated with the teaching and learning of the topic. Finally, the literature on professional development was reviewed as my study is located within a PDI. Since NUGTs are similar to the participants of TFA, the professional development structure of TFA was also described for comparison. The next chapter describes methodology followed in my study.

CHAPTER 3

3. RESEARCH METHODOLOGY

In this chapter, I outline and discuss the research design in the study. This includes an explanation of the research instruments used as well as the pilot tools. The process of data collection and sampling treatment is also highlighted. An indication of how data was analysed for each instrument is given. Validity and trustworthiness in both the quantitative and qualitative research categories are discussed. Finally, ethical implications are discussed.

3.1 Introduction and overview

Since many studies relating to PCK have been done with experienced teachers (e.g Loughran et al., 2004; Rollnick et al., 2008; van Driel et al., 1998), I developed an interest in investigating PCK of novice or beginning science teachers. Therefore the purpose of my study is to examine the extent to which the NUGTs' Topic Specific PCK and CK are influenced by an intervention. Knowing that due to insufficient teaching experience novice high schools teachers are not likely to teach grade 11 or 12, I opted for the topic, the particulate nature of matter, which is taught in grade 10. The study involved the development of CK and Topic Specific PCK tests, followed by the validation and piloting process. The detailed description on the development, validation and piloting process of these tests is outlined in chapter four.

Unlike the study by Mavhunga (2012) which was located within a methodology course as the intervention, my study is situated within a Professional Development Intervention (PDI). In the context of my study, I consider the PDI to be encompassing all NUGTs' experiences in relation to knowledge and teaching in general and to that of the topic under consideration. It began at the beginning of their intensive training and ended after 9 months of teaching. The detailed description of the intensive training is outlined in table 5.1. Part of the PDI also involves the period teachers spend in schools teaching, where I observed some of them teaching the particulate nature of matter and also did interviews.

3.2 Research Methodology and Design

According to Terre Blanche and Durrheim (1999) methodology is the study of procedures (methods) in research used to create new knowledge. Schwandt (1997) further described methodology as the theory of how inquiry should proceed, which involves analysis of the

principles and procedures in a certain field of enquiry. In deciding what methodology to use, researcher positionality is an important factor. Opie (2004) argued that the most significant factor that influences selection and use of methodology is where the researcher is coming from with regard to his/her fundamental assumptions. These assumptions are concerning social reality (ontological) and the nature of knowledge (epistemological). This implies that one cannot think about methodology in isolation from these assumptions, which in turn give rise to methodological considerations. The scope of methodology has many dimensions and is broad. For example research methods form part of the research methodology. Cohen, Manion and Morrison (2007, p. 47) described methods as a range of approaches used in educational research to gather data which is to be used as a basis for inference and interpretation, for explanation and prediction. Opie (2004) defined methods as the specific research techniques used to collect and analyse data such as interviews, questionnaires, observation and documentary analysis etc. According to Durrheim (2004), "research methods" form part of the research design. The author argues that research design can be viewed as the process consisting of four stages: (i) defining the research questions, (ii) designing the research methods (instruments) (iii) implementing or executing the research which includes data collection and (iv) writing up the research report. Therefore the discussion below highlights and justifies the process of my research design in line with Durrheim (2004)'s stages. I begin with the approach used, data collection instruments and process, piloting, sampling and ethical issues.

3.2.1 Mixed-methods

Mixed methods (MM) design has become popular as it has emerged during the past few years. MM is viewed by some as a suitable research methodology from the point of view of its philosophical assumptions, while others view it merely as a set of techniques or methods of collecting and analysing data (Creswell & Plano Clark, 2007). MM research is defined as:

'Research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases in the research process. As a method, it focuses on collecting and analyzing, mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone' (Creswell & Plano Clark, 2007, p. 75).

The underlying philosophical assumption that guides MM research is the pragmatist paradigm which assumes a worldview and interest in both narrative and numeric data and their analyses (Teddlie & Tashakkori, 2009). Different researchers highlight different benefits of employing MM research. Teddlie and Tashakkori (2009) argue that MM seems to be superior to single approach designs in that it (i) addresses a range of confirmatory and exploratory questions, with both methods at the same time, (ii) provides stronger inferences and (iii) allows the opportunity for divergent views. Greene, Benjamin and Goodyear (2001) argue that the possible gain in using MM research is that it enhances validity, increases comprehensiveness of the findings and provides more insightful understanding, as well as increases value consciousness and diversity. Creswell and Plano Clark (2007) warn that prior to designing and conducting MM research, it is crucial to check whether MM best addresses the research problem or question. In order for a researcher to obtain the abovementioned benefits when using a MM approach, it is crucial to distinguish between full MM and partial MM. Leech and Onwuegbuzie (2009) argue that a full MM design takes into account the highest degree of mixing both, with respect to research method and paradigm characteristics. This involves applying the quantitative and qualitative research within one or more, or across all four categories of a single research study, i.e. research objective, type of data and operations, type of analysis and type of inference. However, a fundamental difference between the two types of MM design is that whereas full MM employs mixing the qualitative and quantitative methods within one or more stages or across these stages, with partial MM, the phases are not mixed within or across stages.

As indicated earlier in this chapter, my study aims at investigating the Topic Specific PCK of NUGTs; therefore the MM design addresses the needs for this purpose. The use of both quantitative and qualitative methods in analysing Topic Specific PCK and CK in my study provided inference quality and different views. According to Teddlie and Tashakkori (2009) inference quality describes whether a study adheres to best practice and interpretive rigour. This implies that the use of the MM design appropriately in my study could yield the results that could be trusted and credible. The Topic Specific PCK findings from using quantitative and qualitative method may show divergent views; this would allow the opportunity for exploring the research question under consideration even further.

The design for my study is a concurrent embedded MM approach, where both quantitative and qualitative data is collected at the same time during the research process and analysed separately, aiming to build or bring results together. According to Creswell and Plano Clark

(2007) this type of design intends to determine if there is convergence, differences or some combinations. In my study, the qualitative method (in the form of an intervention as shown in figure 3.1) is embedded or nested within the quantitative method.

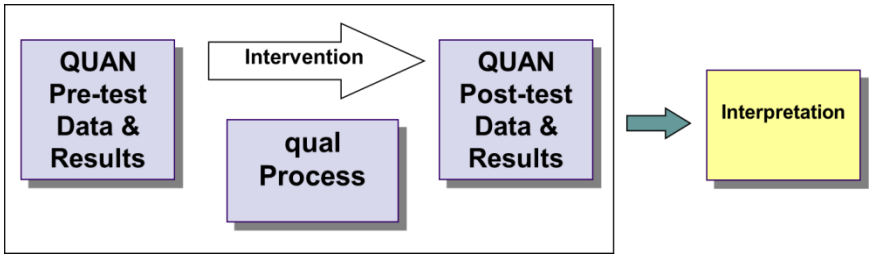


Figure 3.1: The concurrent embedded design of mixed-method design

According to Creswell (2009) the embedding may suggest that the secondary method (qualitative) intends to address a different research question from the primary method (quantitative). However, to some extent in my study there is integration of both primary and secondary methods in answering the research questions. Therefore, research questions 2 and 3: What effect does a targeted PDI have on the NUGTs' CK and of that of Topic Specific PCK, is answered by both methods. Similarly, the primary and secondary methods intend to answer the research questions 1 and 4: How can Topic Specific PCK be measured and what is the relationship between CK and Topic Specific PCK, as there were aspects of both quantitative and qualitative analysis that I looked into. The reason for mixing data from the two methods is to integrate the information and compare one data source with the other (Creswell, 2009).

The concurrent embedded design may be used to serve different purposes. Amongst others Creswell (2009) indicated that the concurrent embedded design allows a researcher to gain broader perspective through the use of different methods, as opposed to using the predominant method only. For instance in my study, instead of relying merely on the Topic Specific PCK test results to determine Topic Specific PCK, further evidence on observation of the case study teachers' lessons on the topic was gathered. This is intended to enrich the description of the NUGTs' Topic Specific PCK. Creswell (2009) also indicated that another advantage of using a concurrent embedded design is that a method may be used within the framework of the other method. This applies in the study where the Topic Specific PCK test served as both quantitative and qualitative method. The tests were analysed quantitatively using Rasch statistical software and case study methodology was used to study how some NUGTs responded to the test questions qualitatively. Therefore, this suggests that one is able

to collect the two types of data at the same time during a single data collection phase. Ultimately, the use of MM may allow emergence of a stronger study, than if one uses only quantitative or qualitative research by itself. However, the limitations of using the concurrent embedded design should also be acknowledged. Both Creswell & Plano Clark (2007) and Creswell (2009) caution the integration of the results from the two methods. They indicated that integration of the results can be challenging and that careful transformation of data is needed. Lastly, it was highlighted that since the sets of data are compared, discrepancies may occur due to unequal priority of the two methods, which may result in unequal evidence in the study (Creswell, 2009). This may affect the interpretation of the final results negatively. In my study I addressed the issue by viewing both methods as equally important throughout the data transformation process.

3.2.2 Research approach - Case study

The research strategy followed in my study is a case study. Denscombe (2007) argues that a characteristic that defines a case study approach is its '*focus on just one instance of the thing to be investigated'* (p.35). The reason behind focusing effort on one case instead of many is that there may be insights gained in looking at the individual case, which may, in turn, have wider implications that would not have emerged through other research strategies that cover multiple instances (Denscombe, 2007). Unlike other research strategies, case study allows in-depth study (Denscombe, 2007). Opie (2004) shares the same sentiment in viewing a case study as '*in-depth study of interactions of a single instance in an enclosed system'* (p. 74). The reason why a case study is described as in-depth study by the two authors above is that things are studied in detail, because researchers devote their time solely to one instance. The more time researchers devote to one instance, the greater the chances of discovering things that were not discovered through superficial research (Denscombe, 2007). Another advantage of a case study is that it allows and encourages both methods (hence the use of MM described above). A researcher may use a variety of sources and data as part of the investigation. However, Denscombe acknowledges that the use of a case study approach is far more aligned with qualitative research than with quantitative research.

For the purpose of my study, dealing with a tacit and complex construct such as PCK, a case study approach might be relevant, not only because of the in-depth investigation, but also because the explanation that may be provided can cope with the complexity and subtlety of a real life situation (Denscombe, 2007). Hence, a case study approach focuses on a real life situation with real people. It could be a single person, a group of people within a particular

setting, such as a class or a school or a department within a school (Opie, 2004). For my study, there is also a case within the case study that involved the four NUGTs who were taught the topic – the particulate nature of matter in grade 10.

Like any other research design, the case study approach has its disadvantages too. Denscombe (2007) indicates that credibility of generalisation attached to its findings was severely criticised. This approach is often seen as producing soft data, due to its lack of degree of rigour, because it focuses on (i) process rather than measurable data and (ii) qualitative and interpretative procedures rather than quantitative and statistical ones. In my study, both the quantitative and qualitative process are utilised hence the use of MM approach.

3.3 Data collection instruments and process

Prior to discussing the data collection instruments in detail, it is worthwhile to give an overview of the sequence of the research process. The first phase of the process began with deciding on the sample participants (novice teachers). The lack of teaching experience of the novice teachers led to the choice of the topic – the particulate nature of matter. With the topic of the study available, I began with the process of developing both the CK and Topic Specific PCK tests. This was followed by the validation and piloting of the tests with a group of practicing teachers.

The 2012 cohort for NUGTs started their intensive training in December 2011. It was for this reason that I started engaging with the group of teachers at that time. This second phase involved the administration of the pre-tests, introduction of Topic Specific PCK and the development of an initial CoRe which took place during the training put together by the Teach South Africa organisation. The detailed description of the intensive training is discussed in chapter five.

The third phase of data collection started at the beginning of the first school term (January 2012 - March 2012). During this phase, the NUGTs were expected to start with their teaching. I observed the case study teachers' lessons on the topic under consideration (a more detailed description is in chapter five). The interviews with the same teachers were conducted before and after teaching each lesson. Each teacher was observed for three consecutive days during the teaching of the particulate nature of matter. Mentors, who are veteran experienced teachers recruited by the Teach South Africa, were expected to support teachers with content during the year, at least once per school term.

The final phase of data collection took place during September 2012 (end of school term 3). During this phase I arranged for the NUGTs to come to my institution. This meeting was utilised for administering all the post instruments - CK test and Topic Specific PCK test, as well as developing the final CoRe. It was during this phase that NUGTs completed a reflective questionnaire. Table 3.1 summarises the sequence of data collection discussed above.

Table 3:1: Sequence of data collection

	Task	Approximate Date
Phase 1	• Deciding on the sample participants	July 2011-Novemebr 2011
	• Deciding on the topic choice	
	• Process of test development-Topic Specific PCK and CK test	
	• Validating tests	
	• Piloting tests	
Phase 2	• Intensive training for NUGTs (more detailed description in chapter five)	December 2011
	• Administration pre-CK and Topic Specific PCK tests	
	• Development of the initial CoRe	
Phase 3	• Classroom observation and interviews-Case study teachers	January-March 2012
	• Mentorship	
Phase 4	• Administration post-CK and Topic Specific PCK tests	September 2012
	• Development of the final CoRe	
	• Completion of reflective questionnaire	

The full sequence of delivery for the intensive training programme and data collected including time taken is discussed in chapter five. All the instruments mentioned were used in my study. The discussion below elaborates on the use of each instrument as well as their advantages and disadvantages.

3.3.1 Pencil and Paper Instruments

Pencil and paper instruments included both CK and Topic Specific PCK tests which I developed. Pre and post tests were administered to the NUGTs at the beginning and the end of the Professional Development Intervention (PDI). Although several fixed response items were used, some of the questions in both tests are open-ended. Cohen, Manion & Morrison (2000) argue that administering open-ended questions captures the authenticity, richness,

depth of response and honesty which are viewed as the hallmarks of qualitative data. However, the disadvantage noted by Cohen et al. (2000) and Neuman (1994) is that open-ended questions contain problems of data handling. Both authors agreed that (i) it is likely that different respondents will give different degrees of detail in answers, (ii) it becomes a challenge for a researcher to make comparisons because of lack of commonality and (iii) a greater amount of time is consumed when completing it. In order to minimise the biases in terms of scoring both the diagnostic tests, a co-researcher was requested to do validation of scoring and results. The diagnostic tests were self-administered and supervised. The responses from the Topic Specific PCK test provide evidence for answering research question 1 concerned with the purpose of measuring the construct. The purpose of both the pre and post diagnostic tests was to assess the influence that the PDI had on NUGTs' CK and Topic Specific PCK. This contributed to answering research questions 2 and 3. The CK and Topic Specific PCK tests also provided evidence for answering research question 4, the purpose of which is to attempt to find the relationship between them.

3.3.2 Observations

In my study, observation by video recording was used as a primary data source for capturing NUGTs' PCK from their actual lessons on the particulate nature of matter. Cohen et al. (2000) argue that '*observational data are attractive as they afford the researcher the opportunity to gather 'live' data from the 'live' situation' (*p.305). The advantage of using the video recording is that the transcripts can be used to provide a check against bias or misinterpretation and offers rich data (Opie, 2004). However, it also has its limitations in that people may consciously and unconsciously change their behaviour (Opie, 2004) and there is an invasion of the privacy of subjects and their private space (Cohen et al., 2000). This was addressed by video-recording at least one lesson prior to the actual lesson for data collection as a way of getting learners to be familiar with being video-recorded. Video-recording also has technical problems such as quality of sound and this was addressed by finding a trained person to use it. The purpose of lesson observations in my study was to find rich and in-depth understanding of NUGTs' PCK of the particulate nature of matter. This was triangulated with the actual Topic Specific PCK test results as demonstrated in chapter seven. The third research question is linked to this instrument, intending to find out of the extent to which the PDI has influenced NUGTs' Topic Specific PCK. As indicated earlier the lesson observation is also part of the PDI.

3.3.3 Interviews

In my study, interviews were used to further obtain a deeper understanding of NUGTs' views on the lessons taught (see Appendix A). Park et al. (2011) referred to these as pre/post-observation interviews because they are conducted before and after teaching a lesson. Opie (2004) argues that respondents are encouraged to develop their own ideas, feelings, insights, expectations or attitudes when interviewed. In a way, this allows respondents to express what they think with greater richness and spontaneity (Opie, 2004). The advantages of semi-structured interviews are that they allow probes, expand interviewees' responses and shape the interviews, therefore preventing aimless rambling (Opie, 2004). The other reason for conducting the interviews was to pull together teachers' knowledge of subject matter (learners' misconceptions), strategies intended to be used when teaching and also an element of how the lesson was planned, as well as how it was expected to turn out. No method of collecting information is free of pitfalls and Opie (2004) acknowledges that there is a possibility of the researcher's bias getting in the way. In my study the interviews are audio-recorded. Opie (2004) argues that tape-recorders may work in relatively close situations such as in small groups rather that in a classroom setting. Similar to the observations, the purpose of the interviews was also to triangulate what was seen during the teaching and to what was deduced from the test responses. The interview responses provide evidence in answering research question 3, which address the impact of PDI on NUGTs' Topic Specific PCK.

3.3.4 CoRes

A CoRe intends to capture and portray NUGTs' Topic Specific PCK (Loughran, Berry, & Mulhall, 2006). It is a grid representation of teacher knowledge, either of single teachers or groups of teachers. This includes rationales for how the concepts might be taught and why, as well as considerations of learners' thinking, curriculum issues and assessments. As indicated in chapter two, the CoRe consists of big ideas and eight prompts. Loughran et al. (2006) described the big idea and prompts as follows:

- *Big idea* is an idea that has a profound impact on the way scientists understand the world and teachers see it as being at the heart of understanding the topic for a particular class under consideration.

- Prompt 1: *What you intend students to learn about this idea*

  This prompt emphasises the idea of being specific about what a particular group of learners should be able to learn as an important aspect of well-developed PCK.

- Prompt 2: *Why is it important for students to know this?*

  In order to make decisions on what to teach, teachers' knowledge on what science content is relevant to learners' everyday lives and how the content links with other areas that learners study needs to be taken into consideration.

- Prompt 3: *What else you might know about this idea (that you would not share with students yet)*

  When selecting what to teach, a difficult decision has to be made regarding which content should be omitted.

- Prompt 4: *Difficulties/ limitations associated with teaching this idea*

  As part of important aspects of teachers' PCK, it is important to take into account teachers' insight into potential difficulties when teaching a particular topic to the class.

- Prompt 5: *Knowledge about students thinking that influences my teaching of this idea*

  This prompt makes explicit the influence of the decision-making of teachers' experience in teaching the topic. Teachers draw on their knowledge about alternative conceptions that are held by learners about the topic when planning their lessons.

- Prompt 6: *Other factors that influence my teaching of this idea*

  Contextual knowledge about learners and general pedagogic knowledge that influences teaching approaches are indicated in this prompt.

- Prompt 7: *Teaching procedure (and particular reasons for using these to engage with this idea)*

  The purpose of teaching procedures from a constructivist perspective is to influence learners' thinking in ways that promote better understanding of science ideas.

- Prompt 8: *Specific ways of ascertaining students' understanding or confusion around this idea*

  Teachers need to constantly monitor the progress of learners' understanding in order to determine the effectiveness of their teaching of the topic and plan future lessons.

In my study, an adapted CoRe in which prompts are grouped according to the Topic Specific PCK categories (as shown in chapter five) was used. The NUGTs worked in the same groups in both the early (initial) and later (final) stage of the PDI in an attempt to complete the

prompts for allocated big ideas. It is important to emphasise that in my study an adapted CoRe was used as a data collection tool rather than an analytic tool in both the initial and final phases. This implies that NUGTs constructed the CoRes which I analysed. There is more on how the NUGTs constructed and engaged with the CoRes in chapter five, where it is discussed fully. For an adapted CoRe refer to Appendix B.

3.3.5 Reflective Questionnaire

The questionnaire was meant to gather NUGTs' experiences and personal reflections at the end of the PDI. The reflections included, amongst others, their first time experience teaching in schools (in particular the topic considered), and the usefulness of mentorship and workshops attended. I have put together the relevant questions that NUGTs reflected on and completed at the end of the PDI (see Appendix E).

3.4 Research instruments requiring development

As I mentioned earlier in this chapter, CK and Topic Specific PCK tests were used to answer research questions 1, 2 and 4 in my study. The questions are concerned with the construct measurement and influence of PDI on both CK and Topic Specific PCK, including the relationships between them.

3.4.1 The development of the CK tool on the particulate nature

Over the period August to October 2011 I concentrated on developing tests. It was crucial to design a tool for measuring both the conceptual understanding and misconceptions of the particulate nature of matter. There were already existing questions or test items on the particulate nature of matter in the literature (e.g. Garnett et al., 1995; Kelder, 2005). Many of these items explore well known misconceptions (e.g. heat causes water molecules to expand) and learner ability to draw suitable representations of matter (e.g. learners have difficulties in visualising matter in terms of a particulate model). I needed to select items that related specifically to the concepts taught at grade 10 level.

Garnett et al. (1995) indicated that several studies have documented students' understanding of the particulate nature of matter. It was reported that students have common alternative conceptions which can be classified as misconceptions. In my study, the achievement test questions were adapted from a large body of research, such as Brook, Briggs and Driver (1984) and Driver (1989). They are highly referenced in empirical studies on the learning and teaching of the particulate nature of matter. In my study, the CK test covers different parts of topic of particulate nature of matter:

- Defining key concepts in chemistry – such as Atoms, Molecules, Elements and Compounds, etc.
- Representing microscopic representation of different types of particles in different phases.
- Identifying elements, compounds, mixtures, pure substances and gases at both the macroscopic and particulate level.
- Identifying basic atomic structure, isotopes and average atomic mass.

Some of the questions are meant to represent the qualitative insight reasoning of participants, while others are meant to expose the misconceptions. Responses were captured using the traditional pencil and paper method, where participants write on the test sheets. The CK test is attached as Appendix C. The detailed analysis on the CK test is in chapter six.

3.4.2 The development of a Topic Specific PCK test

Most tools that were developed in the PCK literature focus mainly on the probing and reporting of the PCK, but neglect its quality. A probe-type instrument was developed by Krauss, Jurgen and Blum (2008) and it only focuses on the three PCK categories: subject matter knowledge, learners' difficulties and pedagogical knowledge. This tool was developed and used mainly in mathematics education in Germany. Another tool that is widely used is the CoRe and PaP-eR developed by Loughran et al. (2004), discussed in detail in section 2.3 in chapter two. Both the PCK tools discussed are good for qualitative, rather than quantitative results, as required in my study.

As indicated in chapter two, there is no Topic Specific PCK test on the particulate nature of matter, so for my study a Topic Specific PCK test on the topic was developed. This test is in designed such a way that it is aligned with the theoretical framework as discussed in chapter two. The sections of the questionnaire relate to the five categories of Mavhunga and Rollnick's (2013) model of Topic Specific PCK, namely *learners' prior knowledge* including misconceptions, *curricular saliency, what is difficult to teach*, *representations* and *conceptual teaching strategies*. The development of the test adapted similar steps followed by Mavhunga and Rollnick's (2013) study. The test elicits teachers' Topic Specific PCK from which transformation emerges, as well as the pedagogical reasoning about their teaching. It is envisaged that the Topic Specific PCK test will not only elicit teachers' PCK but also measure the quality of its strength, which will ultimately be a major point in my study and to

the body of science research on PCK. The PCK test was scored using a rubric adapted from Mavhunga and Rollnick (2013). The authors' rubric assessed all five categories of Topic Specific PCK, as my study. Hence the rubric was adapted in order to be aligned to the particulate nature of matter test. More description of the development of the Topic Specific PCK test is provided in chapter four on piloting and validation. The completed tool is shown as Appendix D.

3.5 Piloting tools

Piloting was done for both tests: CK and Topic Specific PCK. A reference team of experts was used to establish content validity of the test instruments. These tests were administered to a small volunteer group of teachers. The group was asked to provide me with feedback and input. I was expected to know more about the time it had taken the group to complete each tool, as well as problems related to the questions in terms of difficulties and ambiguities. The duration of the CK test was found to be about 30 minutes and that of the Topic Specific PCK an hour (60 minutes).

Most of the CK test questions were taken from the existing literature and physical science grade 10 text books. However, after piloting the first test draft I noticed that the pilot teachers struggled with the question on average atomic mass shown in figure 3.2. Based on how they responded, it was assumed that the question may have been too broad and in need of scaffolding. Hence the scaffold questions in figure 3.2 - after the pilot. The final version of the CK test is in Appendix C

***9**

Pilot

Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of chlorine is 35,5amu. Between the two isotopes which one is the most abundant? Explain how you got to your answer.

_____

_____

_____

Scaffold question-after

Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? Justify your choice

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

Figure 3.2: Sample of the CK test questions before and after

The findings from the pre-pilot of Topic Specific PCK test responses assisted in shaping the test items for each category. Examples of responses in the pre-pilot are shown in detail in chapter four. The Topic Specific PCK test was later revised, based on the pilot findings which are discussed in full in chapter four. The final version of the test is in Appendix D

3.6 Sampling

The participants were 16 novice teachers recruited by Teach South Africa working together with the Department of Education. They hold science degrees, have done chemistry for a minimum of one year during the course of their degree, have graduated in the last five years and have no teaching qualifications. At the time of intensive training, these participants were about to start with 2012/2013 cohorts and were expected to commit to teaching for a minimum of two years in some of South Africa's most disadvantaged schools. The teachers were willing to participate in the study and also because they represent the physical science group from a content point of view. This means that the teachers were in a position to teach grade 10 which is the targeted grade in my study.

The schools were located in the Gauteng province, Western Cape, Eastern Cape, Mpumalanga and Free State Province of South Africa. These schools were selected based on availability of science posts. The entire group of teachers constituted the sample of the study, depending on whether the schools allocated them a grade 10 class to teach. However, a small sample of 16 or less may pose a challenge when conducting quantitative research methods. Therefore, it was important to explore statistics for quantitative methods applicable to small samples (discussed in chapter seven). Demographic details on the 16 participants are shown in table 3.2 below:

Table 3.2: Demographic information of NUGTs in the study

Teacher	Highest qualification	Major subjects	Year completed
ZD	BSc	Chemistry and Mathematics	2011
NN	BSc	Physics and Economics (Agricultural Economics)	2011
DN	BSc	Materials sciences	2011
SS	BSc	Microbiology and biochemistry	2010
MJ	BSc Honours	Biochemistry, Genetics, Plant science	2010
WM	BSc	Chemistry and physiology	2010
DR	BSc	Chemistry	2010
TM	BSc	Biology	2009
LM	BSc	Chemistry and Biochemistry	2011
MB	BSc	Human genetics, Medical Biology and Biochemistry	2007
SR	BSc	Chemistry and Biochemistry	2010
KK	BSc	Physiology and psychology	2010
AN	BSc Honours	Applied physics	2008
TS	BSc	Microbiology	2008
TC	BSc Honours	Mathematics, Chemistry and Process Engineering	2001
KT	BSc Honours	Chemistry then Biology	2010

Most of them were from Gauteng and Limpopo Province, with one each from the Eastern Cape, North-West and Free State Province. The remaining three teachers were foreign nationals from Zimbabwe. These participants all hold university degrees and obtained their degrees from various universities.

3.7 Analysis

In MM research, data analysis occurs both within the quantitative and qualitative approach (Creswell & Plano Clark, 2007). Discussed below is the analysis for each set of data.

3.7.1 Analysis of the Topic Specific PCK data

The construct was analysed both quantitatively and qualitatively. The responses from the pre- and post-tests were scored using a rubric. The rubric consisted of four different categories, differing with regard to the degree of engagement with the questions. Chapters four and seven provide more on the rubric scoring. The rubric scores were peer validated by independent raters who have an understanding of PCK and work in the field of science education. In order to obtain consistent and reliable results, the independent raters first had to

familiarise themselves with the test and instructions of the rubric to be followed. For example if a respondent has not given a response, a lowest score was allocated. In terms of validating; if the scores are different the raters have to agree on the final score. These scores were analysed using different statistical software. The Rasch statistical model was used with the intention to find out whether the test items were measuring the single construct of Topic Specific PCK which relates to validity of the test. The other non-parametric statistical test was the Wilcoxon-signed rank test which analyses the significant difference between the pre- and post-test responses. Chapter four elaborates on what the Rasch statistical model does.

The qualitative data was generated by the written test responses and the observed lessons taught on the particulate nature of matter, which were video-recorded. This, however, was triangulated by the data from initial and final CoRes, as well as pre- and post-observation interviews.

3.7.2 Analysis of the CK data

The responses in the CK test were scored using a marking memorandum. Unlike the Topic Specific PCK items, the CK questions do consist of one correct answer. The chemistry specialist peer validated all the marked tests for accuracy of the content to confirm the consistency of my marking. The reliability of a scale (internal consistency) was checked by calculating Cronbach's alpha coefficient by means of SPSS software. Ideally, the Cronbach alpha coefficient of the scale should be above 0.7 (Bond & Fox, 2001). This indicates that all the items are measuring the same underlying construct.

The scores obtained from the raters were compared and an overall agreement rate of 80% was obtained between them. The total score of the test was 105, which was later converted into a percentage and subjected to a test of significance difference between both the pre- and post-tests, using the Wilcoxon signed-ranked test. A comparison between both pre- and post-test responses was done and generated qualitative analysis.

Figure 3.3 below shows the summary of the sequence of data collection and analysis in the MM approach followed in my study

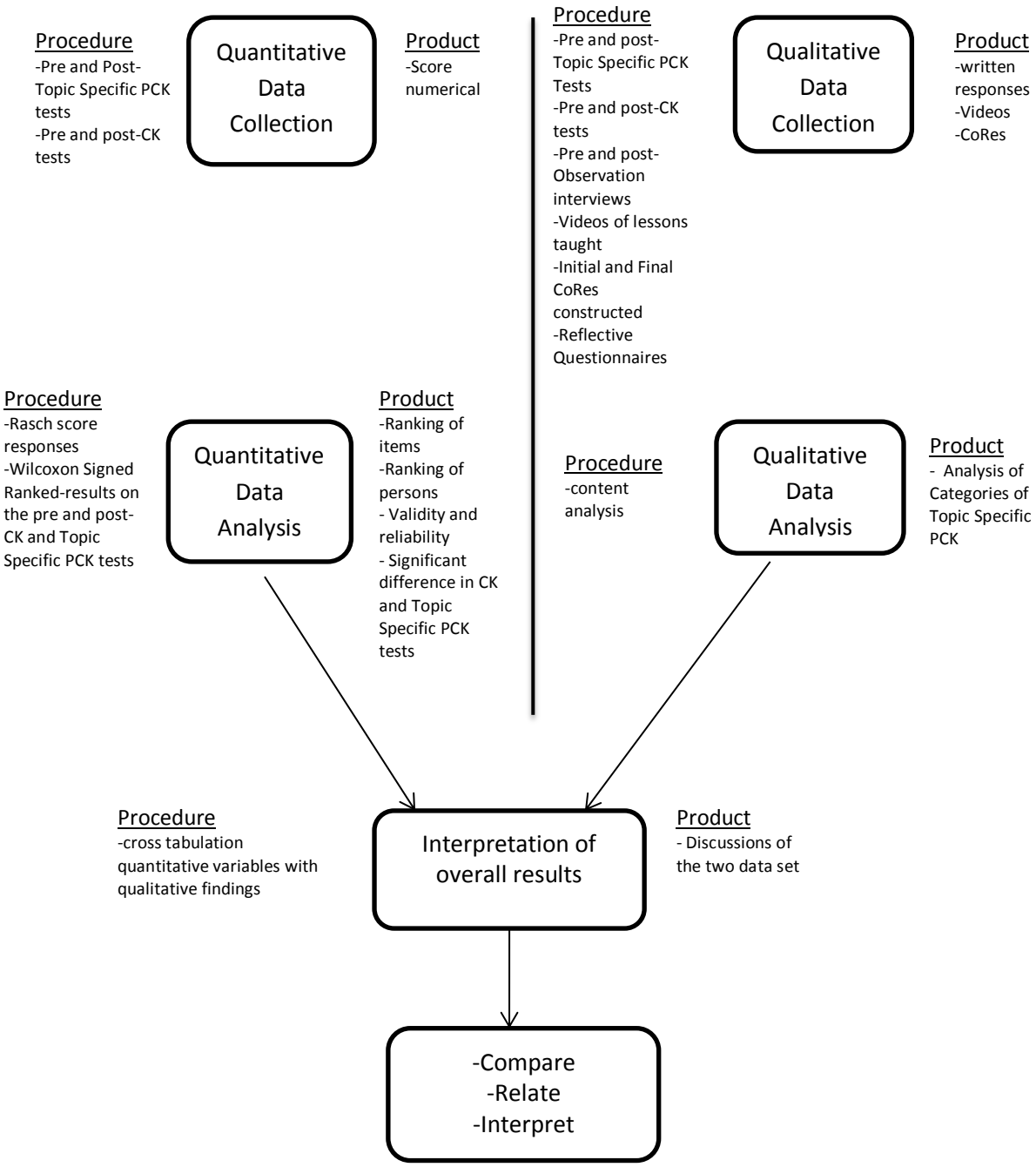


Figure 3.3: Summary of the sequence of data collection and analysis

3.8 Validity and Trustworthiness

Teddlie and Tashakkori (2009) argue that high-quality data are necessary requirements for high-quality answers to research questions. In MM approach, data quality is determined by the separate standards of quality in qualitative and quantitative strands. According to the

authors, a MM study will have high overall data quality, provided its quantitative and qualitative data are valid and credible. Discussed below are the different standards for assessing the quality of data generated in the qualitative and quantitative strands.

3.8.1 Quantitative Method

Validity in quantitative research according to Golafshani (2003, p. 599) *'determines whether the research truly measures that which it was intended to measure or how truthful the research results are"*. Therefore the definition of validity in quantitative research reveals two strands: (1) whether the means of measurement are accurate. In my study this was accounted by using different independent raters who are experts in the field for test scoring. And also (2) whether they are actually measuring what they are intended to measure. According to Messick (1995), construct validity takes into consideration evidence of statistical inference validity. In my study the Rasch statistical model was used to provide the validity indices. Bond and Fox (2001) argue that Rasch analysis provides two sets of general guidelines in assisting researchers to determine validity measures: (i) all items work together to measure a single variable and (ii) establishing the item difficulty ordering. Ultimately this links to the item and person fit that is deemed to be acceptable if it falls between the fit values of -2; +2, which indicates that the construct measured is valid. In addition Golafshani (2003) also states that construct validity determines which data is to be gathered and how is to be gathered. Construct validity in my study was shown through the ongoing process as the test items were refined (evidence provided in chapter four).

3.8.2 Qualitative Method

The concept of trustworthiness, according to Guba and Lincoln (1985), involves several quality measurements in qualitative research such as credibility, dependability, transferability and confirmability. According to Teddlie and Tashakkori (2009), many qualitative researchers do not believe that a single reality can be triangulated. Hence, they interpret differences in representation of events and phenomena as the alternative realities of the participants in their studies. In my study, the triangulation technique of using different data sources, such as Topic Specific PCK tests, classroom observation of teachers' teaching, interviews and CoRes was looked at in order to improve the trustworthiness for the qualitative strand. For determining credibility, participants' responses from the pencil and paper instrument were verified by the co-researchers for the purpose of inter-agreement reliability purpose. Teddlie and Tashakkori (2009) call it '*member checks'* and maintain that

it is the most important strategy for determining the credibility of the researcher's interpretation of participants' perceptions.

3.9 Ethical Issues

Ethics have to do with respect for rights of participants in research. Any research that involves people is likely to cause *'usually unintentional'* damage (Opie, 2004). Therefore, ethics, which is the application of moral principles intending to prevent harming or wronging others, was requested. The actual ethical approval from the University of Witwatersrand was obtained (see Appendix L). This procedure is intended to promote good practice to be respected and to be fair to others. It is worth indicating that some initial work was done with the larger project's approved ethics.

For my study, formal permission was requested from Teach South Africa that recruits teachers (see Appendix N), as well as the NUGTs themselves (see Appendix M). All prospective research participants were informed fully about the procedures, expectations and intentions of the study, and were asked to consent to participate. Since learners were involved, permission was requested from both the relevant departments of education (see Appendix N) and parents/guardians, since the majority of high school learners are minors (see Appendix M). To honour the ethical process, as well as to ensure that this research does no harm to the participants, a consent form was given to parents requesting permission for their children to participate in the study. The consent form letter states that participants are not forced to participate and assured confidentiality - names of the people involved in the study were not revealed. In any of my writings, pseudonyms were used to protect identities of participants. Data collected was kept in a safe and secure place.

This chapter provided a full methodological process, how data was collected and ethical processes. The next chapter four provides more details on the development of the Topic Specific PCK test and validation.

CHAPTER 4

4. DEVELOPING AN INSTRUMENT FOR MEASURING TOPIC SPECIFIC PCK

This chapter outlines the steps that were followed in the development of Topic Specific PCK test. This includes a description on the development of instrument procedures and adaptation of the rubric. This is followed by the procedure by which the instrument was piloted and validated. Finally, analysis and discussion of the pilot results is presented.

4.1 Introduction

This chapter focuses on the different stages of the development of the Topic Specific PCK test instruments and its reliability and validity. The chapter consist of two main phases: the process of explaining the different phases of designing the tests and validation as well as piloting. The need to establish the level of PCK in the teacher sample (NUGTs) is motivated by the fact that they do not hold teaching qualifications and never taught before. As indicated in chapter two, there are no available tests in the literature measuring the PCK of teachers in the particulate nature of matter. Although several studies have elaborated on the notion of PCK, there are still differences and debates that exist regarding its nature. Rohaan, Taconis and Jochems (2009) acknowledge that measuring PCK is accompanied by problematic aspects which are also experienced in measuring teacher cognition in general. This is because PCK is a tacit construct. However, there is agreement that PCK is a useful and powerful construct, particularly in the development of teacher education (Kind, 2009). Part of what is highly debatable about PCK is the issue of what exactly is to be assessed (Mavhunga, 2012) and how to make judgments in terms of its quality (Rohaan et al., 2009). Mavhunga (2012) argues that the value of PCK aiming at improving the quality of teaching depends on its topic specific nature, hence the need for a topic specific instrument. Thus the purpose of this chapter is to describe the development of an instrument for the measurement of PCK of the particle nature of matter.

4.2 Conceptualisation of test items

Prior to the development of the instrument, several issues were taken into consideration. Similar to Carlson (1990) and Kromrey and Renfrow (1991) the aim of the tool was viewed as important and should be made explicit in order to determine its level. Kromrey and Renfrow (1991) aimed to increase the practical value of teachers' tests. The aim of this tool is similar to that of Mavhunga (2012), which is to ultimately be useful to a large base of teachers as a target and able to sufficiently accommodate both novice and expert teachers.

Therefore, it was important to take into account the construction of the test items both in terms of selection and crafting. The second issue is with regard to the construction of test items that measure only Topic Specific PCK. According to Carlson (1990) PCK test items are those that require the application of pedagogical knowledge to specific content areas. This implies that his emphasis was on producing the test items that assess teachers' PCK, rather than testing pedagogical and content knowledge separately. However, Carlson (1990) acknowledges that it is more of a challenge to identify justifiable cases of pedagogy applied to content. On the other hand Kromrey and Renfrow (1991) extended the view of PCK test to what they termed content-specific pedagogical knowledge (C-P items). C-P items do not only require knowledge of teachers' subject matter blended with general pedagogical knowledge, but also the knowledge of specific pedagogical techniques. Kromrey and Renfrow (1991) further emphasise that there is a need to include those items that '*depend(s) upon the knowledge of the treatment of content in educational situations'* (p5) that will determine teachers' correct responses. In contrast to Carlson (1990), Kromrey and Renfrow (1991) did not find challenges in developing test items, but found that the planning, writing and editing required more attention. While acknowledging the views of Carlson (1990) and Kromrey and Renfrow (1991), the focus in my study is similar to that of Mavhunga (2012), which is on Topic Specific PCK whereby transformation of a specific content of a topic emerges. According to Mavhunga (2012), in order for teachers to respond to PCK test items, better understanding of Topic Specific PCK is required, in addition to knowledge of categories (*learners' prior knowledge*, *curriculum saliency*, *what is difficult to teach*, *representations* and *conceptual teaching strategies*). In line with both researchers above, the Topic Specific PCK requires teachers or examinee to have sufficient content knowledge of a particular topic so to '*recognize the correct application of the pedagogical principle'* (Rohaan et al., 2009, p. 331).

4.3 Development procedures

The procedure for developing the tool was similar to Mavhunga's (2012). The procedure followed chronologically is: (i) production of the test items (ii) confirming the characteristics of the test items fitting the topic specific PCK construct (iii) judgment of items (iv) re-construction of the instrument (v) piloting and (vi) validation of the instrument.

Prior to the development process, I had to select a topic from the South African physical science CAPS document. I opted for the grade 10 topic of the particulate nature of matter, which falls within the knowledge area of matter & materials. The reason for choosing the

topic is that it underpins chemistry and incorporates macroscopic, sub-microscopic and symbolic representations and is a widely researched topic. The topic presents great challenges in teaching due to its abstract nature. In addition to that, the teachers involved in the study are not experienced and therefore would be unlikely to teach physical science in higher grades.

After reviewing the research literature on the particulate nature of matter, the production of open ended test items began. The test is structured according to the five categories of Topic Specific PCK described in chapter two.

The initial question regarding category A of *learner prior knowledge* consisted of two questions which relate to common learners' misconceptions. The origin of the first question was influenced by Garnett, Garnett, and Hackling (1995) on learners alternate conceptions of the nature of matter. The authors indicated that learners hold the alternative idea about temperature affecting the shape or size of the molecules. The second question related to atomic structure, where learners often report that the force attracting the electron towards the nucleus is a 'pull' force. It was also found that learners tend to think that an electron further from the nucleus would be attracted by a stronger force as it is further away and therefore it would need a stronger force to draw the electron towards the centre (Taber, 2002). Similar to Mavhunga (2012) the questions in category A were designed in such a way as to assess and provide response to the learners by the teachers.

Much of the type of questioning in categories B to E was adapted from Loughran, Berry, and Mulhall (2004)'s CoRe template. Category B: *curricular saliency* consists of three sub-questions. The first question relates to the main ideas that Loughran et al. (2004) referred to as big ideas within a topic, while the last two questions within this category relate to the CoRe prompts: "why it is important for students to know about the topic" and "what else is known about the idea that students do not know yet?" There were also some questions added with regard to the sequencing to be followed as well as how to organise the big ideas. The only question in category C: *what is difficult to teach* looked into the analysis for conceptual aspects on the difficulty of the topic. In the CoRe template (see Appendix B), this question is referring to the prompts: difficulties/limitations connected with teaching the idea and knowledge about the students' thinking which influences the teaching of this idea. The last categories are D (*representations*) and E *(conceptual teaching strategies)*. D is made up of three questions and E consists of one question which asks respondents to show how given representations were adapted and the different strategies suggested for certain cases. The last

two prompts of Loughran et al. (2004)'s CoRe on teaching procedures and specific way of ascertaining students' understanding or confusion around the ideas are addressed in this question (see Appendix F). A teacher is expected to show different *conceptual teaching strategies* which might incorporate various *representations* such as analogies, models, demonstrations etc. Similar to Mavhunga (2012), all the first test items produced were open ended in nature. Producing the test items on the particle nature of matter did not seem to be a challenge because of the similar big ideas done by Loughran et al.'s (2004) CoRe. However, the greater challenge was coming up with sub-topics of atomic structure and ways of blending the topic specific content knowledge combined within the five knowledge categories of Topic Specific PCK for different generated tasks. Table 4.1 below gives a summary of a description of each test item, its purpose and the reference.

Table 4.1: Description and purpose of test items of the particulate nature of matter

Categories	Content of the questions	Purpose
A. Learner prior knowledge (2 questions)	The shape or size of molecules is not affected by change in temperature.	To investigate teachers' knowledge about alternative misconceptions held by learners about particles (Garnett et al., 1995).
	Intends teachers to confirm that electrons further away from the nucleus experience a smaller force of attraction than those nearer.	To investigate teachers' ability to explain the effect of distance of charge from the nucleus and the effect of shielding (Taber, 2002).
B. Curricular Saliency (2 questions)	Teachers are required to identify future topics that require the understanding of particle nature.	To find out whether teachers can identify future topics requiring learners' understanding of particulate nature (Loughran et al., 2004).
	Identifying the main big ideas to be taught about the particulate nature of matter and show their sequence.	For teachers to identify what they see as crucial for learners or see as being the heart of understanding the topic (Loughran et al., 2004).
	Linking the main ideas to the subordinate ideas.	For teachers to show their understanding of how to teach, they draw on their knowledge of what science content is relevant and how main ideas link with subordinate ideas same topic (Loughran et al., 2004).
C. What is difficult to teach (one question)	Difficulties/limitations connected to teaching the particulate nature of matter.	Expert teachers use the knowledge (learners' alternative conceptions/misconceptions and limitations) to shape the way in which they teach the topic

Categories	Content of the questions	Purpose
		(Loughran et al., 2004).
D. Representations (three questions)	Comparing and evaluating different types of representations (macroscopic and sub-microscopic) used when teaching particulate nature matter.	To find out if teachers can evaluate and choose different suggested representations for use in teaching.
E. Conceptual Teaching Strategies (One question)	Outline appropriate conceptual teaching strategy when teaching about the average relative atomic mass of isotopes.	To find out if teachers can suggest conceptual teaching strategies by incorporating various representations such as analogies, models and demonstrations which will influence learners' thinking and may promote better understanding of the topic (Loughran et al., 2004).

Almost all the categories followed Mavhunga (2012)'s format of questioning. However, there was one change made on categories of *curricular saliency* in item 3.4. In Mavhunga's chemical equilibrium test, teachers were expected to identify topics that must have been covered in chemistry before they could teach chemical equilibrium. For the particulate nature of matter test, teachers are expected to identify topics in chemistry that require the understanding of the particle nature of matter in order to teach them. The reason for this change was because the particulate nature of matter underpins much of chemistry and tends to be taught at the beginning of the curriculum rather than when needed as prerequisite concepts.

As shown in figure 4.1, category A (*learners' prior knowledge*) consisted of open ended test items and required some refinement. Therefore, the discussion to follow demonstrates how the open-ended test item for this category was refined through the pre-piloting process explained in section 4.4. The test item, question 1, of *learners' prior knowledge* is used as an example in figure 4.1.

The open ended items were exposed to a reference team for judgment and for confirming the characteristics of items fitting Topic Specific PCK. This reference team involved doctoral students in science education, high school physical science teachers, senior teacher educators and a physical science mentor assigned for NUGTs employed by Teach South Africa. Feedback from the reference group further highlighted the need for more refinement on the

test items, hence the reconstruction. For example, the initial wording in the question for the item shown in Figure 4.1 below was: "How would you comment on Teboho's response?" The reference group emphasised clarity on the wording of the test items in such a way that the teaching context of the given scenario became explicit. Figure 4.1 below shows the final version:

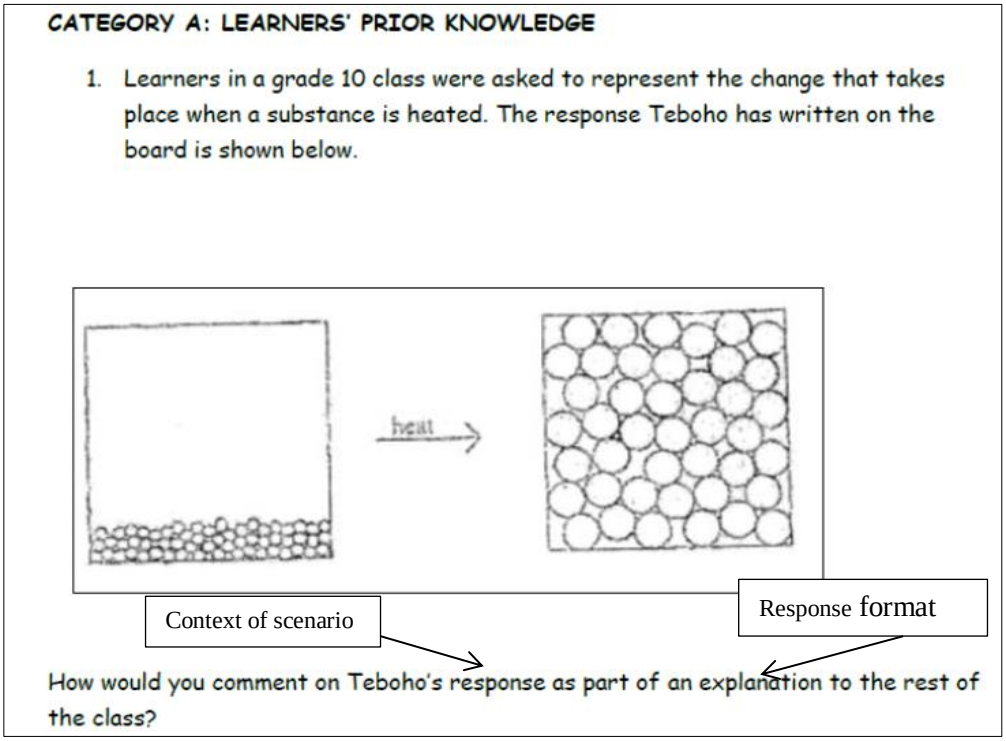


Figure 4.1: Test item with context included

The question in Figure 4.1 has now expanded and does not only request a teacher to comment but also to provide an explanation to the whole class.

4.4 The Pre-piloting procedure

The peer reviewed test items were pre-piloted with a small group of pre-service science teachers. The hand written responses required about 60 minutes for the students to complete. Figure 4.1 shows an example of a test item pre-piloted from the Topic Specific PCK. The full pre-pilot version is in Appendix G. Based on the responses received from the pre-piloted data, a decision was taken about how to change the open ended questions format into semi-closed questions. Verbatim responses from pre-pilot subjects were selected for inclusion in the test as options.

However, only formulations using acceptable responses from the pre-pilot were used. The reference team assisted with this task. Figure 4.2 shows the responses of the *learner prior knowledge* category that were considered correct from two pre-service teachers. The circled words were incorporated in the formation of the final test's multiple choice responses.

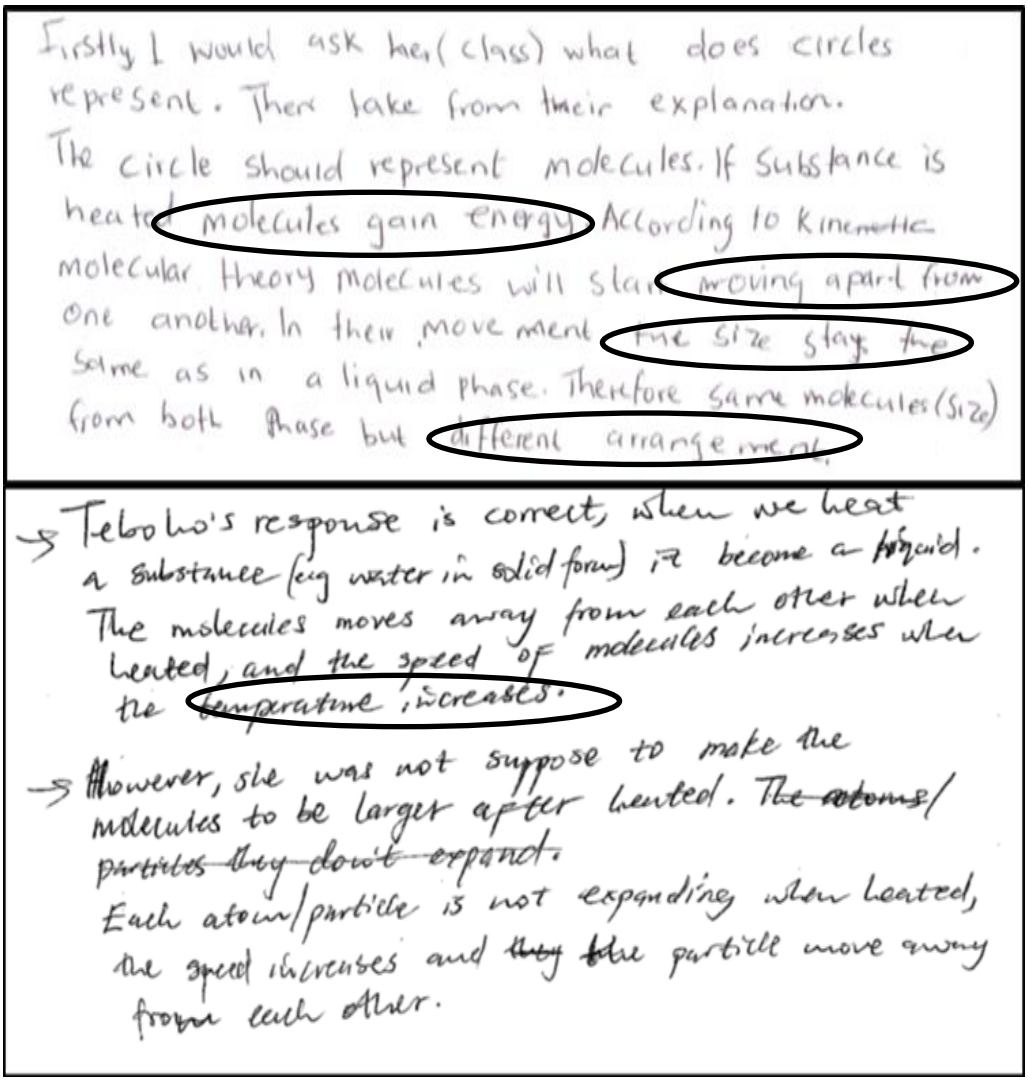


Figure 4.2: Sample of acceptable pre-pilot responses

Figure 4.3 below shows the completed question on the *learner prior knowledge* category with hierarchy of all correct answers. Similar to Rohaan et al. (2009), Mavhunga (2012) and Carlson (1990), a decision for developing best-answers rather than correct-answer items was followed in my study. This is because in teaching there is no single correct way of teaching something.

How would you comment on Teboho's response as part of an explanation to the rest of the class?

Response A: Teboho's response is incorrect. All substances have small particles called atoms that may combine chemically with each other to form molecules. When substances are heated their molecules do not expand in size. The size of the molecules stays the same.

Response B: Teboho's response is incorrect. When a substance is heated, molecules gain kinetic energy. The molecules will start vibrating and the bonds between them weaken to allow re-arrangement and in some cases allowing the molecules to move away from each other. The molecules themselves do not change in size when heated. It is the re-arrangement of molecules that changes.

Response C: Teboho's response is incorrect. When a substance is heated, a phase change occurs. The molecules of a substance become more free from each other as the bonds are weakend in some cases completely broken. Substances that were originally solids may become liquids and liquids may become gases

Response D: None of the above

Figure 4.3: Sample of semi-closed test item from Topic Specific PCK

In addition to that, as in Mavhunga (2012) the examinees were provided with an opportunity to further explain and expand their choices. The pre-piloting process also helped in shaping other test items for other categories as well. For example, in the category of *curricular saliency*, initially the question about the big ideas in 3.1 consisted mostly of one word answer (see Appendix G). Due to most teachers giving sub-ordinates concepts as big ideas, the single words were changed to sentences, as can be seen in the final test

Table 4.2 below shows the allocation of specific content areas included in the final tool of particulate nature of matter. According to the grade 10 curriculum learners are expected to know the states of matter and the kinetic molecular theory. More on what is included in the curriculum is shown in table 5.4.

The complete tool can be seen in Appendix D

Table 4.2: Allocation of specific content areas of the particulate nature of matter

Category A	Q1-States of matter and Kinetic Molecular Theory
	Q2-Atomic structure
Category B & C	Particle theory of matter
Category D	Different representations used for teaching phases of matter
Category E	How to find relative atomic mass of naturally occurring elements given the percentage of each isotope.

4.5 The adaptation and development of the rubric

A rubric developed by Mavhunga (2012) for the topic of chemical equilibrium was adapted and used to score the topic specific PCK tool in my study. Like the author, the five categories of Topic Specific PCK were rated on a four point scale where 1 stands for limited PCK to 4 (exemplary PCK). Each point on the scale was established through the use of criteria. The rubric was adapted to make it suitable for the particulate nature of matter Topic Specific PCK test. The greatest adaptation was required of two of the categories: *curricular saliency* and *representations*. The change made on the *curricular saliency* category was to specify that respondents provide pre-concepts rather than post-concepts as the particulate nature test required teachers to name pre-requisite concepts rather than post- concepts in the teaching of the topic. For the *representations* category: adaptations were made in the criteria for all the levels (see Appendix H). The original rubric designed to use for chemical equilibrium involved testing for the use of symbolic representations which did not apply to the particulate nature of matter test. Therefore, the criteria were adapted by limiting requirements to only the use of macro and sub-microscopic representations. There were no changes made on the categories of *learner prior knowledge, what is difficult to teach* and *conceptual teaching strategies* as they suited the responses.

Although each category comprised several questions, each was scored singly as an item. Therefore, the test consisted of five items, each having a maximum score of 4. Table 4.3 below shows a sample of the categories: *what is difficult to teach* and *conceptual teaching strategies* criteria extracted from the full rubric (see Appendix H).

Table 4.3: Extract from the topic specific PCK rubric of the particulate nature of matter

Topic Specific PCK Categories	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Conceptual Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions • Lacks aspects of curriculum saliency • Use of representations limited to macroscopic or symbolic scientific representation with no linking explanatory notes • Suggested activities are largely teacher centred	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy • Lacks aspects of curriculum saliency • Use of macroscopic and symbolic representations for With no linking explanatory notes • Limited involvement of learners	• Overall, strategy workable • Considers confirmation/confrontation of student prior knowledge and/or misconceptions • Considers at least one aspect related to curriculum saliency: sequencing or what not to discuss yet or emphasis of important concepts • Uses at least two different levels of representations to enforce an aspect of a concept with explanations • There is evidence of encouraged learner involvement	• Overall , excellent strategy to teach required concept • Considers confirmation/confrontation of student prior knowledge and/or common misconceptions • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce a singular aspect of a concept. • Highly learner centred lesson
What makes topic difficult	• Identifies broad topics without specifying the actual sub-concepts that are problematic • Reasons not given	• Identifies specific concepts but provides broad generic reasons such as 'abstract'	• Identifies specific concepts with reasons related to specified prior knowledge of students or common misconceptions	• Identifies specific concepts with reasons related to prior knowledge of specified students or common misconceptions • Provides reasons linking to specific gate keeping concepts that when not fully understood adds to the difficulty of a concept regarded as difficult

Comments made by the reference team showed some of the limitations of the rubric. One of the limitations of the rubric was found to be on the category of *learner prior knowledge,* which consisted of two questions on different aspects of the particulate nature of matter. It was found to be a challenge to handle scores that vary by a larger margin from different questions in the same category. A decision to consider the highest score between the questions as the final score was agreed upon. Another limitation was on the entire rubric in that, generally very low responses tended to fit in a higher level. Thus general rules were established during the marking of the tests by me and independent raters in order to maintain consistency and were as follows:

- The first general rule which applied to all the categories was – the respondent was scored according the highest level response given. For example, even if a teacher scores most of his/her points in the "limited" category and has at least one at the basic level, he or she is placed on the basic level.

- The second rule only applies to the category of *learner prior knowledge* and misconceptions which consist of two separate questions: one for identifying a misconception and the other which confirms accurate understanding. In this case where the scores are extreme, a higher score will be considered final. Both of the questions have a multiple choice question format, where teachers are required to make their choice and expand on it. In cases where teachers only write A, B or C without any expansion, they are considered to have identified a misconception or prior knowledge and are placed in the basic level. Those who chose D ("none of the above"), implying no further explanation, were placed on the limited level which was allocated one mark. A decision was made by the team to make the lowest score one.

4.6 Validation of instrument

The refined Topic Specific PCK instrument was administered to a group of 11 experienced physical science teachers for piloting. These teachers were enrolled for a two year part time honours degree at the university of the Witwatersrand. They had teaching experience ranging from 1 to 23 years in teaching physical science at high school level. The majority of the teachers held a first degree, either a Bachelor of Science or a Bachelor of Education with chemistry or physical science as a major. The remaining teachers held a three year teachers' diploma, which was upgraded to degree level.

The tests were marked using the rubric. The scores obtained were validated by the independent raters before the test can be given to the actual intended participants. The raters are not only working in the science education field but are also involved into PCK research. They first familiarised themselves with the rubric and how to engage with it. The scores from each rater were compared using MedCalc statistical software for inter-rater agreement–Kappa (www.medcalc.org/kapp). An agreement rate (K value) of 47.9% indicating a moderate strength was reached (See Appendix I). In cases where there were differences, particularly with a large margin, the raters got together and reached an agreement in terms of the scoring. Table 4.4 in the analysis section shows the validated raw scores obtained.

In my study the Topic Specific PCK tool was constructed. Wainer & Braun (1988) assert that in this case a researcher actively affects the interplay between construct and data for validation purposes. It is for this reason that in my study, the use of Rasch WINSTEP

statistical method to assess the validity of quantitative instrument was used for the piloted data. As for the CK test, a Cronbach alpha coefficient was calculated.

4.7 Pilot data analysis

4.7.1 Quantitative Analysis

Table 4.4 shows the raw scores generated from the teachers' scores on the Topic specific PCK tool which were subjected to the Rasch Winstep software.

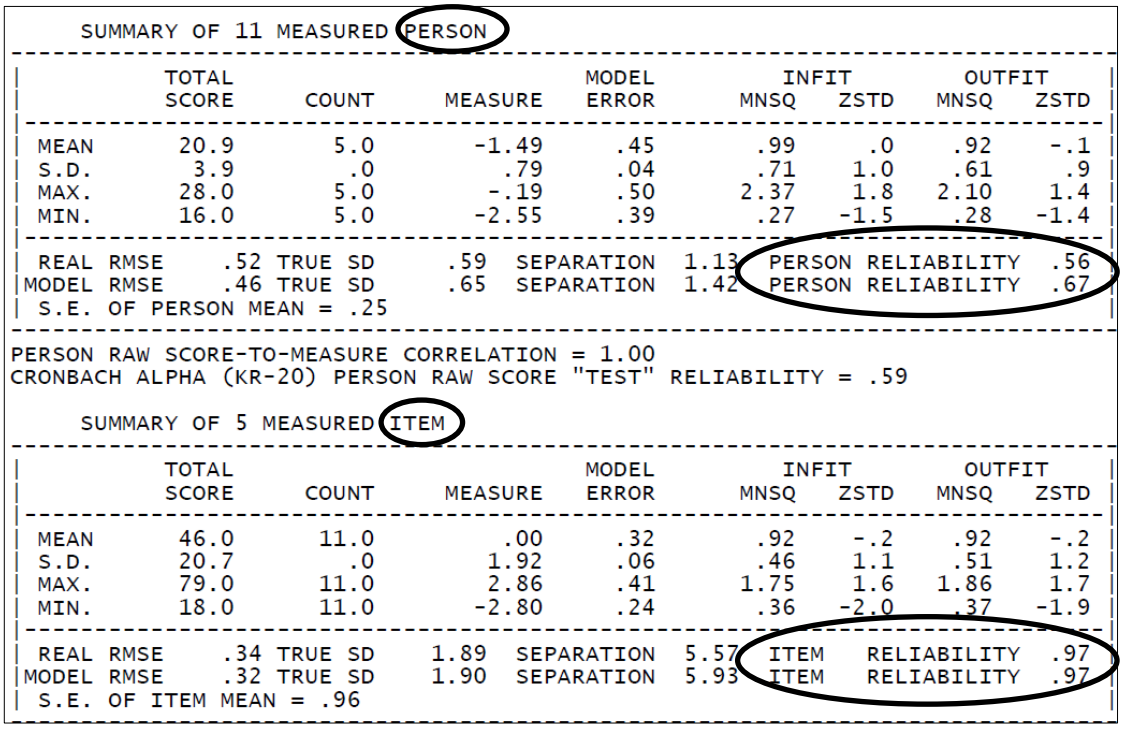
Table 4.4: Raw scores from responses of in-service honours teachers

In-service honours science teachers	Learners' prior knowledge	Curricular saliency	What is difficult to teach	Representations	Conceptual teaching strategies
NDL	3	2	4	2	1
KIZ	3	2	2	3	2
KGO	3	1	2	2	1
MAL	2	2	2	2	1
EDM	3	2	4	4	3
ELA	2	2	3	2	2
AUS	3	3	4	3	2
MAT	3	3	4	4	1
MBI	2	2	4	1	1
REF	1	1	3	2	1
NGW	3	2	2	3	1

The Rasch model is able to transform raw data from the human sciences into abstract, equal-interval scales (Bond & Fox, 2001). In my study, the raw test data obtained from the graded scale type rubric was changed into linear measures. The use of Rasch analysis also allows the calculation of person measures and item difficulty measures on an equal-interval scale. Boone & Rogan (2005) outlined the advantages of using the Rasch person measures rather than the raw scores. Firstly, the raw scores at either end of the scale have the greatest margin of error and Rasch person measure gives a more accurate picture of performance. Secondly, *unlike other probabilistic measurement models, the Rasch model is the only one that provides the necessary objectivity for the construction of a scale that is separable from the distribution of the attribute in the person it measures* (Bond & Fox, 2001, p. 7). Therefore, making use of Rasch person measure would add far more rigorous analysis and add value to it as the assumptions of linearity is achieved.

Figure 4.4 shows the reliability indices (circled), which display both the Rasch model person and the item's reliability. The values of 'Real RMSE' shown in figure 4.4 were preferred

over ‘Model RMSE’. The reason for reporting ‘Real’ values over ‘Model’ is to avoid thinking that I have measured the sample better than I really have. The ‘Model’ values imply that one is at a point in the analysis where one can say all the unexpectedness in the data is the randomness predicted by Rasch model (Bond & Fox, 2001).



SUMMARY OF 11 MEASURED PERSON

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	20.9	5.0	-1.49	.45	.99	.0	.92	-.1
S.D.	3.9	.0	.79	.04	.71	1.0	.61	.9
MAX.	28.0	5.0	-.19	.50	2.37	1.8	2.10	1.4
MIN.	16.0	5.0	-2.55	.39	.27	-1.5	.28	-1.4

REAL RMSE	.52	TRUE SD	.59	SEPARATION 1.13	PERSON RELIABILITY .56
MODEL RMSE	.46	TRUE SD	.65	SEPARATION 1.42	PERSON RELIABILITY .67
S.E. OF PERSON MEAN = .25					

PERSON RAW SCORE-TO-MEASURE CORRELATION = 1.00
CRONBACH ALPHA (KR-20) PERSON RAW SCORE "TEST" RELIABILITY = .59

SUMMARY OF 5 MEASURED ITEM

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	46.0	11.0	.00	.32	.92	-.2	.92	-.2
S.D.	20.7	.0	1.92	.06	.46	1.1	.51	1.2
MAX.	79.0	11.0	2.86	.41	1.75	1.6	1.86	1.7
MIN.	18.0	11.0	-2.80	.24	.36	-2.0	.37	-1.9

REAL RMSE	.34	TRUE SD	1.89	SEPARATION 5.57	ITEM RELIABILITY .97
MODEL RMSE	.32	TRUE SD	1.90	SEPARATION 5.93	ITEM RELIABILITY .97
S.E. OF ITEM MEAN = .96					

Figure 4.4: Reliability Indices

Reliability in quantitative research refers to replicability or repeatability of results, which will ultimately inform the stability and consistency of a measurement (Golafshani, 2003). There are general estimators used to determine the reliability of an instrument such as Inter-Rater, Test-Retest, Parallel-Forms and Internal Consistency Reliability. In my study, internal consistency reliability was utilised. Often the internal consistency of the results across the items only, is measured using Cronbach’s Alpha (Boone & Rogan, 2005). For my study, the Rasch model provides indices of both person and item reliability. The person reliability was found to be slightly higher than 0.5 at 0.56, as shown in figure 4.4 and therefore restricted to the range 0 to 1. This gives an estimate on the ability of the person in responding to the whole test which proved to be reliable. It also indicates that there were enough items spread along the continuum and enough spread of ability among persons. However, person reliability of 0.56 might be improved by not only increasing persons but also adding high ability persons in order to demonstrate a hierarchy of ability on the Topic Specific PCK construct. As a value of 0.56 means that the test was not able to separate the persons very well.

The item reliability was found to be 0.97, which is well above the generally recognised standard of 0.7 for Cronbach. This is pointing out that the items are even more replicable compared to person reliability. This indicates that the spread of items was narrow, the standard errors are not very large and the ability to develop a reliable measure was not compromised (Boone & Rogan, 2005). It is an indication that the items are measuring a single construct which is Topic Specific PCK - indicating very good reliability indices for items.

In terms of validity, Rasch software provides indices of "fit statistics" called infit and outfit. According to Boone and Rogan (2005), infit devices provide a statistic that can provide a way to quickly evaluate how unexpected the answer (right or wrong) to an item by a specific person might be, while outfit devices considers items that are quite distant from a person's ability level (p.34). Both item and persons measured probability for the misfit mean-square (fit and outfit) statistics within the range -2 and +2 are regarded as good. However, mean square statistics that are above 2 are deemed problematic. Circled below in figure 4.5 is the fit residual statistics for each item.

ITEM STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PT-MEASURE CORR.	PT-MEASURE EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	ITEM
5	18	11	2.86	.41	.82	-.2	.68	-.4	.66	.51	54.5	56.6	Conceptual teaching Strategies
3	32	11	1.18	.32	.36	-2.0	.37	-1.9	.82	.62	63.6	38.4	What is difficult
1	46	11	-.20	.31	.73	-.5	.72	-.5	.43	.59	54.5	41.7	Leraner Prior Knowledge
4	55	11	-1.04	.30	1.75	1.6	1.86	1.7	.67	.63	27.3	37.4	Representations
2	79	11	-2.80	.24	.93	.0	.99	.1	.61	.68	18.2	30.8	Curricular Saliency
MEAN	46.0	11.0	.00	.32	.92	-.2	.92	-.2			43.6	41.0	
S.D.	20.7	.0	1.92	.06	.46	1.1	.51	1.2			17.6	8.6	

Figure 4.5: Fit statistics for Items

The individual item fit ranges between +2 and -2 which is the recommended fit range. All the items are well within the range except the item *what is difficult to teach* which is exactly at -2.0. However since the item is at -2.0, it is therefore valid.

PERSON: REAL SEP.: 1.13 REL.: .56 ... ITEM: REAL SEP.: 5.57 REL.: .97

PERSON STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PT-MEASURE CORR.	PT-MEASURE EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	PERSON
7	28	5	-.19	.39	.71	-.4	.60	-.6	.88	.88	60.0	32.4	AUS
5	26	5	-.49	.39	1.26	.6	1.14	.4	.83	.88	20.0	33.1	EDM
8	25	5	-.64	.40	.27	-1.5	.33	-1.4	.99	.88	60.0	34.0	MAT
1	22	5	-1.17	.45	.41	-.8	.45	-.8	.96	.88	40.0	41.1	NGL
6	22	5	-1.17	.45	.44	-.7	.61	-.4	.94	.88	80.0	41.1	ELA
2	20	5	-1.61	.48	.27	-1.2	.28	-1.2	.99	.89	60.0	48.9	KIZ
11	20	5	-1.61	.48	2.31	1.6	2.09	1.4	.81	.89	20.0	48.9	NGW
4	18	5	-2.07	.48	1.18	.5	1.01	.3	.91	.88	60.0	41.5	MAL
3	17	5	-2.30	.49	.65	-.4	.60	-.4	.92	.87	40.0	42.4	KGO
9	16	5	-2.55	.50	2.37	1.8	2.10	1.4	.81	.86	20.0	43.9	MBI
10	16	5	-2.55	.50	1.04	.3	.97	.2	.86	.86	20.0	43.9	REF
MEAN	20.9	5.0	-1.49	.45	.99	.0	.92	-.1			43.6	41.0	
S.D.	3.9	.0	.79	.04	.71	1.0	.61	.9			20.6	5.5	

Figure 4.6: Fit statistics for Persons

The individual person fit is also within the range -2 and +2 as shown in Figure 4.6 circled above. Both the fit residual for items and persons indicate a good fit and therefore indicate that the construct is valid.

The Rasch model can simultaneously measure the person's ability and item difficulty in the same metric. These two estimates are presented in a "person-item map". The items are scaled and the higher the number, the more difficult the item. Figure 4.7 below represents the person-item map. It indicates the item difficulty estimates and the person ability estimates.

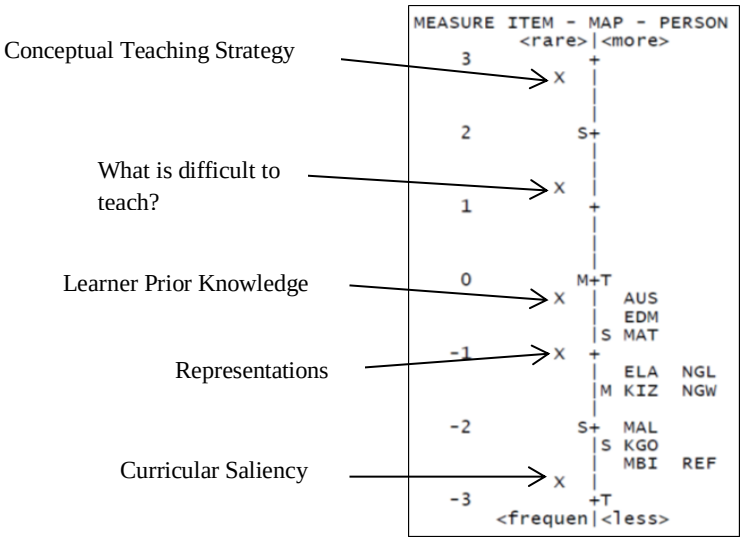


Figure 4.7: Person-Item map

In terms of items, *conceptual teaching strategies* is situated at the top level in the map followed by "*what is difficult to teach*" and "*learner prior knowledge*", indicating that they were found to be difficult by teachers with *conceptual teaching strategies* as the most difficult. *Curricular saliency* and *representations* are situated lower, indicating that teachers found them easier.

Teacher AUS above in figure 4.7 is likely to succeed on three items (*learner prior knowledge* and *curricular saliency*). For person ability, it can be deduced that teacher AUS is at the top level of the map, implying that her person ability, in this case Topic Specific PCK, is better than the rest of the teachers and that most items were easy for her. The fact that AUS lies on the same level as *learner prior knowledge* means that AUS has a 50% likelihood of mastering this task. Hence the *conceptual teaching strategies* and *what is difficult to teach* category is higher than hers.

However, this is a different case to EDM, the second highest whose measure is higher than the *representation* and *curricular saliency* categories. This implies that teacher EDM is capable of correctly answering questions with regard to those categories but not the ones on *what is difficult to teach*, *learner prior knowledge* and *conceptual teaching strategies*. All the teachers are most likely to answer items on *curricular saliency* correctly. This is because the category curricular saliency is situated at the bottom and is the least difficult.

Wright and Masters (1982) also argue that Rasch model can evaluate the construct validity of an instrument by obtaining difficulty order of the items. Table 4.5 below shows the Rasch measures in terms of rank of difficulty of items.

Table 4.5: Rasch measures for item difficulty

Curricular Saliency	Representation	Learner prior knowledge	What is difficult to teach	Conceptual teaching strategies	Mean
-2.80	-1.04	-0.20	+1.18	+2.86	-1.49

Item measure mean set to zero & Units per Logit (log-odds unit) =1 for the entire test (UIMEAN=0 and USCALE =1)

The results show that the experienced teachers found it easy to identify the big ideas and concepts that require the understanding of the particulate nature of matter. This can be seen from the lowest Rasch measure on the category of *curricular saliency*. This may be influenced by the fact that the particulate nature of matter underpins chemistry and teachers fully understand topics that require the understanding of the particulate nature of matter. This

was followed by the *representations* and *learners' prior knowledge*. *What is difficult to teach* and *conceptual teaching strategies* were found to be the most difficult. The observed Rasch measures on the *representations* and *learners prior knowledge* may be attributed to the experience that teachers have about the big ideas of the topic, therefore equipping themselves with various types of representations that can be used to make the abstract accessible to learners as well as prior ideas that could assist learners in the process.

4.7.2 Qualitative analysis

The *conceptual teaching strategy* category was found to be the most difficult, preceded by *what is difficult to teach*, which ultimately influenced the mean (-1.49) which reflects the quality of teachers' Topic Specific PCK. Taking for example the category of *curricular saliency*, all teachers were likely to respond correctly to this item as shown in figure 4.7. However, looking qualitatively at this item, most teachers got it partially correct. Only two teachers scored 3 and were therefore placed on the developing level. Out of the remaining nine teachers, eight scored 2 (basic level) and one scored 1 (limited level) indicating poor performance. In order to show what has contributed to this performance in this category, I would look at the responses from teacher REF who score 1 (limited) and MAT who obtained 3 (developing level) and this can be seen in Table 4.4. The first question asked under the category of *curricular saliency* is: what do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10 (see Appendix D) The response on what big ideas are was adopted from the work done by Loughran et al (2004) on the particulate nature of matter. Big ideas are what teachers see as being the heart of understanding the topic. The identified big ideas for the particulate nature of matter are:

- Particles are in constant motion
- Matter is made up of small bits that are called particles
- There are different types of small bits of substance
- Molecules have forces between each other and
- Matter is found in different phases.

REF responded as follows in Figure 4.8 below:

REF	MAT
1. Matter is found in different phases 2. There are different atomic theories. 3. Atoms are smallest particle. 4. Elements are made from atoms	1. Matter is found in different phases. 2. Matter is made up of small bits that are called particles. 3. Particles are in constant motion, 4. Other: There are repulsion and attraction forces between the particles

Figure 4.8: Response from REF and MAT (*curricular Saliency*-first question)

In her response, REF identified concepts which are mostly subordinate ideas such as responses 2 to 3. Only concept 1, matter is found in different phases is considered a Big Idea. Therefore her incorrect response has affected questions two and three of the *curricular saliency* category. REF was found to have sequenced the ideas correctly, which made a little sense due to mixed concepts and this impacted on the link of her big ideas and subordinate ideas. Lastly, it was found that reasons given for the importance of the topic where limited to generic benefit of education. In the manner in which REF responded, according to the rubric, she was placed on the limited level as shown in Table 4.4.

MAT's response was considered to be at the developing level. There were a number of reasons considered. Firstly, MAT was not only able to identify at least three Big Ideas (she actually identified four), but she also provided a logical sequence of concepts for all the big ideas as shown in Figure 4.8 above:

Secondly, MAT was also able to identify correct subordinate ideas and clearly explain links to Big Ideas. This can be seen clearly from Figure 4.9, where each Big Idea is linked to its subordinate ideas.

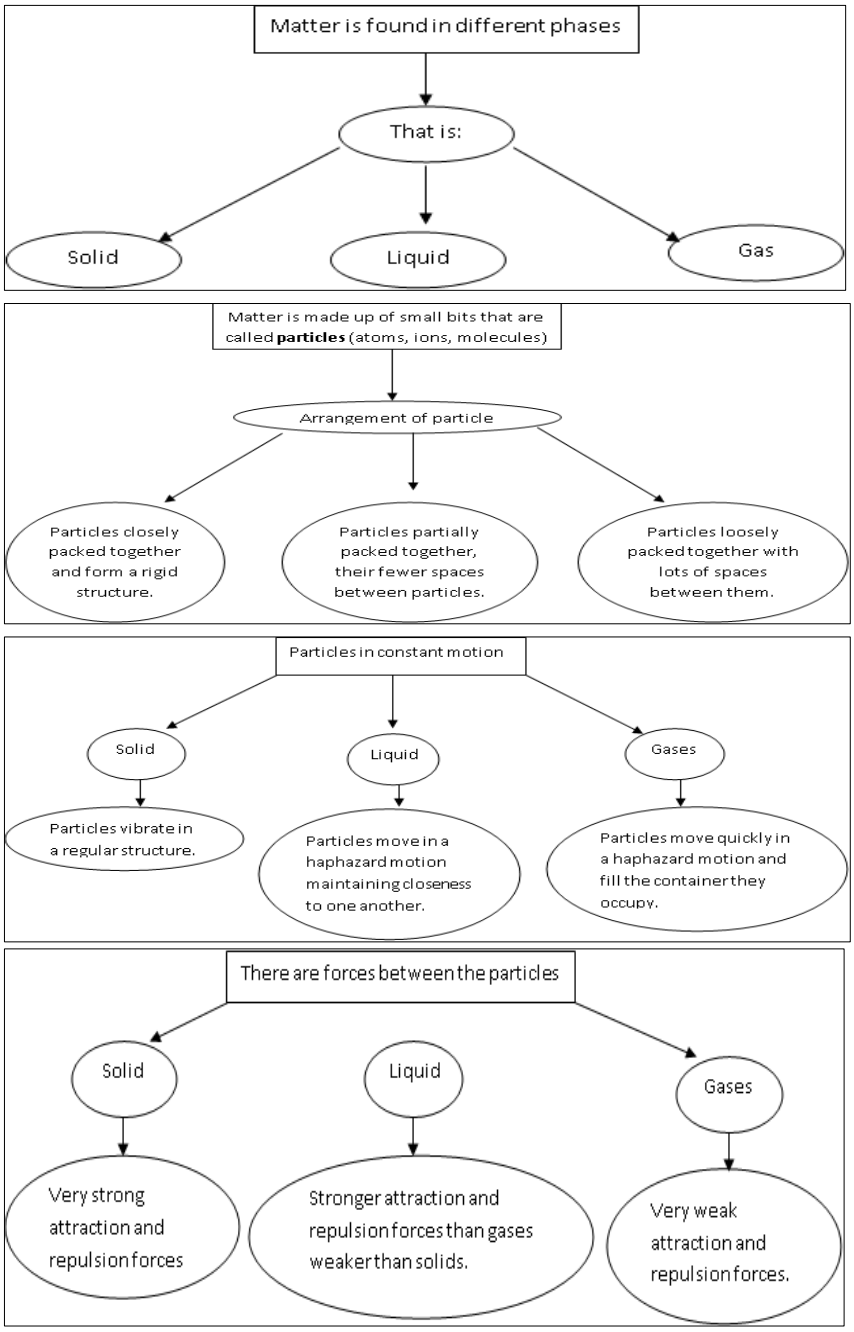


Figure 4.9: Response from MAT curricular Saliency-third question

However, MAT's response to question four and five of the category was not sufficient to place her at the exemplary level. In terms of question four on the identification of post-concepts, MAT identified the post-concepts and included for the current topic concepts such as Boyle's law (relationship between pressure and volume), temperature, the general gas law, representation of physical and chemical change (macroscopic and microscopic representation). MAT neglected the concept needed for the current topic and in the next Big Ideas such as states of matter and Kinetic Molecular theory. In question five, MAT was unable to specify and link the importance of the topic to conceptual scaffolding or sequential

development of other topics in the subject. For example, in the question on: why is it important for learners to learn about particle nature of matter when relating to conceptual progression-MAT's response is:

> *'The learner will be equipped with a clear comprehension of macroscopic properties of matter and microscopic properties of the substance'*

The response above does not show any link to some of the topics to come in either grade 11 to 12 that require an understanding of macroscopic and sub-microscopic properties. Most teachers on the basic level struggled to meet the criteria met by MAT explained above and also to improve on the last two questions of the category.

In terms of the teaching strategy category, a contrast between REF and EDM will be looked into. Figure 4.10 shows the response written by REF regarding the question on *conceptual teaching strategies* (see Appendix D). According to Table 4.3 REF obtained only 1, which shows her limited level of competence under category *conceptual teaching strategies.* Her response is shown below.

Atomic mass is the mass of the atom. Relative atomic mass of an element is the average of the isotopic number of the element. When calculating the average atomic mass of an atom, you need to know or find the percentage abundance of the element. The percentage abundance of the element must be converted to a decimal. In the case of oxygen it would be: 99,790 will be 0,9970

: 0,037 will be 0,00037

: 0,173 will be 0,00173

The next step then is to multiply the decimal answers with the isotopic mass:

0,9970 x 16 = 15,952

0,00037 x 17 = 0,00629

0,00173 x 18 = 0,03114

Then add them together

15,952 + 0,00629 + 0,03114 = 15,989 is the average atomic mass of oxygen

Figure 4.10: Response from REF's conceptual teaching strategy

REF's response in figure 4.10 clearly shows the steps that a learner should have followed in order to get the question asked in the test correct. However, in her response, there is (i) no acknowledgement and confirmation of prior knowledge and misconceptions (ii) no evidence of the use of two levels of representations (macro and sub-microscopic) (iii) no emphasis of important concepts needed to understand the concept of average relative atomic mass. It is for these reasons mentioned above that REF was scored at the limited level on the rubric. This is

in contrast with EDM who scored 3 (developing level). Shown below is EDM's response on the teaching strategy category.

Learners should have a clear understanding of the concept of atomic number. I would write different atoms of magnesium atoms on the board and ask learners to complete the nuclides by writing in the atomic number on each of the isotopes. I would then emphasise that any atom with atomic number 12 would be the magnesium atom regardless of the mass number. The learner seems to use mass numbers of isotopes to calculate the relative atomic mass of oxygen by simply finding their average. Learners would be informed that they should consider how much of each isotope is present in the sample as each isotope contributes to the relative atomic mass according to its abundance. Learners would refer to the relative atomic mass of oxygen obtained (17) and compare this value to the isotopic masses in the table and suggest which isotope contributes more mass to the 17 amu.

From this, learners would pick up O-17, but this would be untrue as the O-17 has the lowest percentage abundance. The formula

Ar = (abundance of isotope 1 × mass number of isotope 1) + (abundance of isotope 2 × mass number of isotope 2)/ 100 would be discussed.

I would then write the percentage abundances of the respective isotopes of magnesium and the relative atomic mass would be calculated by whole class.

I would also emphasise the fact that relative atomic masses do not have units, as these are comparative numbers (compared to the C-12 atom).

Learners would then be required to re-do the exercise on oxygen.

Figure 4.11: Response from EDM conceptual teaching strategy

In his response, EDM was able to consider *learners prior knowledge*, such as the need for them to have a clear understanding of the concept atomic numbers and confirms it by giving learners an activity on identifying atomic number of magnesium atoms. Secondly, EDM was also able to confirm that there is a misconception on how learners responded to the question. According to the rubric, an aspect related to sequencing of concepts should emerge. EDM clearly showed that in preparation of the teaching of isotopes, learners should understand the nuclide concept. His response in Figure 4.11 also shows evidence of learners' involvement. In terms of *representations*, EDM utilised symbolic representations only. Taking into consideration all his responses, EDM was placed in the developing level.

4.8 Concluding discussions and implications

All the person and item maps of the practicing teachers fall within the acceptable range of the fit statistics -2 and +2, therefore indicating that the Topic Specific PCK instrument is valid and measuring a single construct. The two reliability estimates for person and item were also

measured and indicated that the instrument is reliable. However, the ordering of items was more reliable than the one of persons. I assume that for future purposes, person reliability can be improved by using a greater number of teachers and more ability to teach, which might suggest stronger Topic Specific PCK.

From the analysis it emerged that the teachers found the *conceptual teaching strategies* and *what is difficult to teach* categories most difficult and the *curricular saliency* easy. In comparison with Mavhunga (2012)'s findings, *representations* and *conceptual teaching strategies* were found to be the most difficult. What has emerged to be easy in *curricular saliency* is that most teachers did (i) identify the suitable Big Ideas (ii) correctly explain the link to the ideas (iii) provide logical sequence of all the Big Ideas (iv) include the post-concepts needed in the next Big Ideas on the current topic (v) link the reasons given for the importance of the current topic, which links to the understanding of topics in the subjects to come, particularly under conceptual progression.

Similar to Mavhunga (2012)'s findings, the teaching strategy was found to be the most difficult for most teachers. In my study, this was attributed to non-consideration of (i) confirmation or confrontation of prior knowledge and misconception (ii) aspects related to *curricular saliency*: sequencing of topics (iii) the three levels of representations but mainly sub-microscopic representation and (iv) learner centredness. It has to be made explicit to teachers what constitutes Topic Specific teaching strategies in order to improve their competence in each category. An improvement in Topic Specific teaching strategies may result in lower Rasch measures than those obtained in my study and ultimately may have a positive effect on the mean result which would be an indication of higher quality Topic Specific PCK. Finally, the tool has proven to be appropriate for use in the collection of data in my study. Prior to looking at the use of the tool in NUGTs, it is important to first give a full description of the targeted PDI in my study, which is in the next chapter.

CHAPTER 5

5. PROFESSIONAL DEVELOPMENT INTERVENTION

Beginning teachers require support, guidance and orientation during the transition to their first teaching career. This chapter looks at the intervention NUGTs were exposed to as part of the Professional Development Intervention (PDI). It provides a description of the two weeks' intensive training and how they engaged with Topic Specific PCK categories through the development of the initial and final CoRe. These CoRes are compared in order to determine whether their Topic Specific PCK had emerged or not. Furthermore, the chapter shows the description of case study teachers' visits and some analysis of lessons they taught which may have influenced some of their responses in the final CoRe. Ultimately, the chapter aims to elicit evidence of the emergence of NUGTs' Topic Specific PCK during the PDI. The data source for the chapter comes from the CoRes, the lessons and interviews of the case study teachers.

5.1 Description of the initial intensive training

The NUGTs were recruited by Teach South Africa which was also responsible for organising the intensive training. Prior to the intensive training, all the NUGTs were contacted and informed about the venue for the training. All expenses such as transport, accommodation and food were paid for by Teach South Africa. The duration of the training was two weeks. The theme for week one was '*about to teach'* and week two *'into teaching'*. These NUGTs were divided into three groups - Mathematics, Science and English. They spent most of the time working in their respective subject groups. However, there were instances where the groups were combined for the sessions that dealt with the general pedagogical knowledge issues. Table 5.1 gives an indication of what was covered by the science group, which is the interest of my study. The workshops were spread over the two weeks. All these workshops were conducted by experts from different universities in South Africa as well as reputable private organisations that are involved in teacher training. The sessions for each day lasted almost 12 hours including two tea breaks and a lunch break. Each NUGT group was assigned a mentor responsible for taking them through the training specifically for content related sessions. It is important to mention that I did not attend the entire workshop. I facilitated the sessions: *What is science - content theme (Atom* and *Introduction of Topic Specific PCK)*. As

indicated in table 5.1, the content of activity in the workshop on *atoms* included the topic in my study –the particulate nature of matter.

Table 5.1: Description of training for NUGTs (science group)

Workshop	**Content of the activity**	**Contact time with trainers**	**Science group/Mathematics & Science group/All group combined**
WEEK 1-ABOUT TEACHING			
Administration of pre-instruments	*CK test * Topic Specific PCK test *Development of initial CoRe	3hrs	Science group
Classroom related issues	*classroom management *classroom discipline *Generic lesson planning *Introduction to Integrated Quality Management System (IQMS)	10hrs	All groups combined
What is science: content theme Atom (Facilitated by science group mentor)	*the particulate nature of matter *periodic table * size of atoms *atomic nucleus and isotopes-atomic number, mass number, symbols, ions and isotopes *Atomic mass and relative atomic mass	8.5hrs	Science group
Content theme-Number in science	*the importance of patterns in science and mathematics *pattern seeking and problem solving	6hrs	Mathematics & Science group
Science and Language	*language across the science curriculum *the language of science and the science of language development	4.5hrs	Science group
Assessment	*an introduction to modes of educational assessment *introduction to classroom observation instruments *developing marking rubric	7.5hrs	All groups combined
WEEK TWO-INTO TEACHING			
Cognition	*multiple intelligence, types of knowledge, modes of learning and Bloom's & Barrett's taxonomies *constructivist theory and co-operative learning *deconstruction constructivism - the durability of misconceptions	5.75hrs	All groups combined
The educational environment	*Innovation, change and communities of practice *the state of education in South Africa and challenges facing young teachers	2.5hrs	All groups combined
Science Curriculum	*CAPS through content theme: NS/Life sciences *analysing syllabus grade 6-10 *Progression and concept building schemes	10.5hrs	Science group

Workshop	Content of the activity	Contact time with trainers	Science group/Mathematics & Science group/All group combined
	using text books		
Developing lesson plans	*GET & FET lessons	3.5hrs	Science group
Introduction on Topic Specific PCK (particulate nature of matter) - facilitated by me	*What is PCK *description of categories of Topic Specific PCK	2.5hrs	Science group
Assessment and Resources for science teaching	*writing questions	8hrs	Science group
Total hours		72.25 hours	

Prior to beginning the intensive training on the first day, I was given an opportunity by the Teach South Africa to administer the pre-CK test described in chapter three. The CK test was meant for eliciting initial knowledge NUGTs hold about the particulate nature of matter, which is the topic they are expected to teach for the purpose of my study. Since the "what is science" session dealt with the particulate nature of matter (as shown in table 5.1), it was necessary to administer the test prior to this session, to avoid any influence of the training on the results of the test.

I was allocated a three-hour slot during the second week of the training (as shown in table 5.1). In the first half an hour of the session, I introduced and explained the idea of Topic Specific PCK to the NUGTs. This included a description of the categories. It was followed by a written pre-test of Topic Specific PCK which was administered to the NUGTs (see Appendix D). It took them an hour to complete the test. In the remaining one and half hours, NUGTs were requested to construct an initial CoRe on teaching the particulate nature of matter. As indicated in chapter three, a CoRe is based on the notion that a science topic can be conceptualised with regard to the Big Science Teaching Ideas (Loughran et al., 2004). Due to time constraints and the fact that the NUGTs had not taught before, a decision was taken to provide them with the big ideas. They were provided with the following big ideas as identified by Loughran et al. (2004).

- Big idea 1 - Matter is made up of small bits called particles
- Big idea 2 - There is nothing (empty space) between the particles that makes up matter

- Big idea 3 - The particles are in constant motion

The CoRe template used in my study was similar to the one used by Mavhunga (2012) who adapted it to accommodate the categories of Topic Specific PCK (Mavhunga, 2012). The NUGTs were divided into three groups, two groups of five and one group of six. Each group was allocated one big idea and was asked to complete the CoRe prompts for their big idea. The NUGTs were given different science textbooks for different grades as well as the curriculum guidelines for physical science. Analysis on NUGTs' initial CoRes is discussed later in this chapter under the heading - evidence of emerging Topic Specific PCK in case study teachers.

A careful look at the description of the training programme in table 5.1 suggests that the organisers had in mind that NUGTs may need to revise some science topics, suggesting that they wished to address CK. There is also evidence of the general pedagogical issues on the training programme, amongst others assessment and lesson plan development. However, few 'content teaching' issues, in particular PCK, were explicitly discussed other than the 2.5 hour slot allocated to me. This may suggest that Teach South Africa considers the intensive training important for basic 'survival skills' of NUGTs in schools.

5.2 The profile of NUGTs in the study

As indicated in chapter three, 16 science NUGTs participated in the intensive training programme. Shown below in table 5.2 is the demographic detail of the participants, reproduced for convenience.

Table 5.2: Demographic information of the NUGTs

Teacher	Highest qualification	Major subjects	Year completed
ZD	BSc	Chemistry and Mathematics	2011
NN	BSc	Physics and Economics (Agricultural Economics)	2011
DN	BSc	Materials sciences	2011
SS	BSc	Microbiology and biochemistry	2010
MJ	BSc Honours	Biochemistry, Genetics, Plant science	2010
WM	BSc	Chemistry and physiology	2010
DR	BSc	Chemistry	2010
TM	BSc	Biology	2009
LM	BSc	Chemistry and Biochemistry	2011

Teacher	Highest qualification	Major subjects	Year completed
MB	BSc	Human genetics, Medical Biology and Biochemistry	2007
SR	BSc	Chemistry and Biochemistry	2010
KK	BSc	Physiology and psychology	2010
AN	BSc Honours	Applied physics	2008
TS	BSc	Microbiology	2008
TC	BSc Honours	Mathematics, Chemistry and Process Engineering	2001
KT	BSc Honours	Chemistry then Biology	2010

Four of these teachers were allocated grade 10 and became the case study teachers for my study. Of the 16 NUGTs who were involved in the intensive training, 14 were placed in different high schools across the country. Of the remaining two (teacher TM and DR), one dropped out while the other one had personal constraints and was not placed at school the same year. Table 5.3 shows the allocation of grades taught by NUGTs during the time of my study, excluding teacher DR and TM. The NUGTs are arranged with the case study teachers first in table 5.3.

Table 5.3: NUGTs' science teaching allocation per grade

NUGTs	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Province
*ZD		√	√			Western Cape
*NN		√	√			Western Cape
*DN		√	√	√		Eastern Cape
*SS	√		√			Free State
MJ			√ **(not allocated the topic)**	√		Gauteng
WM	√	√				Mpumalanga
LM		√		√	√	Gauteng
MB	√					Free State
SR	√	√				Gauteng
KK		√		√		Gauteng
AN		√		√		Eastern Cape
TS	√	√				Gauteng
TC	√	√				Gauteng
KT	√					Free State

It can be deduced from table 5.3 that most of the NUGTs were allocated to grade 8 and/or 9 teaching and sometimes in conjunction with grade 10 or higher. This was anticipated to be the case, as the teachers did not have any teaching experience. Five of them were allocated to the senior grades (10-12). Since the focus of my study is on the teaching of the particulate nature of matter in grade 10, only the four teachers who were allocated grade 10 class were observed teaching the topic. This was with exception of MJ, who taught grade 10 but was not allocated the topic to teach at her school. She was able to observe a senior grade 10 teacher

teaching the particulate nature of matter. The only topics she taught in grade 10 are: chemical bonding, electricity and electrostatics. In the section below, a detailed description is presented of the four NUGTs who were observed teaching the topic.

The NUGTs started teaching in their respective schools in term 1 which begins in January in South Africa. The period of PDI ended in school term 3 and the post-test was written. Therefore these teachers are presumed to have taught the work done in term 1 to 3 (end of September) in schools, which is considered the end of the PDI in my study. Table 5.4 below shows a description of the teaching done by the NUGTs per term during the 9 months' teaching.

Table 5.4: Teaching done by the NUGTs per grade within the PDI period

Grade	Term 1	Term 2	Term 3 (end of the intervention)
8	LIFE & LIVING Interdependence in ecosystem: *abiotic, Biotic factors & Ecology * soil fertility *survival *human impact, influences on a population and natural selection PLANET EARTH AND BEYOND The atmosphere on Earth *Atmosphere, Greenhouse effect	PLANET EARTH AND BEYOND The atmosphere on Earth *climate, adaptations to climate Exploring beyond planet Earth *planet Earth *Gravity, the moon, telescopes, satellites and space travel *Solar system	MATTER & MATERIALS The particle model of matter *atoms & molecules, models in chemistry Elements and Compounds *elements and compounds to chemical reactions ENERGY AND CHANGE Cells and electrical circuits *electrical energy and circuits including incandescent bulbs (light) *effects of current
9	LIFE & LIVING Microscopic world of living things *Micro-organisms, diseases and drugs Cells as the basic units of life *cells Life processes and systems of humans *body systems and its interdependence *Healthy living Pregnancy, birth, parenting and adult sexuality *puberty	LIFE & LIVING Pregnancy, birth, parenting and adult sexuality *sexual intercourse *STDs *parenting and child care PLANET EARTH AND BEYOND Minerals and mining in South Africa *mineral deposits Oxides and reaction of metals with oxygen *extraction methods	MATTER & MATERIALS The particle model of matter in chemical reactions * molecules & compounds *models-chemical reactions Some important chemical reactions *chemical balancing, reactions and reactivity ENERGY AND CHANGE Electrical systems *electrostatics *mechanical systems
10	MATTER & MATERIALS Revise matter & classification *Mixtures, pure substances, names and formulae of substances, metals, metalloids, non-metals, semiconductors, insulators, electrical conductors, thermal conductors, magnetic and non-magnetic materials **States of matter and the Kinetic Molecular Theory** *Three states of matter *Kinetic Molecular Theory The Atom: basic building of all matter *Models of the atom *Atomic mass and diameter *Structure of the atom *Isotope *Electron configuration Periodic Table *The position of the elements in the periodic	MATTER & MATERIALS Particles substance are made of *Atoms and compounds Physical and chemical change *separation of particles in physical change and chemical change *conservation of atoms and mass *Law of constant composition Representing chemical change *Balanced chemical equation Magnetism *magnetic field of permanent magnets *poles of magnets, attraction and repulsion, magnetic field lines Earth's magnetic field, compass Electrostatics *two kinds of charge *charge conservation Electric circuits	CHEMICAL CHANGE Reactions in aqueous solution *electrolytes and extent of ionisation as measured by conductivity *Precipitation reactions Other chemical reaction types in water solution Quantitative aspects of chemical change *atomic mass and the MOLE concept *Molecular and formula masses *Determining the percentage composition of substances *amount of substance(mole), molar volume of gases, concentration of solutions Basic stoichiometric calculations MECHANICS Vectors & Scalars Motion in one direction *reference frame, position, displacement and distance

Grade	Term 1	Term 2	Term 3 (end of the intervention)
	table related to their electron arrangements *similarities in chemical properties among elements in group 1,2, 17 & 18 Chemical Bonding *covalent bonding, ionic bonding, metallic bonding WAVES, LIGHT AND SOUND Transverse pulses on a string or spring *Pulse amplitude, Superposition, transverse waves, Longitudinal waves, wavelengths, frequency, amplitude, period, wave, speed, sound waves & sound Electromagnetic Radiation *Dual (particle/wave nature of EM radiation), nature of EM radiation, EM spectrum, waves, legends and folklores	*Emf Potential difference(pd), current, resistance, resistors in series & parallel	*average speed, average velocity, acceleration Instantaneous speed and velocity and the equations of motion *Instantaneous speed and velocity *description of motion in words ,diagrams, graphs and equations
11	MECHANICS Vectors in two dimensions Motion in one direction *resultant of perpendicular vectors *resolution of a vector into its horizontal and vertical categories *different kinds of forces Forces diagrams, free body diagrams *Newton's first , second and third law and Universal Gravitation MATTER & MATERIALS Atomic combinations: Molecular structure *A chemical bond *Molecular shape using Valence Shell Electron Pair Repulsion theory *Electronegativity of atoms to explain the polarity of bonds *Bond energy and length Intermolecular forces *intermolecular and interatomic forces (chemical bonds) *Physical state and density explained in terms of these forces *particle kinetic energy and temperature *the chemistry of water	WAVES, LIGHT AND SOUND Geometrical optics *Refraction, Snell's Law *critical angles and total internal reflection * diffraction Ideal gases and thermal properties *motion of particles * kinetic theory of gases *Ideal gas law *Temperature and heating pressure CHEMICAL CHANGE Quantitative aspects of chemical change *Molar volume, of gases, * concentration of solutions *more complex stoichiometric calculations *Volume relationships in gaseous reactions	ELECTRICITY AND MAGNETISM Electrostatics *coulomb's Law * Electric field *magnetic field associated with current carrying wires * Faraday's Law Electric circuits *Ohm's Law *Power, Energy CHEMICAL CHANGE Energy and Chemical *Energy changes in reactions related to bond energy changes *Exothermic and endothermic reactions *activation energy Types of reaction *Acid-Base
12	MECHANICS Frame of reference *Vertical projectile motion *Graphs *Conservation of momentum in 1D *Impulse *Work, power and energy *Relationship work and energy *Power MATTER & MATERIALS Optical phenomena & properties of materials *transmission and scattering of light *Photoelectric effect *Emission and absorption spectra Organic molecules *functional groups *systematic naming and formulae *physical properties *chemical properties-substitution, addition and elimination reactions	WAVES, LIGHT AND SOUND Doppler effect 2D and 3D wave front *Diffraction *interference CHEMICAL CHANGE *Rates of reaction *Chemical equilibrium and factors affecting equilibrium *Equilibrium constant *application of equilibrium principles *electrochemical reactions *relation of current and potential to rate and equilibrium *understanding of the processes and redox reactions taking place in cells *Standard electrode potentials *writing of equations representing oxidation and reduction half reactions and redox reactions	ELECTRICITY AND MAGNETISM Electrodynamics *electrical machines (generators, motors) *Alternating current Electromagnetic radiation *Particle/wave (dual) nature of EM *nature of EM *EM spectrum CHEMICAL SYSTEMS Chemical industry-resources, needs and the chemical connection *Chloralkali industry (soap, PVC) *The fertilizer industry (N, P, K) *Industrial application of cells and batteries-torch, car, batteries etc.)

The particulate nature of matter falls under the knowledge area 'Matter & Materials'. The topic is taught within 'the state of matter and the kinetic molecular theory' as circled in table

5.4 under the grade 10 curriculum done in school term l. The pre-requisite concepts of 'Matter & Materials' taught in grade 8 and 9 are also circled in table 5.4.

5.3 The case study teachers

Teachers ZD, DN, SS and NN are considered 'case study teachers' in my study because they were allocated a grade 10 class to teach, and thus they taught the particulate nature of matter. As shown in table 5.3, teacher ZD and NN were placed in the Western Cape Province in the same private school. Teacher DN was placed in the Eastern Cape while teacher SS was placed in the Free State Province, both in government schools. Table 5.5 gives a full description on lessons taught by the case study teachers, the description of school context and so forth.

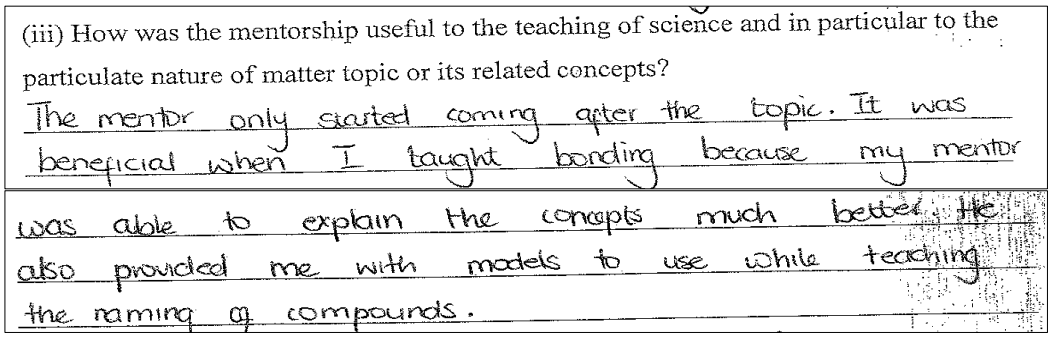
Table 5.5: Description of case study teachers

Teacher code	Number of lesson observed	Description of the lessons	Total number of hours observed	School context (type of school, number of learners per class, province)	Assigned school science mentor (Yes/No)	Assigned organisation science mentor		
						(Yes/No)	Number of visits (during intervention period)	Visited when? Indicate school term
ZD	*2	*Kinetic Molecular Theory (two grade 10 classes)	2	*Private school *25-30 learners per class * Western Cape	No	Yes	4 (monthly)-came after teaching the topic	2&3
	*4	*Atoms and its structure (two grade 10 classes)						
DN	*2	*Kinetic Molecular Theory (two grade 10 classes)	1	*Township school *40-50 learners per class * Eastern Cape	No	Yes	1	2
NN	*1	*Kinetic Molecular Theory (one grade 10 class)	2	*Private school *25-30 learners per class *Western Cape	No	Yes	4 (monthly)-came after teaching the topic	2&3
	*3	*Atoms and its structure (two grade 10 classes. One class had a double period)						
SS	*2	* Kinetic Molecular Theory& states of matter (two grade 10 classes)	2,5	*Township school *50-60 learners per class *Free State	No	No	0	n/a
	*2	*Atoms and its structure (two grade 10 classes)						
	*2	*Ions & Isotopes (two grade 10 classes)						

It is important to mention that I observed the case study teachers over three consecutive days. This is with exception of teacher DN, who was only observed for one day due to a teachers' union strike in the province at the time. This is evident from the lower number of hours and lessons observed, indicated on table 5.5. Prior to teaching all the lessons, a pre-observation interview was conducted by me, followed by the post-observation interview. However in a case where a teacher had to teach two different classes the same lesson for the first time, the pre-observation interviews were done once for both classes but the post-observation interviews were conducted separately.

The physical science mentor involved during the intensive training was also responsible for mentoring the NUGTs in their respective schools. This mentor is based in the Gauteng Province and therefore was only able to provide mentorship to the NUGTs teaching in the nearby Provinces such as Free State, Mpumalanga and Gauteng. For those teachers in the Western and Eastern Cape Province, a different mentor based in the coastal region was assigned.

I requested the NUGTs to reflect on their mentorship experiences on the reflective questionnaire completed at the end of the PDI. This included explaining how the mentorship was useful to the teaching of the particulate nature of matter. Of the 14 NUGTs, only six indicated that the mentor visited them at their respective schools at least once a month. Of these six, three are the case study teachers (ZD, NN & DN). However, they all indicated that the mentor came after they had taught the particulate nature of matter. Figure 5.1 shows a response from teacher ZD from the reflective questionnaire.


(iii) How was the mentorship useful to the teaching of science and in particular to the particulate nature of matter topic or its related concepts?

The mentor only started coming after the topic. It was beneficial when I taught bonding because my mentor was able to explain the concepts much better. He also provided me with models to use while teaching the naming of compounds.

Figure 5.1: Teacher ZD's response on mentorship

Her response above suggests that the mentorship received played an important role only when she taught chemical bonding. This suggests that it didn't have any influence in the teaching of the topic, particulate nature of matter, as it is taught before chemical bonding as shown in table 5.4. The remaining eight NUGTs have indicated at the time that they had not

had a mentor visit. This includes case study teacher SS, as shown in table 5.5. Furthermore, they were also asked if they had received any mentoring from their school. Their responses revealed that only one (teacher MJ) indicated that she was assigned two mentors within the school. None of the case study teachers received support at their schools. This suggests that within their respective schools, almost all the NUGTs were not receiving any kind of induction.

Most NUGTs indicated that they had an opportunity to attend in-service training. However, most of them indicated that the training they attended was based on new Curriculum Assessment Policy Statement (CAPS) training, which was to be implemented for the first time in grade 11 in 2013. Others highlighted that apart from CAPS, the training they attended concentrated on general pedagogical issues such as teaching methods, planning of the lessons, as well as classroom management. Only three teachers did not attend any in-service training. Based on the evidence from the NUGTs, it may be assumed that none of the workshops they attended dealt with the particulate nature of matter and therefore may not have been beneficial during the teaching of the particulate nature of matter.

Furthermore I attempted the use of social network Facebook (www.facebook.com) as a way of keeping in touch with all the NUGTs across the country. This was meant to give them an opportunity to discuss issues related to teaching in the form of a forum and also to share their experiences. However, this turned out not to be successful as most of them were overwhelmed with the teaching load during their first year of teaching and also registered for the Post Graduate Certificate in Education (PGCE) on a part time basis.

5.4 Evidence of developing Topic Specific PCK

In this section, the initial and final CoRes on the particulate nature of matter developed during the PDI are analysed in the context of additional data collected during the study. The CoRe was used as the primary vehicle to find to what extent NUGTs' Topic Specific PCK was emerging during the PDI. Through the use of the CoRe, NUGTs were able to capture and document their PCK of the topic. As stated above, during the initial CoRe development session the NUGTs were divided into three groups - two groups of five and one group of six. Each group was assigned a big idea and had to complete its prompts. The same groups of teachers were used in the development of the final CoRe, with the exception of the two

NUGTs (TM and DR) who were not placed in schools and one (AN) who did not attend the post-session with the rest of the group. It is important to mention that NUGTs did not have access to the first CoRe when constructing the final one. I did not want them to have an initial CoRe as it was anticipated that it would influence their thinking during the construction of the final CoRe.

The analysis of prompts for each big idea discussed below is done according to the respective groups. The first group engaged with the prompts for big idea 1- *Matter is made up of small bits called particles.* The second group focused on the prompts for big idea 2 - *There is nothing (empty space) between the particles that make up matter* and the third group worked on *big* idea 3 - *The particles are in constant motion*. For all three big ideas the prompts are grouped and discussed according to each Topic Specific PCK category. This gives an indication on the 'knowledge' aspect NUGTs have about the teaching of the particulate nature of matter. Given that observation evidence was available for some of the teachers who had experience teaching the topic, this evidence could be used to find possible reasons for any change in PCK knowledge and its possible origin in practice, since PCK is known to grow with experience in practice (Van Driel, De Jong, & Verloop, 2002). Therefore evidence of emerging Topic Specific PCK from actual classroom practice could be linked to the responses of the CoRe prompts. However, evidence of teaching linked to what is seen in CoRe will only be used where available. Mostly the case study teachers' classroom practice work was reviewed in this regard, because they had taught the topic required for my study in grade 10. As can be deduced in table 5.3, all NUGTs taught grade 8 and 9 (including the pre-requisite concepts of the topic in consideration) or 10, except teacher MJ. This implies that they had a chance to improve the knowledge of teaching the particulate nature of matter. However, I have only direct evidence of case study teachers. But it would be likely that non-case study teachers gained indirect experience from grade 8 and 9 teaching.

Prior to looking into the analysis of the big ideas, it is important to explain the quality of criteria followed, as it underpins the analysis to follow. I decided to use the CoRe for particle theory developed by Loughran, Berry, & Mulhall (2006) as an expert CoRe (see Appendix F). This CoRe was chosen because the topic is identical to the one for my study. In addition to that, the three big ideas from the authors' CoRe were adopted as big ideas for the CoRes in my study. Finally, Loughran et al. (2006)'s CoRe was developed by a group of experienced high school science teachers working collaboratively, who have taught both general science

and senior science. In the South African context, these teachers would have had experience in teaching both General Education and Training (GET) and Further Education and Training (FET). Taking into consideration that NUGTs are beginning teachers, it was important to compare their CoRe responses with those of expert teachers. Therefore, the responses to the prompt from the experts' CoRe were used as a form of guidance in marking the NUGTs' responses where possible.

Table 5.6 shows how the CoRe was adapted and how the five categories of Topic Specific PCK were deduced in Loughran et al. (2006)'s CoRe. The adapted CoRe template was used by NUGTs in both the development of initial and final CoRe.

Table 5.6: Adaptation of CoRe

5 Categories of Topic Specific PCK	**Loughran et al. (2006)'s CoRe**	
	Prompts already in CoRes	Additional prompts
Curricular Saliency (4 prompts)	*What do you intend students to learn about this idea? *Why is it important for students to know this? *What else you know about this idea (that you do not intend students to know yet)?	*What concepts need to be taught before teaching this big idea?
What is difficult to teach (1 prompt)	*Difficulties/limitations connected with teaching this idea.	
Learners' prior knowledge (1 prompt)	*Knowledge about students' thinking which influences your teaching of this idea.	
Conceptual teaching strategies (2 prompts)		*What effective teaching strategies would you use to teach this idea? *What questions would you consider important to ask in your teaching strategies? Comment: this prompt falls under 'Specific ways of ascertaining students' understanding or confusion around this idea' in Loughran's CoRe.
Representations (1 prompt)		*What are representations would you use in your teaching strategies? Comment: In Loughran's CoRe, 'representations' are included in the teaching procedures prompt.

5.4.1 Analysis of big idea 1- *Matter is made up of small bits called particles*

Table 5.7 below shows the composition of the group for this big idea. The teachers with an asterisk are the case study teachers in that group. As stated above, DR was only present during the development of the initial CoRe.

Table 5.7: Composition of group for big idea 1

Initial CoRe	Final CoRe
*DN**	*DN**
*SS**	*SS**
DR	_
MB	*MB*
TS	*TS*

Prior to discussing the analysis, it is worth noting that the order of the Topic Specific PCK categories in all the discussions of the big ideas followed their arrangement in the adapted CoRe (see Appendix B).

5.4.1.1 The category of *curricular saliency*

Some of the group's responses on the prompts of *curricular saliency* of the initial CoRe (figure 5.2) are in line with Loughran et al. (2006)'s responses. Considering that the NUGTs had no teaching experience at the time of the development of the initial CoRe, this implies that the initial exercise of constructing the CoRe forced NUGTs to envisage how they would teach a topic - particulate nature of matter. Conspicuous

Initial CoRe

Curriculum Saliency	
What are the big ideas for the topic?	All matter is made up of small bits called particles
What do you intend the learners to know about this idea?	Any object is made up of tiny particles, which are microscopic i.e. cannot be seen with a naked eye
Why is it important for learners to know this big idea?	>Because the chemistry behind matter occurs at the microscopic level >It will enable them to understand what science is all about, how and why things happen the way they do >It will and assist learners to understand the properties of matter
What concepts need to be taught before teaching this big idea?	None.
What else do you know about this idea (that you do not intend learners to know yet)?	>The behaviour of particles - Particles move in a constant motion - There is empty space between particles - Calculations e.g using Avogadro's number

Final CoRe

Curriculum Saliency	
What are the big ideas for the topic?	All matter is made up of small bits called particles.
What do you intend the learners to know about this idea?	>All matter is made of small building blocks >These building blocks have specific properties. >These building blocks are called particles and may be individual atoms or molecules >
Why is it important for learners to know this big idea?	>Because this is the foundation for studying basic concepts of chemistry >It explains microscopic behaviour better. >Provides a solid platform for the use and application of scientific terms
What concepts need to be taught before teaching this big idea?	>What is matter?? The concept of mass and space.
What else do you know about this idea (that you do not intend learners to know yet)?	>The subatomic particles i.e. atoms have protons, electrons and neutrons. >Matter exists in different phases i.e. solid, liquid, gas >Kinetic energy and intermolecular forces.

Figure 5.2: Curricular saliency prompts for big idea 1

In terms of the first prompt ‘what do you intend the learners to know about this idea’, the group’s final CoRe responses were more refined as compared to the initial CoRe. The group did not only indicate that learners need to know that the smallest bit is a ‘particle’ but also hinted that these particles can be discriminated as either atoms or molecules, as also suggested by the expert teachers in the expert CoRe (see Appendix F).

Evidence of knowledge gain was also seen on the response for the prompt ‘why is it important for learners to know about this big idea’. The group indicated that ‘it will enable them (learners) to understand what science is all about and how and why things happen the way they do”. This response implies that knowledge of this big idea will help learners explain the behaviour of everyday things, which is acceptable as documented by expert teachers in the expert CoRe. However, in the final CoRe besides the response ‘it explains the microscopic behaviour better’, which was also implied in the initial CoRe, there has also been some improvement. Although not documented by the expert teachers (see Appendix F), the response highlighted by the group in the final CoRe that ‘for learners to know this idea will enable them to understand the basic concepts of chemistry’ seems appropriate as the topic serves as the foundation in chemistry.

More evidence on emerging Topic Specific PCK is noticeable from the prompts ‘what else do you know about this idea that you do not intend learners to know yet’ and ‘what concepts need to be taught before teaching this idea’, which talk to the pre and post-concepts of the topic. Most of the responses (initial CoRe) on this prompt ‘what else do you know about this idea that you do not intend learners to know yet’ were not entirely acceptable as compared to the experts’ CoRe, because the group gave big ideas 1 & 2 as the answers instead of concepts or topics still to be taught. But the response ‘the behaviour of particles’ is acceptable, as it links to the experts’ response that says ‘at this stage particles is used in a general sense without discriminating between atoms and molecules’. This also means that the learners do not know yet how particles are arranged and move.

However, in the responses of the final CoRe the group showed major differences relative to the initial CoRe. In the initial CoRe the group only mentioned one acceptable response of ‘behaviour of particles’ as indicated earlier. However, in the final CoRe the responses suggest that teachers have now acquired the knowledge of concepts still needing to be taught at a later stage that are needed for the understanding of this big idea. In the final CoRe, suitable

responses such as subatomic structure, phases of matter as well as explaining about the kinetic energy and intermolecular forces were documented. It is important to emphasise that different acceptable answers can be given in this regard. However, a similar response of 'subatomic structure' can be seen in both NUGTs' final CoRe and experts' CoRe (see Appendix F). The prompt 'what concepts need to be taught before teaching this big idea', appeared to be difficult for this group, as they indicated 'none' as the response in the initial CoRe. However, in the final CoRe teachers indicated that the understanding of what matter is needs to be grasped by the learners. It is evident that there was a shift in all the prompts of *curricular saliency,* indicating developing Topic Specific PCK.

It was mentioned above that some of the case study teachers' enactment during classroom practice is incorporated, in order to identify possible sources of the growth portrayed in the final CoRe. The last *curricular saliency* prompt 'what concepts need to be taught before teaching this big idea' is analysed in order to investigate evidence of emerging Topic Specific PCK of the particulate nature of matter. This prompt is selected because the evidence is more explicit in the taught lesson. The response given by the group for this prompt in the initial CoRe shows that it is difficult for beginning teachers to identify concepts that need to the taught before teaching the big idea, as they indicated there are no pre-concepts, in figure 5.2. However, the response in the final CoRe response showed that the understanding of 'what matter is' needed to be grasped by the learners. As shown in table 5.4, some pre-requisite knowledge of the particulate nature of matter is also taught in grade 8 and 9. Therefore the response indicated by this group is acceptable. Since this concept was not mentioned in the initial CoRe response as a response, it can be assumed that teachers who taught the topic might have had some influence prior to the development of the final CoRe.

Case study teachers SS and DN were part of the group engaging with prompts for big idea 1, as illustrated in table 5.7. Evidence from the teaching experience to support growth in PCK is explicitly seen from teacher SS's excerpt below, during the lesson on states of matter and kinetic molecular theory.

TeacherSS: today we are going to learn about the states of matter ok or matter just by itself. What are we talking about? (Asking learners to define matter)

Learners (chorusing): anything that occupies space and has a mass

Teacher SS: and has a mass ok. And when we talking about the states of matter, what are we talking about?

The excerpt above shows that prior to teaching about the states of matter and kinetic molecular theory, teacher SS began his lesson by asking learners to define matter. Although not explicit, it is almost as if teacher SS expected the learners to know or have an idea about what matter is. Indeed this it is expected of the learners that they know this, because the basic concepts of matter such as the particle model of matter are taught in both grades 8 & 9 (see table 5.4). Based on how teacher SS introduced the lesson during the teaching of the topic; it may be possible that his experience may have contributed to the improvement of the final CoRe in his group.

5.4.1.2 The category of *what is difficult to teach*

Unlike the category of *curricular saliency*, *what is difficult to teach* is represented by one prompt in the CoRe. Figure 5.3 shows the group's response on both initial and final CoRe.

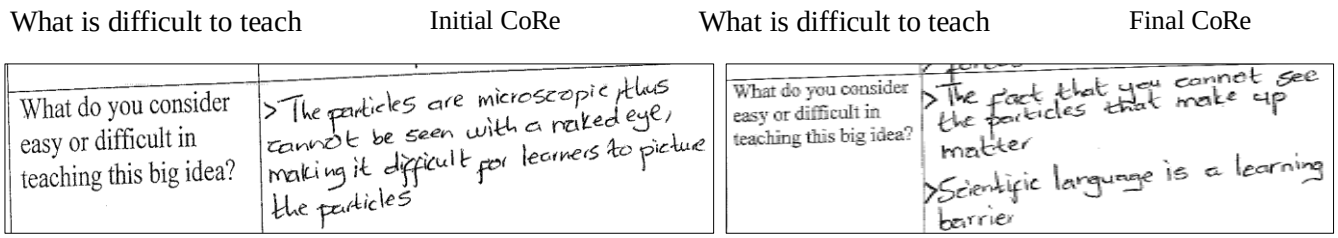


Figure 5.3: What is difficult to teach prompt for big idea 1

In the initial and final CoRe, the group portrayed the same answer in that 'particles' which are too small to see might pose difficulties to learners. This response was also indicated by expert teachers in the expert CoRe (see Appendix F), therefore it is considered acceptable. Furthermore, in the final CoRe the group indicated that the language used in science might confuse learners in the South African context. This response is not necessarily linked only to the big idea at hand. However, the use of certain science models could be a barrier to science learning, as indicated by Loughran et al (2006). This is attributed to the fact that science models do not always make science in everyday life easier to comprehend (Loughran et al., 2006). Due to the same high quality responses in both initial and final CoRes, the group found the category of *what is difficult to teach* the easiest.

5.4.1.3 The category of *learners' prior knowledge*

Similar to the category *what is difficult to teach, learners' misconceptions and prior knowledge* is also addressed in one prompt in the CoRe. The group's response in the initial CoRe builds on the previous category of *what is difficult to teach*. They indicated that learners might tend to think that everything that exists can be seen with the naked eye and if not, its non-existence (see figure 5.4).

Initial CoRe

Student Misconceptions	
What are the typical student misconceptions on this big idea?	>According to most learners, everything that exists can be seen with a naked eye i.e. if it cannot be seen, it does not exist e.g. particles

Final CoRe

Student Misconceptions	
What are the typical student misconceptions on this big idea?	> That one can see an atom under a microscope > They think the building blocks and matter are the same

Figure 5.4: Learners' prior knowledge prompt for big idea 1

The group of NUGTs gave different responses about *learner prior knowledge* (misconceptions) in the final CoRe. They indicated that learners seem to think that atoms can be seen under a microscope. Learners also think atoms and molecules are the same. This implies that learners may mean that atoms are like tiny versions of the bulk substance. In the field notes captured during teacher DN's lesson about 'atoms', learners were asked to define an atom. A learner gave the following as an answer - *an atom is a tiny particle that we can't see with our naked eye*. This response suggests that an atom can be seen when using something else, presumably a microscope. The learner response resonates with the misconception documented in the final CoRe. Therefore, an assumption can be made that some of the improved responses documented in the final CoRe may have been influenced by the NUGTs' teaching experience, thus pointing to the developing Topic Specific PCK.

5.4.1.4 The category of *representations*

The similarity between the responses in both initial and final CoRe (figure 5.5) is that the group of NUGTs suggested the types of representations they would use in their teaching. Unlike the teachers in the expert CoRe (see Appendix F), this group of NUGTs did not elaborate on the concept that the representations were meant to explain.

Initial CoRe

Representations	
What representations would you use in your teaching strategies?	>Charts that explain what matter is >Use objects around class >Pictures to explain the microscopic and macroscopic components.

Final CoRe

Representations	
What representations would you use in your teaching strategies?	>Ball and stick models >Space-filling models

Figure 5.5: Representation prompt for big idea 1

Prior to the PDI, the group's response in the initial CoRe suggests that charts and objects displayed in the classroom be utilised. This response is not clear on what the objects are or what type of representation should be portrayed by the chart. However, taking into consideration that NUGTs had no teaching experience at the time of the initial CoRe development, this kind of response was expected. The final CoRe, however, elaborated on what can be used to show the sub-microscopic representations; items such as ball and stick and space-filling models are choices shown in figure 5.5. Although ball and stick and space-filling models are representations, it should be mentioned that they do not have any link to the big idea under consideration. This big idea needs a form of representation that will make learners understand that although something might look like one thing, it could have been made by combinations of different things. Hence the expert teachers used analogies as shown in Appendix F. I am assuming that the representations documented by this group may be suitable for big idea 2 or 3.

5.4.1.5 The category of *conceptual teaching strategies*

In the first prompt for *conceptual teaching strategy* the group only showed the type of activities, representations and to some extent the approach they would use without explaining explicitly how they intend to incorporate them in order to manifest effective strategy. This is observed in both initial and final CoRe, displayed in figure 5.6.

Initial CoRe

Teaching Strategies	
What effective teaching strategies would you use to teach this idea?	>Models >Videos >Drawing
What questions would you consider important to ask in your teaching strategies?	>What is matter? >What is matter made out of?? >What is meant by building blocks >What are particles?

Final CoRe

Teaching Strategies	
What effective teaching strategies would you use to teach this idea?	>Practical activities >Discussion between Peers >Quiz >Demonstrations >Cover contents: facts and Principles on the topic of matter
What questions would you consider important to ask in your teaching strategies?	What are the properties of matter? What is matter made up of? Distinguish between microscopic & macroscopic? What is air made up of?

Figure 5.6: Conceptual teaching strategy prompts for big idea 1

In the initial CoRe, NUGTs gave answers (for the first prompt) that could be suitable for the category of *representation*, which are not appropriate compared to the responses on the expert CoRe of expert teachers. However, in the final CoRe, the responses such as 'quiz, practical activities, demonstrations' could form part of the teaching procedure. However, reasons for using the selected procedures, which include the explanations (incorporating content) on how to engage with this idea is missing. In terms of the second prompt, of the questions considered important to ask, the questions suggested by the NUGTs in both CoRes were not conceptual compared to the ones suggested by the expert teachers. The teachers in the expert CoRe described in detail how they intend to incorporate the representations and probe learners' understanding. The chosen activity about 'behaviour of everyday things' is explained in detail (see Appendix F). The responses from this NUGTs group suggest that they found the category challenging due to the generic nature of the responses in the final CoRe.

5.4.2 Analysis of big idea 2 - *There is nothing (empty space) between the particles that makes up matter*

The composition of the group for this big idea consisted of the following NUGTs (See Table 5.8 below).

Table 5.8: Composition of group for big idea 2

Initial CoRe	Final CoRe
*ZD**	*ZD**
TM	-
WM	*WM*
TC	*TC*
SR	*SR*

As in the case of teacher DR in table 5.7, teacher TM did not take part during the construction of the final CoRe. Figure 5.7 shows their responses on the initial and final CoRes.

5.4.2.1 The category of *curricular saliency*

As shown in table 5.8, the group focused on prompts for big idea 2 - *There is nothing (empty space) between the particles that makes up matter*. Figure 5.7 shows their responses on the initial and final CoRes.

Initial CoRe

Curriculum Saliency	
What are the big ideas for the topic?	There is an empty space between the particles
What do you intend the learners to know about this idea?	- The spaces between the particles determines the phases of matter - know what physical change is - know what melting, boiling & freezing point are - define melting, evaporation, freezing, sublimation & condensation in terms of changes in state.
Why is it important for learners to know this big idea?	- It helps the learners explain how the different phases changes occur - To be able to understand the kinetic theory of gases - Understanding of intermolecular forces
What concepts need to be taught before teaching this big idea?	- All matter is made up of small bits called particles - what matter is - phases of matter
What else do you know about this idea (that you do not intend learners to know yet)?	- chemical change & how it differ from physical change - Intermolecular forces - Bond lengths

Final CoRe

There is an empty space between particles that makes up matter.
• There are spaces between particles of matter i.e. solid, liquid and gas • There is no air between the spaces.
7 Understanding the concept of spaces makes it easier to understand the movement of particles •For learners to understand the structure of atoms.
All matter is made up of particles.
- Particles of the same substance at different phases have different kinetic energy. - The movement of particles is constant - Atoms - Ions

Figure 5.7: Curricular saliency prompts for big idea 2

The first response 'the spaces between the particles determine the phase of matter' from the prompt 'what do you intend the learners to know about this idea' in the initial CoRe is acceptable. The same response is also in the final CoRe. This response may suggest that this group of teachers is aware that 'the relative distances between particles differ in solids, liquids and gases', which is the response documented by expert teachers from Loughran et al. (2006) (see Appendix F). Another important thing is the response in the final CoRe 'there is no air between particles', which belongs more under *learner prior knowledge* but shows good awareness of misconceptions. However, the last three responses in the initial CoRe may not be appropriate for this prompt but could be the answers for the second prompt 'why is it important for learners to know this big idea'. Once the learners are able to grasp the idea about distance between phases, this may assist them in explaining processes such as melting, expansion, boiling and also expansion and dissolving, as captured in the experts' CoRe. All these are manifested as a result of 'movement of particles' which is indicated in the final

CoRe. The inclusion of these responses in the initial CoRe may be linked to a lack of NUGTs' teaching experience at the time of the CoRe construction. However, after engaging in the PDI in particular teaching processes, such kinds of responses were not included in the final CoRe as shown in figure 5.7, which may imply that NUGTs' PCK of the topic is beginning to develop.

In terms of the third prompt 'what concepts need to be taught before teaching this idea' - most answers in the initial CoRe are appropriate as indicated in table 5.4 as pre-requisite concepts taught in grade 8 and 9. However, in both CoRes a big idea 1 'matter is made up of small bits which are particles' is given as an answer, which does not represent a 'concept'. Although this answer makes sense, a response rephrase such as 'knowledge on what a particle is' may be appropriate.

The last prompt of *curricular saliency* 'what else do you know about this idea that you do not intend learners to know yet' intends to find out if teachers know the selection of what to teach within a particular big idea or the topic at hand, including the sequence hence curriculum to be followed. The group response included mostly the suitable topics that need the understanding of the topic (particulate nature of matter), such as chemical and physical change and bond-length, which falls under chemical bonding. These responses are acceptable, because they are still to be taught and also need the understanding of the particulate nature of matter, but they are stand-alone topics. This suggests that the group was beginning to understand the sequencing in terms of the topics still to be taught and that require learners to have the knowledge of the particulate nature of matter during the development of initial CoRe. This might have been influenced by the science curriculum workshop they attended, as shown in table 5.1. But the group's response considered as appropriate is 'intermolecular forces'. Although not elaborated by the group, learners would need to understand that the empty spaces differ with respect to the states of matter and this is as a result of how strong or weak the intermolecular forces are in a particular state. So as a result, the response 'intermolecular forces' is a concept that learners would need to understand during the topic, in particular when engaging with big idea 2 and also 3 -*'The particles are in constant motion'.*

There was even more improvement in a final CoRe response on the same prompt 'what else do you know about this idea that you do not intend learners to know yet', done by the same

teachers. All the post-concepts suggested in final CoRe are acceptable and fall within the topic – the particulate nature of matter.

5.4.2.2 The category of *what is difficult to teach*

The acceptable response on both CoRes in figure 5.8 for the concept 'picturing empty space between the particles' suggests that NUGTs found this category for this big idea easier to reason. The same response of 'hard to picture empty spaces between particles' was documented by the expert teachers (see Appendix F). This particular group of NUGTs has correctly envisaged the difficulty in the initial CoRe.

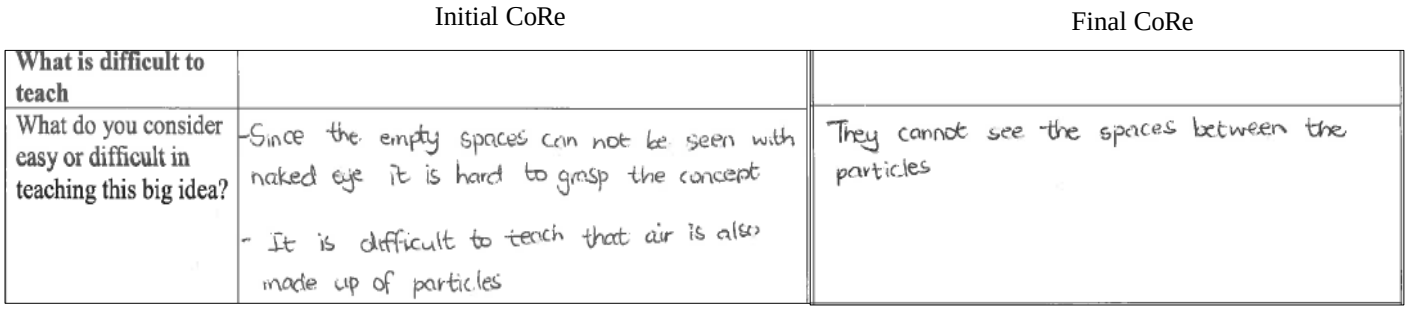
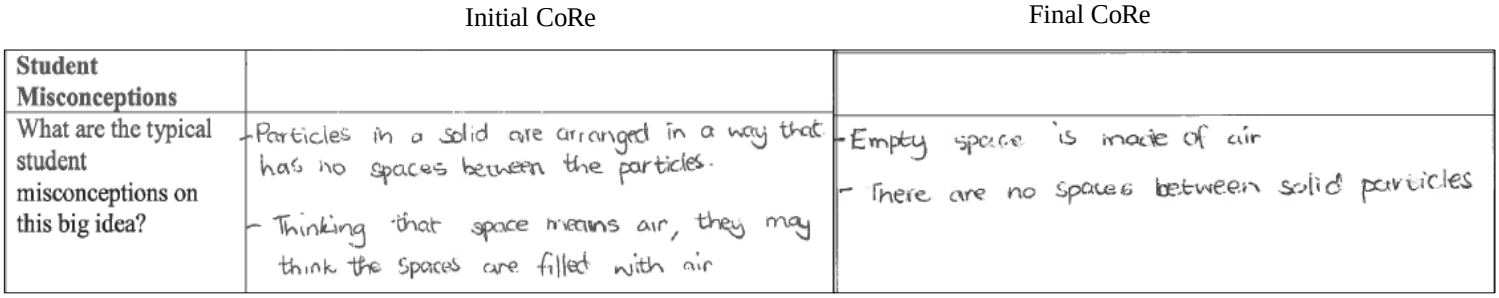


Figure 5.8: What is difficult to teach prompt for big idea 2

Interestingly, in the initial CoRe the group envisaged that it might be difficult to teach learners that air is also made up of a 'particles', which is not in the final CoRe. This response is acceptable, because indeed learners don't tend to think of gases as matter as indicated by Loughran et al. (2006) which ultimately makes them encounter difficulty thinking about empty spaces between the particles of air. This can be supported by what I noted in the field notes from teacher ZD's lesson about atoms, where most learners struggled to understand the concept of 'emptiness'. Teacher ZD emphasised that an empty space means that there is nothing including air, because air is made up of particles. She also highlighted that some learners tend to think that when there is nothing in a room there is air. Based on this observation it can be assumed that because the teachers knew about this difficulty before going into teaching, as shown in the initial CoRe, they might have emphasised it in such a way that learners eventually understand. And it may be for this reason it is not mentioned in the final CoRe and that it may be possible that teacher ZD's teaching experience may have influenced the groups' response.

5.4.2.3 The category of *learners' prior knowledge*

In terms of the misconception associated with teaching this big idea, in both CoRes teachers highlighted that learners tend to find it difficult to think about the notion of 'space', which is acceptable. As indicated by Loughran et al. (2006), that learners seem to think that there is 'stuff' between particles. The CoRe response in figure 5.9 suggests that teachers emphasised the idea that learners tend to think that there is air, which is a misconception. This was also seen and elaborated in the previous category of *what difficult to teach*.



	Initial CoRe	Final CoRe
Student Misconceptions		
What are the typical student misconceptions on this big idea?	- Particles in a solid are arranged in a way that has no spaces between the particles. - Thinking that space means air, they may think the spaces are filled with air	- Empty space is made of air - There are no spaces between solid particles

Figure 5.9: Learners' misconceptions prompt for big idea 2

Another appropriate response on *learner prior knowledge* which appears in both CoRes is the one where learners think that there are no empty spaces in solids. The expert teachers in Loughran et al. (2006) also documented the same response. This may suggest that learners might still find it difficult to differentiate between macro and sub-micro levels. In this case, it would make it difficult to picture empty spaces in, for example, 'a table'.

Evidence on *learner prior knowledge* is observed during teacher ZD's lesson on kinetic molecular theory. In this lesson the teacher asked four learners to do a role-play, where they act as solid particles. After the role-play she captured the following on the board (shown in the excerpt below):

***Teacher ZD**: captures on the board under solids (Spacing, Ordering and Motion). So what can you say about the spacing in between the particles?*

***Learner** (some chorusing): there is no space*

***Teacher ZD**: With solid phase what can you say about the spaces between the particles?*

***Learner Nkosi:** there is small space between the particles*

***Learners** (some chorusing)**:** there are no spaces*

The above excerpt shows that most learners still have difficulty in conceptualising the idea of empty spaces in solids. This is evident from the circled answers from the learners. In order to make learners understand, teacher ZD showed them a sub-microscopic representation of solid on the board. This representation for teacher ZD is elaborated in chapter seven.

5.4.2.4 The categories of *representations* and *conceptual teaching strategies*

Similar to what was seen on the category of *representations* in big idea 1, this group of NUGTs also suggested the kind of representations as illustrated in figure 5.10 but did not elaborate by giving examples (which include content) on how these representations will be used.

Initial CoRe Final CoRe

Representations		
What representations would you use in your teaching strategies?	- Demonstration model - Flow diagrams	- Diagrams (flow diagrams) - Demonstration models - Simulations

Figure 5.10: Representation prompt for big idea 2

It is also not clear which representation is for macroscopic, sub-microscopic or symbolic representation. However, taking into consideration a final CoRe response such as simulations, one may assume that teachers might have had in mind the sub-microscopic representations. This is supported by what I documented in the field notes about teacher ZD's lesson about the kinetic molecular theory. The teacher used a simulation in an attempt to demonstrate both the arrangement and movement of particles in different phases. (http://phet.colarado/edu/en/simulations/states-of-matter). She further used diagrams to represent the sub-microscopic representations of particles in different phases of matter. The simulations and diagrams that were used are discussed in detail in chapter seven.

Initial Final

Teaching Strategies		
What effective teaching strategies would you use to teach this idea?	- Simulation - Videos - Models - Drawings	- Have a demonstration using water and let the learners see how the different phases change - Have flow diagrams that illustrate how the particles behave in the different states
What questions would you consider important to ask in your teaching strategies?	- What is a vacuum? - Why is it wrong to say air is empty space? - Why is it wrong to say there are no spaces between particles in a solid phase?	- How the particles of the different states are arranged? - Explain what happens to the particles when phases change - Ask what is in the spaces so as to see if they understood that there is an empty space

Figure 5.11: Conceptual teaching strategy prompts for big idea 2

Similar to the group response for big idea 1, although only appearing in the initial CoRe response, this group also gave kinds of representations with no linking explanatory notes that includes content as the answer to the prompt 'what effective strategies would you use to teach this idea'. However, this is in contrast with the final CoRe response where they elaborated further on how they would incorporate the representation in order to demonstrate specific concepts needed to be grasped by the learners as part of their *conceptual teaching strategy*. The similar manner of responding is also seen on the experts' CoRe (see Appendix F), although they selected a 'Predict-Observe-Explain (Kearney, 2004) procedure when squashing a syringe of air as a teaching approach.

This strategy involved a demonstration using water intended to show the learners how different phase change occurs which is acceptable-in the final CoRe. Firstly, the idea of phase change links well with this big idea in consideration. This is justified by the appropriate response given in the *curricular saliency* prompt 'what do you intend learners to know about this idea' - 'the spaces between the particles determine the phase of matter'. Evidence of this strategy was observed and documented as part of my field notes during teacher ZD's lesson on the kinetic molecular theory. Although she did not literally bring liquid water, ice or boiling water to class, the teacher used water as an example when explaining the concept of phase change. For example, teacher ZD said to the learners, "If a block of ice is put on a stove that is switched on, what happens to the ice or the particles?" Similar to big idea 1, second prompt of the questions considered important to ask, the questions suggested by the NUGTs in both CoRes were not conceptual relative to the ones suggested by the expert teachers. For example the conceptual question suggested in the expert CoRe is 'why can we smell onions cooked from a far distance' (see Appendix F). However, unlike for the big idea 1 this group suggested the questions that are relevant to the strategy suggested.

5.4.3 Analysis of big idea 3- *The particles are in constant motion*

Table 5.9 below shows the composition of the group for this big idea. Teacher AN did not take part in the development of the final CoRe.

Table 5.9: Composition of group for big idea 3

Initial CoRe	Final CoRe
*NN**	*NN**
MJ	*MJ*
LM	*LM*
AN	--
KT	*KT*
KK	*KK*

5.4.3.1 The category of *curricular saliency*

This group of NUGTs' response to the prompt 'what do you intend the learners to know about this idea' in the initial CoRe of figure 5.12 is acceptable because it is similar to the response documented in the CoRe of expert teachers (see Appendix F). However, what is missing from the response is an emphasis that the particles are always moving which is included the final CoRe from the answer 'particles are never stationary' and 'are in constant motion regardless of the phase they are in'. In the second prompt of the final CoRe the group realised the 'intermolecular spaces' is not the main reason learners know that particles are always moving but has to do with the ability to explain what happens in phase changes.

Initial CoRe

Curriculum Saliency	
What are the big ideas for the topic?	The Particles are in constant motion
What do you intend the learners to know about this idea?	Learner's have to understand that Particles move regardless of the State they are in.
Why is it important for learners to know this big idea?	They have to know it takes more energy to heat a solid to liquid and liquid to gas. Solids vibrate at about their rest position because of strong forces. Liquids move a bit more fast because of their weak forces between them. gases move at a high speed since there is no force between them.
What concepts need to be taught before teaching this big idea?	Knowing the different phases of matter. That matter is made of particles called molecules. And when you referring to the constant motion you referring to that of the molecules not of the subatomic particles. That when given even energy molecules will respond. One of the responses will be motion.
What else do you know about this idea (that you do not intend learners to know yet)?	That subatomic particles also are in constant motion but that's not what were refering to. ->(bending, stretching and torsion) of the board. Which is picked by instruments like infared.

Final CoRe

The particles are in constant motion
Particles are never stationary. -They share kinetic energy -There are forces that exist between the particles. -They are in constant motion regardless of what phase they are in.
-Because it explains how phase change occurs. -Makes it easier to teach the transmission of sound waves at different states of matter.
-Phases of matter -That there are empty spaces between particles that make up matter.
-You don't want to talk about Kinetic energy before they know about spaces between particles.

Figure 5.12: Curricular saliency prompts for big idea 3

In terms of concept to be taught before this big idea, the teachers gave two acceptable answers 'phases of matter and 'understanding of particles'. The final CoRe response included a new concept 'knowledge of empty spaces between particles'. In the last prompt of *curricular saliency*, the group did not clearly list the concepts or topics that need an understanding of this big idea which can't be taught now. However, in the final CoRe the teachers appropriately showed the sequencing, indicating that at this stage 'kinetic energy' in the particles is not to be discussed. Based on the improved responses in the final CoRe, this shows that this group of NUGTs has also found the category of *curricular saliency* easier to engage with.

5.4.3.2 The category of *what is difficult to teach*

It is evident in this category that teachers were not initially aware of difficulties associated with the teaching of this big idea. The response in the initial CoRe in figure 5.13 suggests they were not certain of what exactly is difficult. The response includes numerous concepts and it is not clear what exactly is difficult as they provided generic reasons as shown in figure 5.13 below.

	Initial CoRe	Final CoRe
What is difficult to teach		
What do you consider **easy or difficult in** teaching this big idea?	Difficult that a lot of factors causes the molecules to move and not just energy. That there are also forces involved. Also the average distances between solids + liquids is relatively the same but the major jump is in gases have a significant difference due to these forces.	- Hard to understand the idea that particles are always in constant motion when the object is stationary especially if the particles are in a solid state.

Figure 5.13: What is difficult to teach prompt for big idea 3

However, the final CoRe showed improvement as it specified that learners may find it difficult to imagine particles in a solid moving. This concept was also identified in the CoRe by the expert teachers in Loughran et al. (2006). In order to instil the idea of 'particles are always in constant motion', in his lesson on kinetic molecular theory teacher NN made use of simulations to show the movement of particles in different phases and in particular for a solid.

5.4.3.3 The category of *learners' prior knowledge*

In this category the teachers were able to envisage correctly what learners' misconceptions associated with teaching this big idea could be. As indicated in the figure 5.14 in both CoRes, the idea of particles particularly in solids seemed to be the one that learners do not

understand as suggested by the responses. The same response was also captured by the expert teachers in the expert CoRe (see Appendix F).

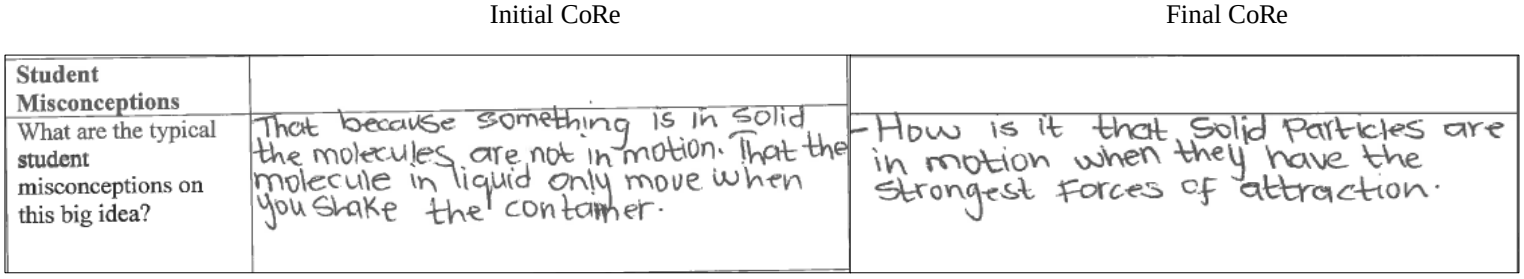


Figure 5.14: Learners' prior knowledge prompt for big idea 3

Although not explicitly elaborated, the response in the initial CoRe 'the molecules in liquid only move when you shake the container' is a common misconception held by learners. This kind of misconception may suggest the inability of learners to differentiate between macro (seen) and micro (unseen) levels. An example related to this was documented by expert teachers in Loughran et al. (2006) as students' thinking that influences the teaching of this idea. They argued that although learners encountered 'states of matter' they do not understand the ideas in terms of particle movement. A notion of melting was given as example, where learners tend to think certain particles melt.

Evidence relating to the difficulty in differentiating between macro and sub-microscopic levels was seen and documented in my field notes from teacher NN's lesson on kinetic molecular theory. The teacher asks learners to describe the motion of particles in liquids and gave an example of a glass of water. A learner indicated that the particles in liquid flow. It was clear from this response that the learner is unable to differentiate between the two levels.

5.4.3.4 The category of *representations*

Similar to all the responses seen in all the big ideas so far, teachers only gave types of representations used without elaborating on how they are used. A similar response is seen in the initial CoRe in figure 5.15 where teachers gave answers such as drawings, demonstrations with lack of explanation.

Initial CoRe | Final

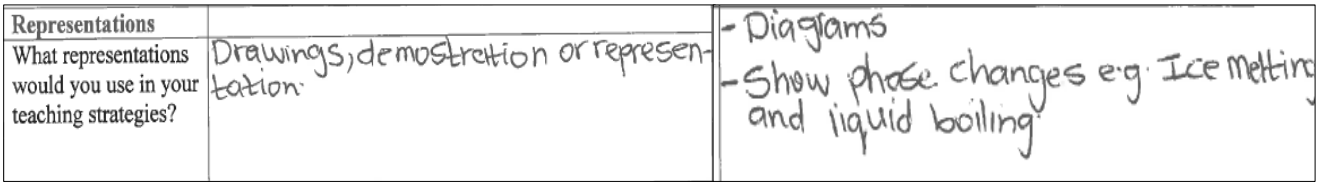


Figure 5.15: Representation prompt for big idea 3

However, in the final CoRe the group showed an improvement. They have shown a little elaboration in that, in order to show phase changes, ice and boiling water will be used. This example relates to the macroscopic representations. As indicated under the category *what is difficult to teach*, teacher NN utilised simulations to show movement of particles in different phases. Surprisingly, his group did not document this as a response in both CoRes. I am assuming that the preferred representations captured in the final CoRe could have been the influence of other teachers who were not observed but who taught other grades that teach the pre-requisite concept of the topic in consideration.

5.4.3.5 The category of *conceptual teaching strategies*

The response relating to the effective strategy selected in the initial CoRe as shown in figure 5.16 only indicated the type of representations to be utilised, which is not appropriate. This kind of response was observed in all big ideas in the initial CoRe. However, the suggested *conceptual teaching strategy* in the final CoRe is suitable for the big idea in consideration. The idea of having learners act out the motion of particles at different phases is a type of translation activity suggested in the experts' CoRe as one of the teaching approach (see Appendix F). In this case learners had to do a role-play which literally engages them.

Initial CoRe | Final CoRe

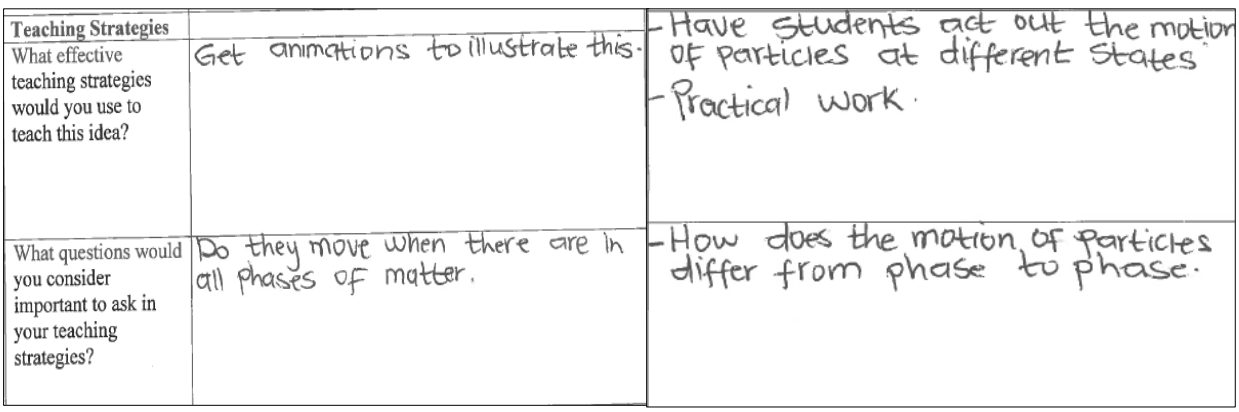


Figure 5.16: Conceptual teaching strategy prompts for big idea 3

During his lesson on the kinetic molecular theory, teacher NN divided the learners into three groups representing particles of solids, liquids and gas. The learners were asked to act out the motion of particles in their respective phase. As learners were acting out, teacher NN would engage the remaining learners to confirm or confront what was incorrect or correct about the role-play. Teacher NN's questions were related to spacing, movement and ordering/arrangement of the particles in each phase. In cases where learners acted out incorrectly, the group was requested to re-act. A case of re-acting was observed in the solid particles, where learners didn't show any movement such as vibration. It is important to emphasise that this approach was not only observed in teacher NN's lesson but in all the case study teachers. In the session of re-visitation of the particulate nature of matter during the intensive programme, the science mentor had asked the NUGTs to act out particles in different phases. I am assuming that the teachers might have learned this from their mentor during the training. The question suggested in the second prompt links well with the strategy suggested. As I indicated, in teacher NN's lesson there was evidence of encouraged learner involvement. At the same time learners were responding to the question suggested in the final CoRe.

5.5 Concluding Discussion

The findings from this chapter suggest that the NUGTs' PCK of the particulate nature of matter was starting to develop during the PDI period particularly after experiencing some teaching. The use of a CoRe forced the NUGTs to engage with the construct PCK of the topic. This can be deduced from the improved and refined prompt responses in all the categories by NUGTs' in the final CoRe.

In *curricular saliency*, the general improvement was seen from the refined answers, clearly showing that NUGTs had engaged in the teaching of the topic or its pre-requisite concepts. They found it easier to identify acceptable responses for both the pre- and post-concepts for respective big ideas. This was in contrast with the initial CoRe where (i) pre-concepts identified consisted of either raw big ideas or, to some extent not identified (ii) the post-concepts identified were without the immediate link to all big ideas of the topic. An improvement in categories *what is difficult to teach* and *learner prior knowledge* was also observed in the final CoRe. In all the groups' responses for all big ideas, NUGTs were not only able to indicate exactly *what is difficult to teach* in relation to the big idea in consideration but also included the word 'learners' as part of their explanations. Unlike the

initial CoRe where the responses were generic, the final CoRe identified the concepts considered difficult to teach and explanations that incorporated learners. The *learner prior knowledge* category showed more unpacked responses, in particular elaborating what the misconceptions are.

The categories *representations* and *conceptual teaching strategies* appeared to be challenging for all groups, with *representations* being the most difficult. The category was challenging for NUGTs. However, there were some improvements in the responses from the group engaging with big idea 2 which included suitable *conceptual teaching strategy* that links well with the big idea at hand. In terms of *representations*, most groups gave generic responses such as types of representations to be used, without linking them to specific concepts for respective big ideas. However, in the final CoRe evidence from some groups attempting to incorporate the concepts was observed. Interestingly, this finding is in contrast with the Topic Specific PCK test where the *conceptual teaching strategy* was found to be the most difficult category in both the pilot results in chapter four and NUGTs in chapter seven. The question on *representations* in a test was guided, different representations were given, whilst in the CoRe the question was more open with no suggested representations and had to relate to the big idea in consideration. It can be argued that it is because for this reason that NUGTs found the *representations* category easier in the Topic Specific PCK test than in the CoRe.

Generally, unlike expert teachers in Loughran et al. (2006) who had a full year to construct the CoRe, NUGTs had a limited time of only 1 hour for each development of initial and final CoRe. An assumption can be made that, should NUGTs have a lot of time dedicated to the CoRe development, quality responses in the *representations* and *conceptual teaching strategies* categories may be achieved. Finally, I would argue that by engaging in a CoRe pushes novice teachers to start thinking about how to teach a particular topic. The same teachers portrayed better PCK on the particulate nature of matter after engaging in the teaching of that topic. This can be deduced from evidence shown on some case study teachers' lessons and interviews. More on the case study teachers' Topic Specific PCK is described in detail in chapter seven. But prior to that, it is important to investigate the CK of the particulate nature of matter that NUGTs possess before and after engaging in the PDI, which is in the next chapter.

CHAPTER 6

6. THE ANALYSIS OF TEACHERS' CONTENT KNOWLEDGE

There is a general agreement that teachers' Content Knowledge (CK) impacts their classroom practice which ultimately contributes to the development of effective PCK. Since the main part of my study is to investigate growth in NUGTs' Topic Specific PCK, it is worth looking into the kind of the CK they possess. This takes into consideration the raw CK before and after engaging in the professional development, which includes the teaching of the particulate nature of matter. These teachers' CK is measured using the designed content knowledge test. The pre- and post-test performance of the NUGTs is analysed and compared.

6.1 Introduction

According to Cochran and Jones (1998) science education scholars view CK as one of the categories that falls under subject matter knowledge. The authors described CK as facts and concepts of subject matter. Thus in my study the facts and concepts of the topic particulate nature of matter termed CK test shall be looked into. The purpose of the CK test is to assess NUGTs' conceptual understanding of the particulate nature of matter. Their initial CK before engaging in the PDI (including teaching for 8 months) and after is compared. Both the pre- and post-tests were similar. The pre-test was administered to the NUGTs (n=16) during the intensive training sessions prior to teaching in schools. The post-test was administered to twelve teachers during their first year of their teaching in the third school term period. Both the pre- and post-tests were written under my supervision except for three teachers who could not attend the last meeting. These remaining teachers wrote the test at different times and emailed it to me. One teacher dropped out of the programme and is no longer in the teaching field. Therefore the total number of NUGTs who wrote the post-test is 15.

6.2 The structure of the CK Test

The CK test consists not only of commonly known misconceptions but also of questions that require confirmation of correct understanding of the particulate nature of matter. It was also designed to meet the requirements of the current South African grade 10 curriculum. As shown in Table 6.1, the topics included classification of matter into pure substances, mixtures, states of matter and the kinetic molecular theory, the atom and its basic structure, as well as isotopes. The testing of content paid particular attention to the use of particulate representations and relating them to micro ideas. Table 6.1 below shows the type of questions

asked. However, the content description is specified in chapter three. The full copy of the CK test is in Appendix C

Table 6.1: Description of content of the CK test

Question number	Content of question
1	Differentiating pure substances, mixture, atoms and molecules
2	To identify characteristics of different particulate representations
3	Draw microscopic representations of oxygen in solid, liquid and gas
4a	Recognise that molecules of a pure substance are identical
b	Recognise that Molecules have "empty spaces" between them
c	The mass of a molecule does not change regardless of a phase
d	The forces of attraction between molecules are different in different phases
5a-c	Structure of the atom
d	Identifying isotopes
e	Conceptual understanding of average atomic mass

6.3 Quantitative analysis of the CK Test

The entire test items for NUGTs' both pre- and post-tests were marked by me, using the marking memorandum. Each teacher was assigned a research code. All the marked tests were then given to the chemistry specialist for peer validation for accuracy of the content and confirming the consistency of marking done by me. The scores obtained from the raters were compared using MedCalc statistical software for inter-rater agreement–Kappa (www.medcalc.org/kapp). An agreement rate (K value) of 75.7% indicating a good strength was reached for the pre-test while a rate of 87.7% (very good strength) was obtained for the post-test (see Appendix I). In cases where there were differences, particularly with a large margin, the raters got together and reached an agreement in terms of the scoring. The validation results (i) confirmed the correctness of the content (ii) found that I had counted the total marks of 106 instead of 105 (for the pre-test) and this was taken into account for post-test marking.

The total mark for the test was 105 which were converted to a percentage as shown in Table 6.2 below. Teachers marked with an asterisk taught the topic – the particulate nature of matter. They were followed and mentored and constituted the case study teachers in my study.

Table 6.2: NUGTs' Pre & Post scores for the CK test (N=15)

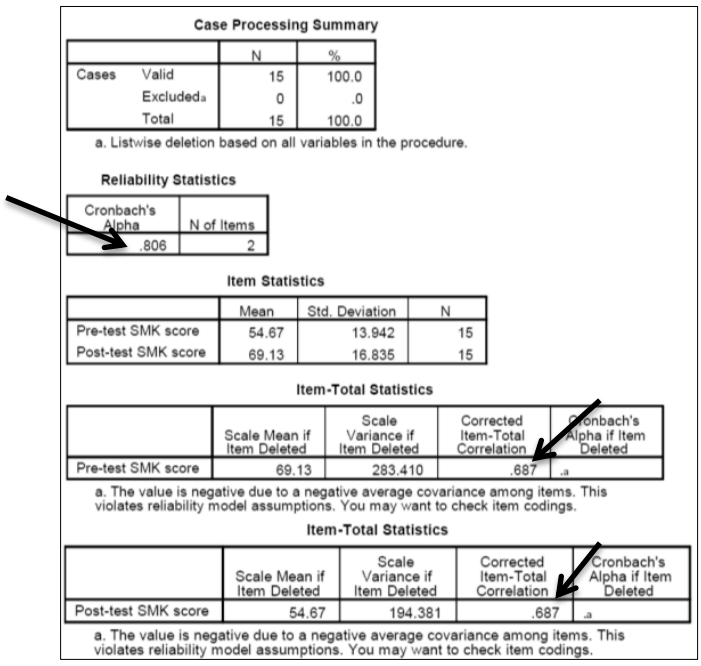
NUGTs	Pre-Score (%)	Post-Score (%)	Hake Factor, *h*
*ZD	46	88	0.78
*NN	60	93	0.83
MJ	56	86	0.68
*SS	66	89	0.67
KT	36	52	0.25
WM	36	50	0.22
MB	33	47	0.16
*DN	60	72	0.30
TM	81	91	0.91
TC	46	56	0.19
TS	51	55	0.08
KK	56	59	0.07
LM	71	73	0.07
AN	52	54	0.04
SR	70	72	0.07
Mean score	**54.66**	**69.13**	

Table 6.2 shows the improvement trend in NUGTs pre and post CK's scores. In order to deduce gain in NUGTs pre and post-test, a normalised gain equation (h=post-pre/1-pre) was used. There was an improvement in all NUGTs' CK of the particulate nature of matter. The first three teachers with largest increase (except teacher TM and MJ) are case study teachers (ZD, NN & SS). Teacher TM showed a large margin although not been able to teach the topic. This is attributed to the fact that she had an opportunity to teach grade 10 before. A notable exception is also seen in teacher MJ, who also showed an improvement by a large margin but did not teach the topic. As indicated in chapter 5, teacher MJ taught grade 10 but was not allocated the teaching of the knowledge area of 'Matter & Materials', where the particulate nature of matter is found. Teacher MJ observed a senior grade 10 teacher teaching the particulate nature of matter. The topics she taught in grade 10 were chemical bonding, electricity and electrostatics. It can be assumed that her experience in teaching other topics, that require her understanding of the particulate nature of matter in grade 10, might have contributed to the observed shift in her CK of the topic at hand, though her observation of the topic may have been a factor.

Teacher DN, who is also a case study teacher, showed a moderate improvement of 0.3%. The improvement in case study teachers' CK could be attributed to the fact that they taught the particulate nature of matter in grade 10. The remaining NUGTs also showed slight improvement from the pre- to the post-test. This improvement may be attributed by their experience in teaching other grades such as 9 (pre-requisite concepts) and 11 & 12 (some

concepts that require the understanding of the particulate nature of matter) as shown in chapter five.

As indicated in chapter three, the CK test raw scores were subjected to SPSS statistic in order to check the internal consistency of a scale. This was achieved by using a commonly used indicator of internal consistency - Cronbach's alpha coefficient. Figure 6.1 shows a summary of the results on the reliability of a scale.



Case Processing Summary

		N	%
Cases	Valid	15	100.0
	Excluded[a]	0	.0
	Total	15	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.806	2

Item Statistics

	Mean	Std. Deviation	N
Pre-test SMK score	54.67	13.942	15
Post-test SMK score	69.13	16.835	15

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Pre-test SMK score	69.13	283.410	.687	.a

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Post-test SMK score	54.67	194.381	.687	.a

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Figure 6.1: Reliability of CK test items

The Cronbach's alpha coefficient of 0.8 was achieved and is indicated by an arrow in figure 6.1. This means that the scale's internal consistency is considered reliable with the sample because the value is above 0.7. Other information of interest is the column marked *corrected item-total correlation* which shows the degree to which to each item correlates with the total scores. Both values obtained are more than 0.3 (indicating that the items are measuring the same underlying single construct.

However, in order to assess whether the difference is significant of Wilcoxon Signed Rank Test, a non-parametric statistic was applied. Non-parametric statistical tests are suitable for small samples which do not meet the assumptions of the parametric statistics. The reason for using the statistic is that it is designed for repeated measures under two different conditions, in this case referring to the pre- and post-tests. Figure 6.2 below shows the results of calculation of the statistical difference and its significance.

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Post-test SMK score - Pre-test SMK score	Negative Ranks	0a	.00	.00
	Positive Ranks	15b	8.00	120.00
	Ties	0c		
	Total	15		

a. Post-test SMK score < Pre-test SMK score

b. Post-test SMK score > Pre-test SMK score

c. Post-test SMK score = Pre-test SMK score

Test Statisticsb

	Post-test SMK score - Pre-test SMK score
Z	-3.412a
Asymp. Sig. (2-tailed)	.001

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Figure 6.2: Comparison of the CK pre and post-tests for significance

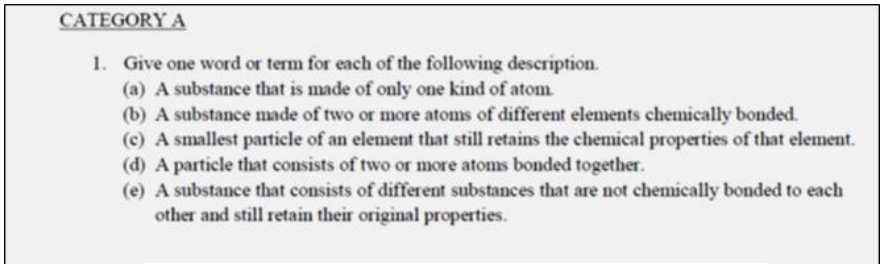
The Z value is -3.412 with a significant level of p=0.001. Thus the probability value (p) is significant at below the 0.1% level. There is thus a highly statistically significant difference between the pre- and post-CK- tests.

However, the pre-scores can be considered low for a group of science graduates since grade 10 level concepts are being tested and all the teachers had passed a minimum of first year chemistry. The pre-scores also seem unrelated to their subject background as the top scorer, TM qualified in biology while one of the bottom scores, KT was a chemistry major as shown in the demographical information of NUGTs in chapter three (table 3.2). The post-test score can be considered reasonable as compared to the pre-test score and this is evidenced by the high mean score in Table 6.2. Although the top post-test scorer NN is qualified in physics and chemistry, the second and third top scores after NN such as TM and SS are biology majors. This implies that the post-scores also seem unrelated to their subject background, as most of the top scorers were qualified in biology while one of the bottom scores, WM was chemistry major. Teacher NN was a top scorer in the post-test while TM, the top scorer in the pre-test is second highest. It is thus worth analysing the teachers' responses in more detail. It is important to indicate that since most of the NUGTs did not teach grade 10, the qualitative analysis below will concentrate mostly on those teachers who were able to teach the topic- the case study teachers. Where a non-case study teacher's example of work is utilised, a justification for choosing that particular teacher will be made explicit. However, where it is

appropriate, answers for the entire group are collected and analysed for trends. Some qualitative analysis of the questions follows below.

6.4 Qualitative analysis of the CK Test

Figure 6.3 investigates whether NUGTs' possessed the understanding of basic descriptions of types of particles such as atoms, molecules, pure substances and mixtures in a given term or one word.



CATEGORY A

1. Give one word or term for each of the following description.
   (a) A substance that is made of only one kind of atom.
   (b) A substance made of two or more atoms of different elements chemically bonded.
   (c) A smallest particle of an element that still retains the chemical properties of that element.
   (d) A particle that consists of two or more atoms bonded together.
   (e) A substance that consists of different substances that are not chemically bonded to each other and still retain their original properties.

Figure 6.3: Formulation of question 1

Table 6.3 shows how NUGTs responded to the sub-questions. The sub-question marked with a tick (√) indicate that a correct response was achieved by the teacher while a cross (X) indicate that a teacher presented an incorrect response. I have included a column reflecting the total number of correct responses, which gives an idea of the NUGTs' overall understanding of question 1. The last row, showing the total number of teachers with incorrect responses gives an idea of the level of difficulty for each sub-question and also which sub-questions were the most challenging. The correct answers are provided in the first row next to the question number.

Table 6.3: NUGTs' responses for question 1

NUGTs	Question 1a (element)		Question 1b (compound)		Question 1c (atom)		Question 1d (molecule)		Question 1e(mixture)		Total number of correct response	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
MJ	√	√	**X**	√	**X**	√	**X**	√	√	√	2	5
*ZD	X	√	√	√	**X**	√	**X**	√	√	√	2	5
WM	√	√	√	√	**X**	√	**X**	√	**X**	√	2	5
TM	√	√	√	√	√	√	√	√	√	√	5	5
LM	√	√	√	√	√	√	√	√	√	√	5	5
*SS	√	√	√	√	√	√	√	√	√	√	5	5
*DN	√	√	√	√	X	√	√	√	√	√	4	5
*NN	√	√	√	√	√	√	√	√	√	√	5	5
MB	√	√	√	√	√	√	**X**	**X**	√	√	4	4
SR	√	√	√	√	√	√	**X**	√	**X**	√	3	5
KK	**X**	**X**	**X**	**X**	√	√	√	**X**	√	√	3	2
AN	√	√	√	√	√	√	√	√	√	√	5	5
TS	√	√	√	√	√	√	√	√	**X**	√	4	5
TC	√	√	**X**	√	√	√	**X**	√	√	√	3	5
KT	√	√	√	√	**X**	√	√	√	**X**	**X**	3	4
Total number of teachers with incorrect responses	**2**	**1**	**3**	**1**	**5**	**0**	**6**	**2**	**4**	**1**		

Table 6.3 shows that there is a decrease in number of incorrect responses in the post-test for all the questions as compared to the results in the pre-test. With the exception of teacher TM, LM, SS, NN and AN, who achieved all questions correct for both pre and post-test, the other seven teachers also showed an improvement in the post-test by achieving all the questions correct. Although Teacher KT did not obtain all five questions correct, she has shown an improvement. It can also be seen in table 6.3 that teacher MB did not show any shift in her CK in both the pre- and post-test. She obtained the same score in both tests and still showed poor understanding in question 1d. Interestingly, unlike the rest, teacher KK portrayed better CK in the pre-test rather than the post-test although currently teaching science. Overall these results imply that there was a shift in most NUGTs as far as question 1 is concerned.

For the pre-test, nearly half of the teachers were unable to identify 'a particle that consists of two or more atoms bonded together' as a molecule. Most of the incorrect responses to question 1d provided the answer "compound", showing the teachers' inability to differentiate macro and micro levels of description. However, this was not the case in the post-test results as all teachers except for MB and KK were able to identify a 'molecule' correctly. It is worth indicating that teacher KK, however, was able to identify a 'molecule' in the pre-test which he could not in the post test. This might be attributed to the fact that KK may have guessed the answer. The result for MB suggests that she is unable to differentiate macro and micro levels of description, having given 'compound' as the answer in both tests.

In terms of question 1c that states 'a smallest particle of an element that still retains the chemical properties of that element', five teachers in the pre-test presented incorrect answers. They gave responses such as protons, nucleus, molecule and electrons. However, such responses show that teachers have a better understanding that the answer to the question is at micro level although being incorrect. Incorrect responses such as protons, nucleus and electrons were amongst those given by the teachers. I am therefore assuming teachers were pre-occupied with the categories of the atom, hence the responses given for this particular question. However, this has completely changed in the post-test results as all the teachers provided the correct response for question 1c.

It was also noted in the pre-test that several teachers did not know what a mixture is in question 1e. They gave incorrect responses such as compounds and elements. Although the answers were all at a macro level, it became clear that they simply didn't know. But in the post-test there was an improvement, as only one teacher was unable to identify a mixture.

Finally, in the post-test results most teachers found the understanding of what an element is easiest, while question 1c about an atom was found to be less difficult. However, the conceptual understanding of a 'molecule' through differentiating between macro and micro levels remained the most difficult and challenging for teachers in both tests. The interpretation of corpuscular characteristics such as macro and micro were found to pose a challenge for pre-service teachers (Van Driel et al., 2002).

Question 2 tested the teachers' ability to interpret different representations of particles and consisted of eight sub-questions, as shown in figure 6.4 below.

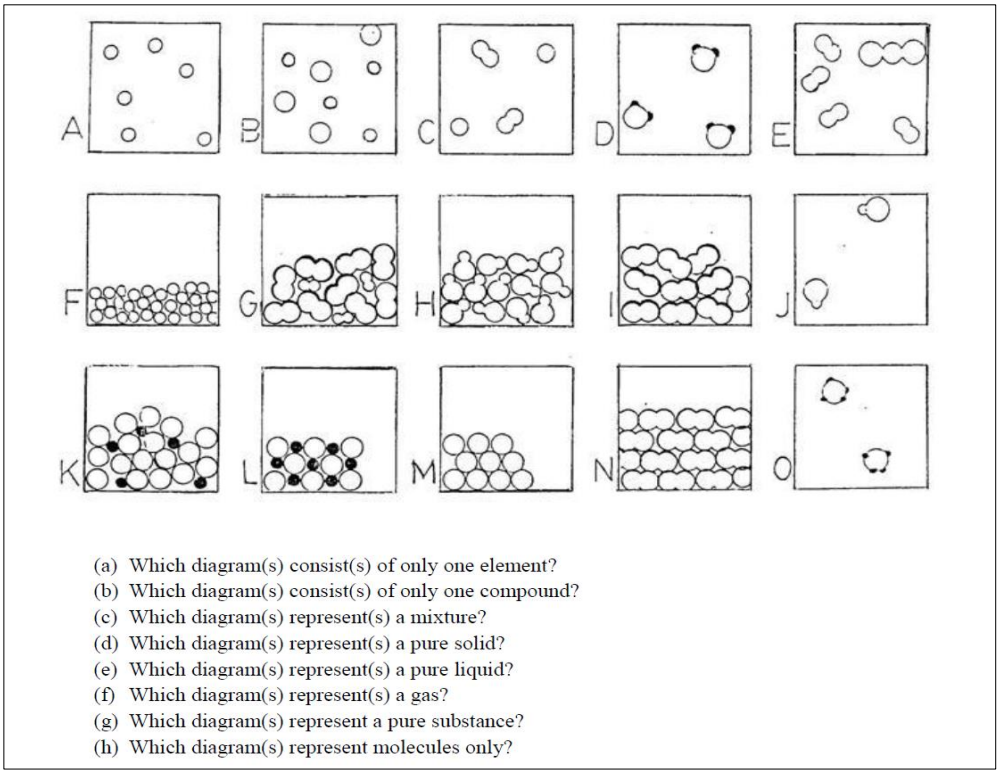


Figure 6.4: Formulation of question 2

More than one of the given representations in Figure 6.4 could be applicable to each question. For example, there are five correct responses to 2(a) which are A, I, F, M and N. The existence of multiple answers made the analysis rather complex. Therefore teachers' responses were classified as correct (if more than half were correct), partially correct (if less than half were correct) and incorrect (if none were correct). This is shown in Table 6.4 below on how teachers' with different responses were categorised.

Table 6.4: Categorisation of teachers' responses to question 2

Sub-questions	Expected number of correct answers	Considered completely correct answer	Considered partially correct answer	Considered incorrect answer
a	5	At least 3 correct	Only 1 or 2 correct	No correct answer(s)
b	5	At least 3 correct	Only 1 or 2 correct	No correct answer(s)
c	5	At least 3 correct	Only 1 or 2 correct	No correct answer(s)
d	3	At least 2 correct	Only 1 correct	No correct answer(s)
e	5	At least 3 correct	Only 1 or 2 correct	No correct answer (s)
f	7	At least 4 correct	Only 1 or 2 or 3 correct	No correct answer(s)
g	10	At least 5 correct	Only 1 or 2 or 3 or 4 correct	No correct answer(s)
h	8	At least 4 correct	Only 1 or 2 or 3 correct	No correct answer(s)

Therefore for this analysis, I decided to categorise teachers' responses as completely correct (C), partially correct (P) and incorrect (X). In order to have an indication of teachers' understanding, a table of results showing their performance was formulated. Table 6.5 below shows a summary of teacher responses for both pre and post-test for each sub-question. The responses were later analysed qualitatively in order to investigate the nature of their understanding and possible causes.

Table 6.5: NUGTs' responses for question 2

NUGTs	Question 2a		Question 2b		Question 2c		Question 2d		Question 2e		Question 2f		Question 2g		Question 2h	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
MJ	C	C	C	C	C	C	C	C	P	C	C	C	C	C	C	C
*ZD	C	C	C	C	C	C	C	C	C	P	C	C	P	C	P	C
WM	C	C	C	C	P	C	C	P	P	P	P	C	P	P	X	P
TM	C	C	C	C	P	C	P	C	P	C	C	C	C	C	C	C
LM	C	C	C	C	C	C	C	C	X	P	C	C	C	C	C	C
*SS	C	C	C	C	C	C	P	C	X	P	C	C	C	C	C	C
*DN	C	C	C	C	P	C	C	C	C	C	C	P	P	P	C	C
*NN	C	C	C	C	C	C	C	C	C	P	C	C	P	C	C	C
MB	P	P	P	P	P	P	P	P	X	P	P	P	P	P	X	X
SR	C	C	C	C	C	C	P	P	P	C	C	C	P	P	C	C
KK	C	C	P	C	P	C	C	P	P	P	C	C	P	P	P	C
AN	P	P	P	P	P	P	P	P	X	X	P	P	P	P	P	P
TS	C	C	P	P	P	P	X	P	X	C	P	C	C	P	P	P
TC	P	C	P	P	P	P	X	P	P	P	P	P	P	P	P	P
KT	C	C	P	X	P	P	P	C	P	P	C	P	P	P	C	C
Number completely correct	**12**	**13**	**9**	**10**	**6**	**10**	**7**	**8**	**3**	**5**	**10**	**10**	**5**	**8**	**8**	**10**
Number partially correct	**3**	**2**	**6**	**4**	**9**	**5**	**6**	**7**	**7**	**9**	**5**	**5**	**10**	**7**	**5**	**4**
Number incorrect	**0**	**0**	**0**	**1**	**0**	**0**	**2**	**0**	**5**	**1**	**0**	**0**	**0**	**0**	**2**	**1**

It can be noted in table 6.5 that generally there was an improvement in almost all the questions in terms of correctness in the post-tests as compared to the pre-tests. This has to some extent reduced the number of partially correct responses. The performances in questions d, e and f are particularly noteworthy in table 6.5. They relate to particulate representations of the three states of matter. It is evident in the pre-test that only 3 teachers were confidently able to identify particulate representations of pure liquids (2e) and 5 teachers could not identify any of the representations. On the other hand, recognising representations of pure gases and, to a lesser extent, solids presented far less of a challenge. Most teachers with incorrect responses identified diagrams that represent gases as pure liquids whilst few identified solids. In terms of gases this is evident in question 2f, where the number of completely and partially correct responses remained the same. This indicates that some NUGTs may tend to think that they are pure liquids. Although there was a slight improvement in teachers who confidently identified pure liquids in the post-test, the majority of the teachers are still not confident hence were scored under partially correct response. This is thought to be due to the incorrect representations used in many school text books like the example in figure 6.7 below. This shows that most teachers do not know how molecules are arranged in different phases of matter, which is influenced by forces holding them together.

Table 6.5 shows that respondents presented a minority of correct responses for questions 2c and 2g in the pre-test. However, there was a shift in the post-test where a number of teachers provided a majority of correct responses. Similar to what was observed in the pre-test, for example, in question 2c where teachers were expected to identify diagrams representing mixtures; most teachers indicated diagrams showing a single compound as mixtures. In question 2g, teachers classified mixtures as pure substances. This suggests that these teachers are unable to recognise the difference between particulate representations of mixtures and compounds, which was also the case in question 1. While on the representations, it would be interesting to see how NUGTs draw the representations sub-microscopically. This is discussed in the next question below.

For question 3, teachers were expected to draw sub-microscopic representation of oxygen as heated from a solid to a liquid and to a gaseous state. A space-filling representation which represents a single  molecule was to be used. It was specified that only 9 molecules are to be drawn in the box when representing each of the states. Unlike solids, in both pre- and post-tests teachers did not encounter any difficulties in representing gaseous

oxygen. This could also be supported by teachers' responses in table 6.5 in question 2f), where none of the teachers incorrectly identified diagrams representing gas in both pre- and post-tests. However, most teachers who found the representation of solid to be a challenge in the pre-test improved in the post-test. One of those teachers is ZD's pre- and post-test, whose responses to a solid sub-microscopic representation of oxygen is shown and discussed in figure 6.5 below.

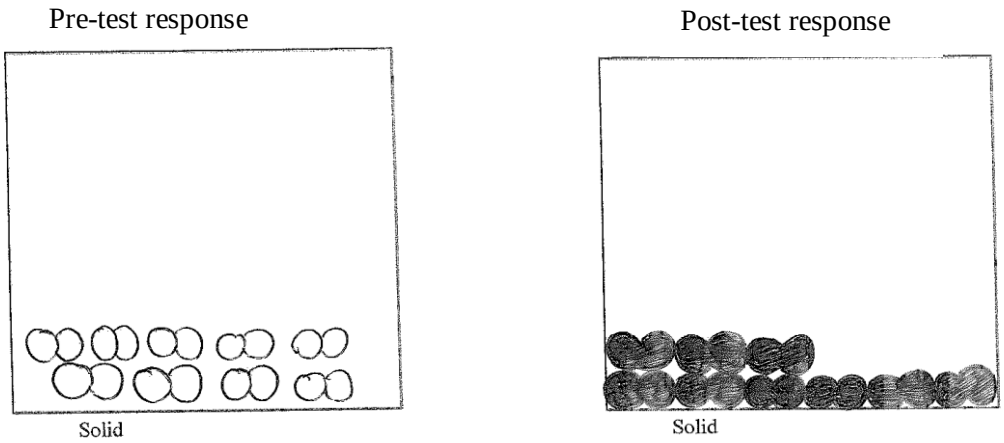


Figure 6.5: Teacher ZD pre- and post-responses to question 3

Prior to discussing teacher ZD's response, it should be made explicit that the discussion in this question is not taking into account the pattern/shape of the solid but the intermolecular distance between the particles. This is restricted because unlike crystalline solids, amorphous solids which are also solids do not have a fixed shape. Therefore this is posing a challenge in discussing pattern/shape of particles in this regard.

In the pre-test teacher ZD showed the representation of most solid particles 'not touching'. This is an incorrect representation because in solids particles are in contact and have small intermolecular distance between them. However, in the post-test teacher ZD portrayed a correct representation of the solid phase. It can be seen in the post-test response that the particles in solid are in contact and that the intermolecular distance is smaller as compared to the pre-test response. The other observation is that teacher ZD in the pre-test response might not have seen the importance of using exactly the same key ●● given. However, in the post-test she used the same space filling representation key. All of the changes and improvement seen in the post-response could be attributed to the teaching experience.

Still on the same question is another scenario of teacher NN who displayed a correct response for the solid representation of particles in the pre-test but portrayed the incorrect one for the post-test as shown in figure 6.6 below. It should be mentioned that this is a unique case because one would expect that after engaging in some teaching, a teacher should even improve further from what he/she initially understood. But this was not the case with teacher NN.

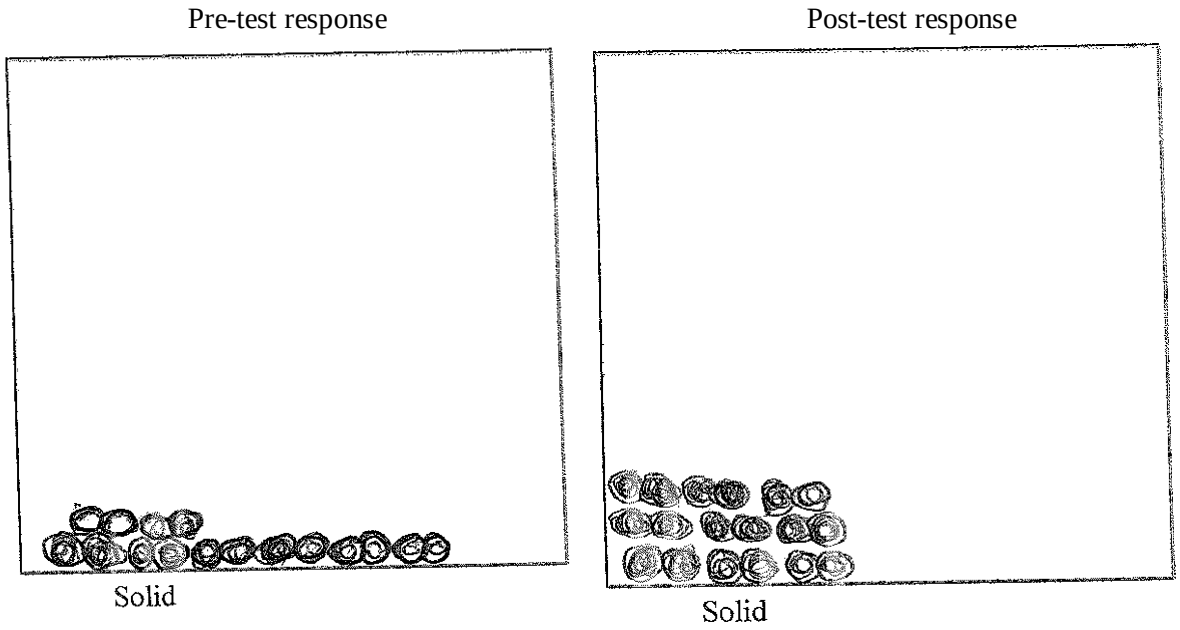


Figure 6.6: Teacher NN responses to question 3

In the pre-test response teacher NN correctly showed the particles of solid touching one another. He also used the space filling representation key given even though it was not properly shaded. However, after being exposed to some teaching and in particular to grade 10 particulate nature of matter, teacher NN presented an incorrect response in the post-test response. His response in the post-test showed the solid particles which are not in contact (not taking in consideration pattern/shape as indicated earlier). It is assumed that teacher NN might have been using some school textbooks which represent solids particles not in contact or touching. This might have influenced his understanding of sub-microscopic solid particles. Figure 6.7 shows an example extracted from a prescribed grade 10 textbook (Kelder, 2005) indicating three states.

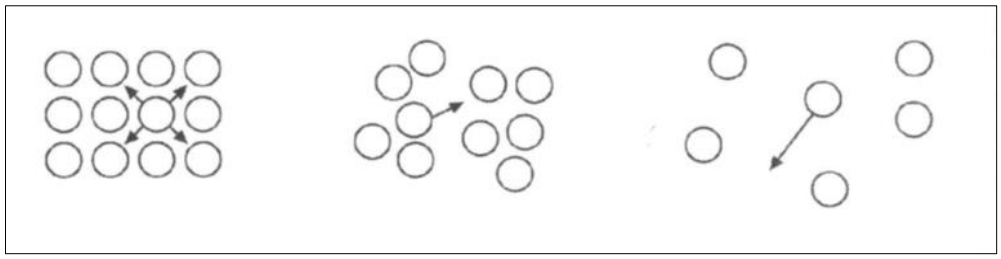


Figure 6.7: Extract (1) from a prescribed grade 10

The solid representation in figure 6.7 resembles the one teacher NN gave in his post response to the question in terms of particles not being attached. Although one can argue that figure 6.7 intended to show intermolecular distance between all three phases which is correct. However, the solid and liquid representations are misleading since the particles are not in contact.

While on the assumption that teaching experience might have influenced both teacher ZD and NN, teacher SS also provided response in the post that might also possibly be linked to the experience gained. Figure 6.8 shows teacher SS's responses on both solid and liquid representations for the pre- and post-test.

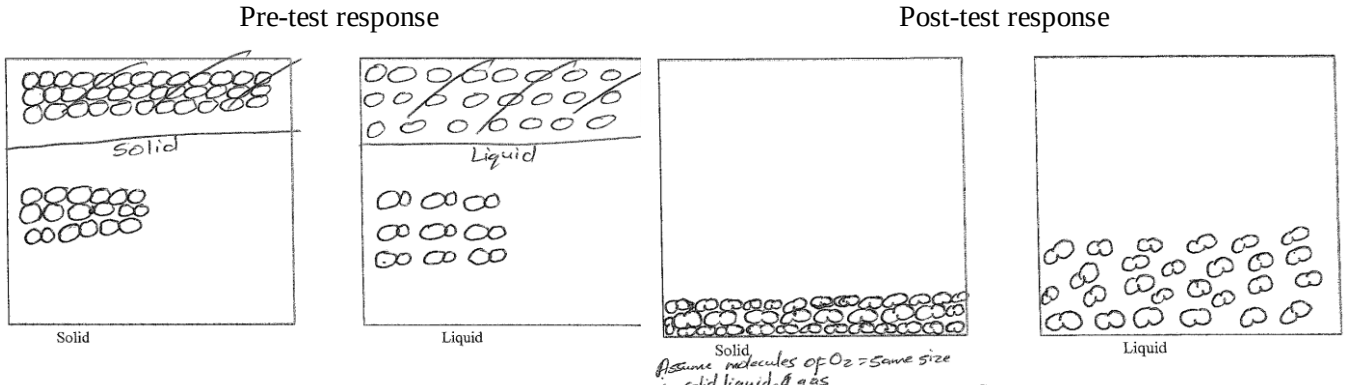


Figure 6.8: Teacher SS responses to question 3

In representing both the solid and liquid oxygen, teacher SS's pre-response shows that he initially intended to draw the representations of the particles towards the top of the box. It is therefore assumed that his initial pre-responses were cancelled as can be seen in figure 6.8 due to realisation of the incorrect space filling representation key used. Teacher SS opted to draw the representations of 9 molecules in the middle of the box for both states. I am assuming that if it was not for the mistake committed, he would have drawn the representations towards the top of the box. As for the post-response, teachers SS showed a

completely different answer from the pre-test. Firstly, teacher SS decided to place both the representations of the two states at the bottom of the box. Secondly, instead of drawing 9 molecules in each representation as required according to the instruction on the question he opted to draw more. It can also be seen in the post-response that teacher SS clearly wrote that *"assume molecules of O_2=same size in solid, liquid & gas"* showing that he is aware that the size of molecules, irrespective of the phase remains the same. An assumption can be made that teacher SS's teaching experience might have influenced his responses in the post-test. The idea of placing particles at the bottom of the container although it doesn't matter can be seen in most high school science textbooks (e.g. Kelder, 2005). An example is shown below in figure 6.9.

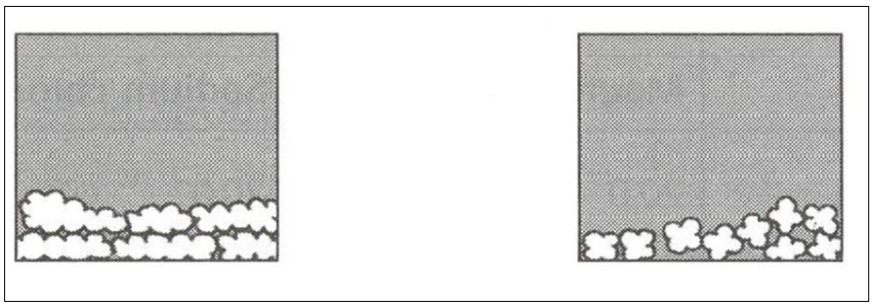


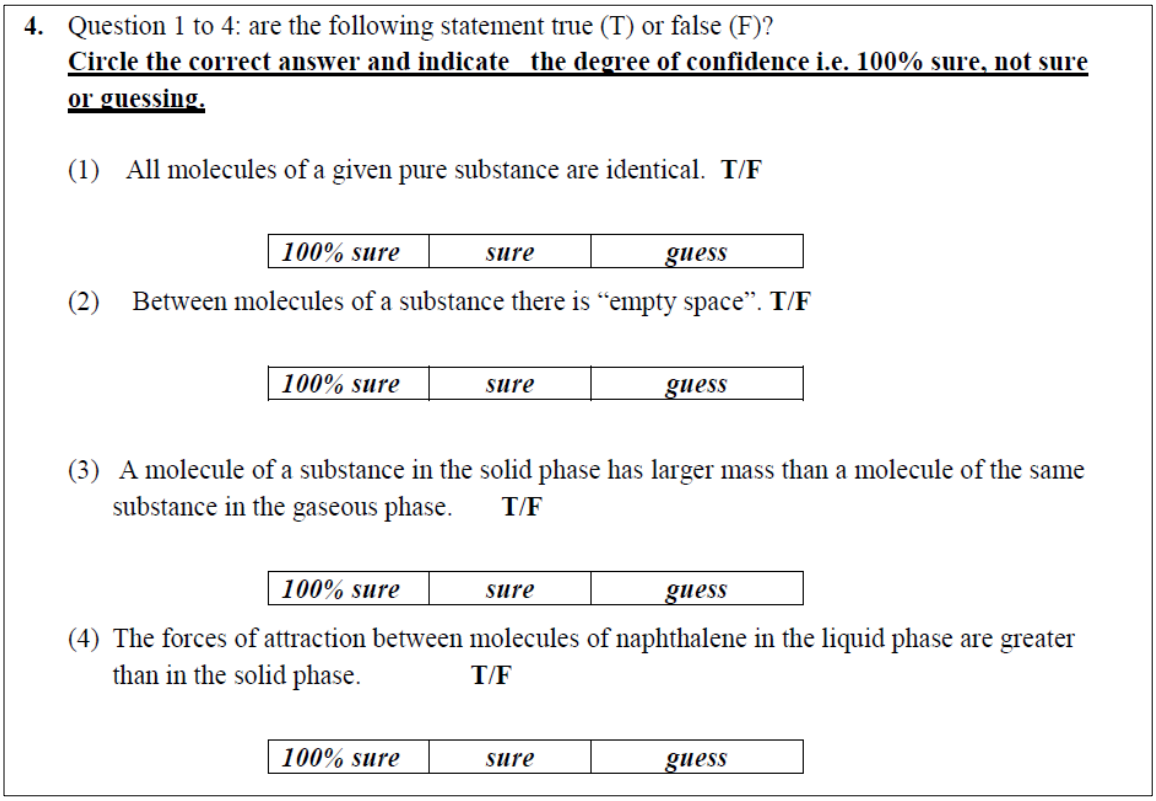
Figure 6.9: Extract (2) from a prescribed book grade 10 textbook (Kelder, 2005)

Some textbooks also show the particles occupying most of the bottom of the container. This might be the reason teacher SS opted for more than 9 molecules. It is therefore assumed that SS might have been using some books similar to the one shown in figure 6.9. Teacher SS has emphasised in the post-response that the oxygen molecules have to be of the same size in all the three states. However, in the pre-response this was not taken into account as can be seen in figure 6.8. It appears that his knowledge and understanding of the properties of a pure substance has improved.

Question 4 of the content test consists of four true/false statements. The NUGTs were also instructed to indicate the degree of confidence as, for example, either 100% sure, sure or guess. This question intended to investigate whether teachers will recognise that:

1) Molecules of a pure substance are identical
2) Molecules have "empty spaces" between them
3) The mass of a molecule does not change regardless of a phase
4) The forces of attraction between molecules are different in different phases

Question 4 from the content test is shown in figure 6.10 below.



4. Question 1 to 4: are the following statement true (T) or false (F)?
Circle the correct answer and indicate the degree of confidence i.e. 100% sure, not sure or guessing.

(1) All molecules of a given pure substance are identical. **T/F**

100% sure	*sure*	*guess*

(2) Between molecules of a substance there is "empty space". **T/F**

100% sure	*sure*	*guess*

(3) A molecule of a substance in the solid phase has larger mass than a molecule of the same substance in the gaseous phase. **T/F**

100% sure	*sure*	*guess*

(4) The forces of attraction between molecules of naphthalene in the liquid phase are greater than in the solid phase. **T/F**

100% sure	*sure*	*guess*

Figure 6.10: Formulation of question 4

For purposes of analysis, all teachers' pre-test and post-test responses for question 4 shown in figure 6.10 were analysed. A breakdown on how each teacher responded for each question in both tests assisted in categorising the types of response and also takes into account the level of confidence. The categories are correct 100% sure, correct sure, guess right, guess wrong, incorrect sure and incorrect 100% sure. Table 6.6 shows how the teachers responded to question 4 in their pre- and post-test.

Table 6.6: Category of NUGTs' pre and post-tests

	Q4(1)		**Q4(2)**		**Q4(3)**		**Q4(4)**	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Correct 100% sure	8	9	1	6	6	5	6	8
Correct sure	6	5	5	5	3	6	3	4
Guess right	0	0	5	1	3	1	3	1
Guess wrong	0	0	0	0	0	0	1	0
Incorrect sure	1	1	3	2	2	2	1	2
Incorrect 100% sure	0	0	1	1	1	1	1	0

Generally there was an improvement in the post-test responses in almost all the questions in terms of correctness and level of confidence. More teachers in the post-test responses are confident in terms of knowing that molecules of a pure substance are identical. This shows growth in their conceptual understanding of the concept. It can also be depicted that sub-question 1 remained the easiest for the majority of teachers as compared to the rest of the questions. They have recognised in both pre- and post-test responses that molecules of a given substance are identical. In addition also a few teachers, although not 100% sure, provided correct responses indicating that they may have a better understanding of the concept. This assumption might also be supported by the fact that only one teacher retained a misconception as she retained it as an incorrect response and yet was sure.

Sub-question 2 posed a challenge for teachers in the pre-test responses as can be seen in table 6.6. Only one teacher was able to correctly and confidently recognise that 'there is empty space between molecules of a substance. However, in the post-test responses almost 40% of teachers correctly and confidently recognised that. This has also led to reduction in the teachers who guessed right (only one as compared to the five in the pre-test response).

Out of all the 4 sub-questions, teachers seem to have more misconceptions on sub-questions 3 and 4. Sub-question 3 has the highest number of teachers with misconceptions (2 incorrect sure and 2 incorrect 100% sure) in the post-test response. These teachers do not know that the mass of a molecule remains the same regardless of its phase/state. Some teachers' continue to have misconceptions about forces of attraction between molecules in sub-question 4. Even sub-question 2, although it showed an improvement, also appeared to be a challenge for some teachers. About three teachers (2 incorrect sure and 1 incorrect 100% sure) continue to have a misconception in their post-test responses.

The graphical representation below in figure 6.11 displays the results from table 6.6 where the following categories are combined as follows:

- Correct 100% sure and correct sure becomes correct sure
- Incorrect 100% sure and incorrect sure becomes incorrect sure

However, the guess categories remained separate. It should be indicated that where the score in table 6.6 is zero, the colour shading will not be visible on the graph in figure 6.11.

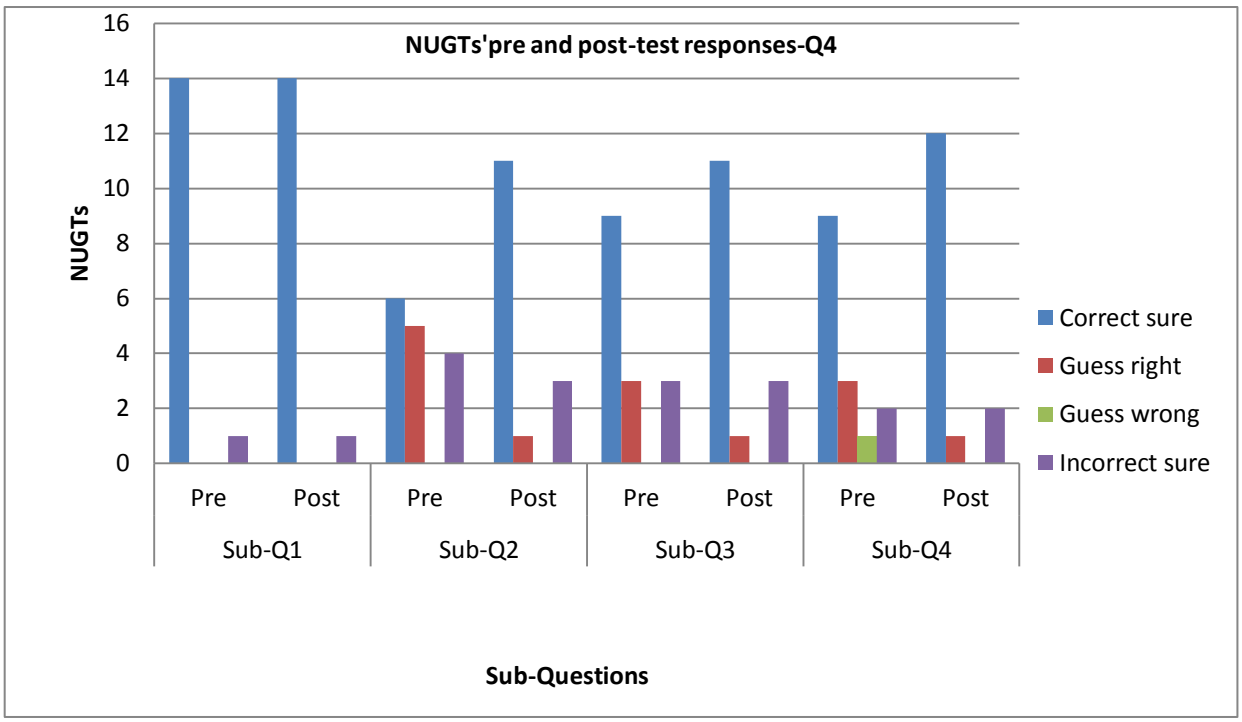


Figure 6.11: NUGTs' pre and post-tests responses with combined categories

It can be deduced from figure 6.11 that generally there was very little guessing in the post-test. This led to an increase in correct sure responses for most sub-questions which implies better understanding of the concepts asked.

An example of teachers' work utilised in the discussion to follow is of teacher WM. She is not one of the case study teachers. Her response was chosen and is discussed in this regard because it demonstrates poor understanding of the relationship between forces of attraction and the intermolecular distance. A breakdown of teacher WM's responses for each question is given in table 6.7. It can be seen that she has a misconception in sub-question 1 & 4, as she displayed an incorrect response and yet showed a level of confidence (sure) in both tests. It can therefore be assumed that she might not have a better understanding of sub-questions 2 & 3 as she moved from correct and guess right to incorrect sure for both questions.

Table 6.7: Breakdown of Teacher WM's responses

	Sub-Questions of Question 4							
	Q1		**Q2**		**Q3**		**Q4**	
Teacher	Pre	Post	Pre	Post	Pre	Post	Pre	Post
WM	Incorrect sure	Incorrect sure	Correct Sure	Incorrect sure	Guess right	Incorrect sure	Incorrect sure	Incorrect sure

Sub-question 4 intended to find out if teachers understand that the forces of attraction between molecules of naphthalene differ in different phases. The correct response is that forces of attraction between molecules in liquid phase are weaker than the solid. However, for both pre- and post-tests teacher WM presented confidently an incorrect response. In the case of question 3, which requested teachers to draw the sub-microscopic of oxygen in three different phases, teacher WM showed the correct response as shown in figure 6.12 below.

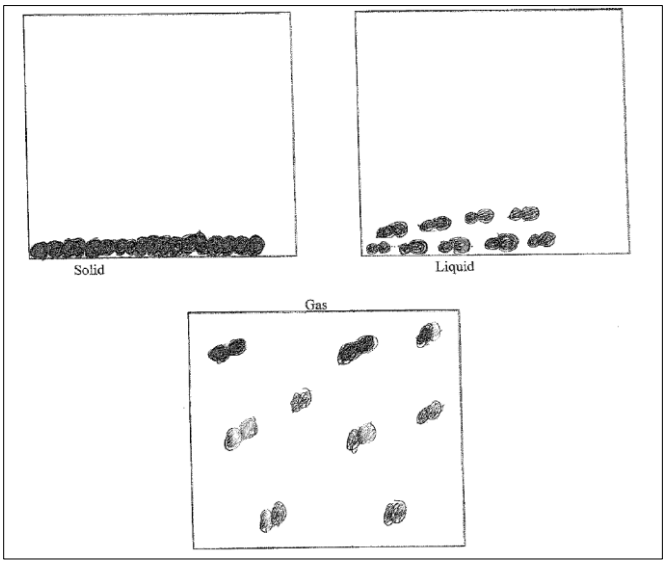


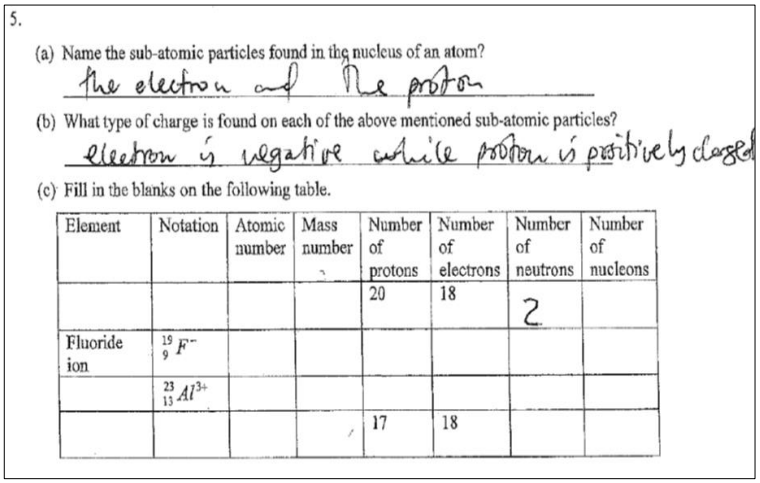
Figure 6.12: Teacher WM response to question 3

Looking at teacher WM's responses to the breakdown of sub-question 4 in table 6.7 and question 3 in figure 6.12, it appears that she does not know how the forces of attraction and intermolecular distance between molecules relate. Teacher WM showed that solid particles have fewer intermolecular spaces than the liquid (see figure 6.12). However, she was unable to relate that response to the forces of attraction question asked in sub-question 4 in both tests. This implies that the teacher does not conceptually understand that the stronger the forces of attraction, the shorter the intermolecular distance and vice versa. With a better understanding of the relationship between the two, teacher WM might have had the misconception shown in the post-response of sub-question 4 remediated therefore giving a correct response.

NUGTs were also tested about their understanding of the structure of an atom and identifying naturally occurring elements in question 5. There was an improvement in teachers' understanding on the structure of an atom. Teachers were asked to name the sub-atomic particles found in the nucleus of an atom. In the pre-test, four teachers included electron as a sub-atomic particle (including protons and neutrons) found in the nucleus of an atom. This

could have been these teachers were not sure of what the two sub-atomic particles were and therefore resorted to all the three sub-atomic particles. Two teachers indicated protons and electrons as the sub-atomic particles found in the nucleus of an atom. One of the teachers is NN whose responses are shown in figure 6.13 below for the pre-test response.

Pre-test response



5.

(a) Name the sub-atomic particles found in the nucleus of an atom?

the electron and the proton

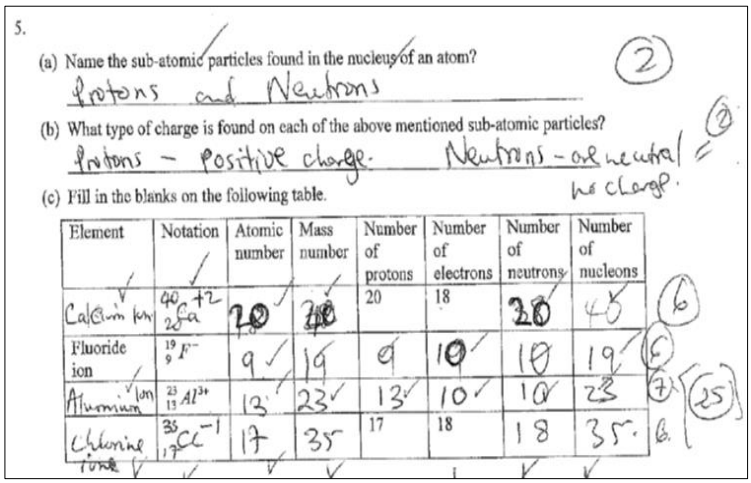
(b) What type of charge is found on each of the above mentioned sub-atomic particles?

electron is negative while proton is positively charged

(c) Fill in the blanks on the following table.

Element	Notation	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons	Number of nucleons
				20	18	2	
Fluoride ion	$^{19}_{9}F^{-}$						
	$^{23}_{13}Al^{3+}$						
				17	18		

Post-test response



5.

(a) Name the sub-atomic particles found in the nucleus of an atom? (2)

protons and Neutrons

(b) What type of charge is found on each of the above mentioned sub-atomic particles? (2)

protons – positive charge. Neutrons – are neutral = no charge.

(c) Fill in the blanks on the following table.

Element	Notation	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons	Number of nucleons
Calcium ion	$^{40}_{20}Ca^{+2}$	20	40	20	18	20	40 (6)
Fluoride ion	$^{19}_{9}F^{-}$	9	19	9	10	10	19 (5)
Aluminium ion	$^{23}_{13}Al^{3+}$	13	23	13	10	10	23 (7) (25)
Chlorine ion	$^{35}_{17}Cl^{-1}$	17	35	17	18	18	35 (6)

Figure 6.13: Teacher NN responses to question 5(c)

This response given by the teachers suggests that they cannot identify the nucleons. However, in the post-tests about 13 of the 15 teachers were able to give correct responses. They showed a better understanding of what the sub-atomic particles in the nucleus are and their charge type. Only teacher KK and WM still found the question a challenge. Similar to his response in the pre-test, teacher KK displayed a response of electron and proton as sub-atomic particles. Teacher WM, who indicated all three in the pre-tests, provided only the neutron as a sub-atomic particle in the post test. It was noted in the pre-test that almost all the teachers were unable to find the atomic number, mass number, number of protons, electrons, neutrons and nucleons in a given nuclide notation. To some extent, teachers struggled to deduce an element or ion when number of protons or neutrons or nuclide notation is given, for example in column two above in figure 6.13. Teacher NN attempted to complete the number of neutrons only in the table for the pre-test response as shown in figure 6.13.

Since these teachers wrote both tests without a periodic table of elements, it is assumed that their poor performance can be attributed to poor identification of elements. This might be supported by the lack of teaching experience during the time of writing the pre-tests. Therefore this has made it difficult for teachers to identify atomic number, nucleons, number

of protons, mass number and number of electrons in their post-tests. However, in the post-tests most teachers including teacher NN, displayed correct responses. It should be emphasised that the post-test was also written under similar conditions without a periodic table of elements. And in retrospect, periodic tables should have been given to them. This change might have been influenced by the experience teachers gained, which indicates growth in their CK.

Another part of question 5 involved a naturally occurring element of two isotopes. This question consisted of four choices in the form of multiple choice questions. However, after selecting their choice, teachers were requested to justify their choice as shown in figure 6.14 below. It can be deduced from table 6.8 that in the pre-test response only one teacher showed a completely correct response. This kind of response implies that teachers provided a rich conceptually justification of their choice. About four teachers were scored as partially correct in the pre-tests where a correct multiple choice answer was given but with no or insufficient justification. The majority of teachers (ten) presented incorrect choices which also lead to incorrect justification and were therefore scored completely wrong.

Table 6.8: NUGTs' responses to question 5e

Completely correct response		Partially correct response		Incorrect response	
Pre	Post	Pre	Post	Pre	Post
1	2	4	7	10	6

In the post-test responses there was a decrease in the number of teachers with completely wrong responses. About six teachers who previously provided completely wrong responses in the pre-test had improved in their post-tests responses to partially correct. The number of teachers with partially correct response in the post-test increased to seven. This led to a reduction to six teachers with completely wrong responses in the post-test when compared to ten in the pre-tests. Although only two teachers (TM and NN) gave completely correct responses in the post-tests, generally there was a slight improvement in teachers' understanding of average atomic mass of naturally occurring elements.

It was observed that none of the teachers were able to move from a completely wrong to a completely correct response. The majority of the teachers shifted from the completely wrong to partially correct response. It is worth looking qualitatively at how teachers' initial knowledge about average atomic mass of naturally occurring elements shifted. Figure 6.14

below analyses and discusses in-depth teacher NN's pre- and post-test responses to the question. This teacher successfully selected the correct answer in the multiple choice question in the pre-tests but displayed insufficient explanation. In the post-test response a completely correct response was given.

Pre-test response

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

B. Isotope ^{35}Cl is expected to be more common than isotope ^{37}Cl. This is easily derived from the average atomic mass of naturally occurring chlorine, which is 35,5amu.

Post-test response

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

3. B

$\frac{x}{^{37}Cl} + \frac{x}{^{35}Cl} = 35,5amu$

35,5amu is significantly closer to 35; it is therefore safe to say ^{35}Cl is contributing more to the average atomic mass of chlorine than ^{37}Cl in the ratio of about 2:1

$\left(\frac{2}{3} \times 35\right) + \left(\frac{1}{3} \times 37\right) = 35,6amu$

66% 33%

Figure 6.14: Teacher NN's responses to question 5(e)

In the pre-test response, teacher NN was able to identify B as the correct choice. However his explanation was not at a satisfactory level. There is no clear justification on the choice of ^{35}Cl. Teacher NN only indicated that his answer was 'derived' from the average atomic mass of naturally occurring chlorine as shown in figure 6.14 for his pre-test response. It should be mentioned that his choice is correct. However, from his explanation it is not clear what it is about the 35,5amu that indicates that ^{35}Cl is contributing more. This is the reason why he was scored as partially correct for the pre-test response. In terms of his post-test responses, a fully correct and well expanded explanation from the pre-test response was given. Firstly, the teacher was able to justify his choice by indicating that the average atomic mass (35,5amu) is significantly closer than that of ^{35}Cl. The teacher also went further by showing calculations using the given percentages of the two isotopes (see figure 6.14). This proves that there is a higher percentage abundance of the ^{35}Cl isotope than the ^{37}Cl and therefore contributing more

to the average mass of chlorine. It is because of this explanation and expansion that teacher NN was scored completely correct in his post-test response. It is assumed that teacher NN's improvement of the concept could be attributed to his experience in teaching the grade 10 physical science in the year the post-test was administered. The concept of isotopes as well as performing calculations on average atomic mass and percentage abundance, forms part of the grade 10 science curriculum (see table 5.4 in chapter five)

There were also cases of teachers who presented incorrect responses in both pre- and post-tests responses. A case illustrated below in figure 6.15 is of teacher ZD who also taught the grade 10 physical science in the year the post-test was administered. Although the teacher was scored incorrect in all the tests, it is worth analysing her responses deeper in order to investigate whether any ideas were developing.

Pre-test response

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
(B)	66	33
C	33	66
(D)	100	1

~~^{35}Cl occurs more naturally than ^{37}Cl because it is more stable the in the first form than it is in the second form.~~ ^{35}Cl is mostly found naturally than ^{37}Cl which only exists in small quantities.

Post-test response

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

C is most likely. The amu of an isotope is calculated by the sum of the percentages of the the different occuring isotopes.

B) 66% ^{35}Cl & 33% ^{37}Cl

23,1 + 12,21 = 35,31

(c) 33% ^{35}Cl , 66% ^{37}Cl

11,55 + 24,42 . => 35,97. =>the closest to the answer

Figure 6.15: Teacher ZD responses to question 5e

In her pre-test response, teacher ZD selected D as a choice which is incorrect, including the explanation given. However, prior to that she had chosen choice B which was cancelled as can be seen in figure 6.15. The similarity between choices B and D is that they both consist of higher percentage abundance of ^{35}Cl. Therefore it can be assumed that she might have had an

idea that ^{35}Cl is contributing more to the average atomic mass of chlorine. The challenge was that she did not know the ratio which can be supported by her final choice D.

In the post-test response teacher ZD was scored incorrect. However, after engaging in some teaching of the concept, teacher ZD opted for algorithmic/calculation strategy when attempting to justify her choice. By looking at her calculation in the pre-test response in figure 6.15, one can see that choices B and C were chosen. This implies that unlike in her pre-test she now knows that the ratio involves 2 and 1. It can therefore be assumed that what she does not know is which one of the chlorine has the ratio 2 or 1. It is explicit though that the teacher knows that the percentage abundance is used to calculate and prove the average atomic mass. It is for this reason that she did the calculation for the post-test response in figure 6.15, although she opted for the incorrect answer C as the closest. This might have had an influence on how she taught this concept to the learners. Although she had given incorrect choices in both tests, one may safely say that teacher ZD's knowledge about the concept has developed. Unlike in her pre-response, she went beyond recognising ^{35}Cl as having high percentage abundance but understanding that through the percentage abundance average atomic mass can be proved.

6.5 Concluding Discussion

The first major finding is that NUGTs' overall knowledge of the particulate nature of matter improved. However, even though there was an improvement in their CK, the mean achieved in both tests is low for science graduates who are considered experts in the study. This finding is similar to Ramot (1992) who found that the knowledge of chemical structure (including the particulate nature of matter) for chemistry students at different levels seemed to be of low quality and only a small percentage had internalised it well. Lutz and Potgieter (2013) also found that chemistry undergraduate students displayed poor understanding of the particulate nature of matter.

The overall improvement showed by the performance mean score might have been influenced by the experience gained in the training academy, the teaching experience acquired or to some extent the in-service training attended. From the analysis it emerged that teachers had improved in differentiating between pure substances, mixtures, atoms and molecules. However, some teachers identified the definition of a molecule as compound and vice versa. This has shown teachers' inability to differentiate between macro and micro, which remained a difficulty. De Jong, Van Driel, and Verloop (2005) found similar results

where the pre-service teachers had difficulties in understanding the multiple macro and micro meaning of representations, which resulted in jumping from one perspective to another.

It was also found that teachers were able to identify most particles representing molecules, gas, pure liquids, etc. However, in both tests some teachers were unable to differentiate between mixtures and compounds. This simply shows that they don't know the difference between mixtures and pure substances. In terms of drawing sub-microscopic representation of oxygen in different phases, a solid representation remained a challenge for some teachers. They represented both liquid and gas correctly. The solid representation was shown with particles not touching after the teaching had taken place, while before the teaching the correct response was given. It is therefore assumed that the influence could be attributed to preference and the use of textbooks by the teachers. This preference was highlighted by Yager (1983) that textbooks have a strong influence on shaping pre-service teachers' teaching.

Finally, the concept of average atomic mass has proven to be the most difficult of all the test items. Most teachers provided partial responses in the post-test response and this implies that conceptual understanding of the concept is lacking. However, with deeper analysis of both incorrect and partial responses a shift in teachers' understanding was observed. It is worth mentioning that when seeing a response as wrong or right only, observing this shift was impossible. This relates to the analysis done on teacher NN and ZD's responses. Their post-test responses on the concept (after teaching) to some extent display the manner in which they might have taught it to their grade 10 learners. The analysis portrayed some of the strategies teachers may use when teaching the concept. In conclusion, what came out of these tests is the improvement in NUGTs' CK of the particulate nature of matter. This is evident from the responses such as in cases such as teacher ZD and NN. It is worth looking into how these teachers have responded on their Topic Specific PCK test which is presented in the next chapter.

CHAPTER 7

7. THE ANALYSIS OF TEACHERS' TOPIC SPECIFIC PCK

In previous chapters, NUGTs' experience on the Professional Development Intervention (PDI), which included work such as general pedagogic knowledge, re-visitation of the particulate nature of matter, introduction of Topic Specific PCK and engagement with the CoRes during the intensive training was discussed. This was followed by eliciting their untransformed CK of the particulate nature of matter in chapter six. In this chapter, the analysis of their Topic Specific PCK is conducted, coupled with the PDI and their teaching involvement. Firstly, the measurement of Topic Specific PCK is discussed through quantitative analysis of both the pre- and post-test data. This is followed by a qualitative analysis of selected cases which includes evidence from taught lessons, interviews, CoRes, and responses from reflective questionnaires in order to investigate the development of different cases of NUGTs' Topic Specific PCK. Finally, in the discussion section the results of the two data sets are compared and integrated.

7.1 The measurement of Topic Specific PCK in Particulate Nature of Matter

The Topic Specific PCK test described and piloted in chapter four was administered to the NUGTs as pre- and post-test before and after the PDI. The aim of the test was to measure the NUGTs' Topic Specific PCK on the particulate nature of matter before and after teaching. Some teachers taught the topic under investigation while others taught different topics.

The pre-test was administered to the 16 teachers during week one of the intensive training. Like the CK post-test, the Topic Specific PCK post test was administered in the third school term of the NUGTs' first year of teaching. Both the pre- and post-tests are identical and were written under my supervision, except for three teachers who could not attend the last meeting. These teachers wrote the tests at different times and emailed them to me. One teacher dropped out of the programme and is no longer in the teaching field. Therefore 16 NUGTs wrote the post-test. It took 60 minutes for the NUGTs to complete both pre- and post-tests and responses were written in the space allocated on the test sheet. The Topic Specific test was marked using a rubric designed specifically for the test.

7.2 Quantitative analysis of the Topic Specific PCK Test

A rubric used to score the test was adapted from the Mavhunga (2012) as described in chapter four. The five categories of Topic Specific PCK were rated on a four point scale from 1 (*limited)* to 4 (*exemplary*). Although categories comprised several questions, each category was scored singly as an item. Therefore, the test consisted of five items, each having a maximum score of 4. The full rubric is attached as Appendix H. The scoring of both pre- and post-tests were peer-validated by two independent raters for accuracy. The MedCalc statistical software for inter-rater agreement – Kappa (www.medcalc.org/kapp) was used. An agreement rate (K value) of 32.4% indicating a fair strength was reached for the pre-test while 52% strength (moderate strength) was achieved for the post-test (see Appendix I). In cases where there were differences, particularly with a large margin, the raters got together and reached an agreement in terms of the scoring. The selected people for validation were familiar with the scoring of the rubric. Sample of a completed pre-test and post-test, with the corresponding marked rubrics, are attached as Appendix J for illustrative purposes.

7.2.1 Scores obtained from the rubric

Table 7.1 shows scores obtained for the pre- and post-test in each category for each teacher. The categories are arranged in the same order as in the CK test.

Table 7.1: Raw scores from responses in the pre and post-tests

NUGTs	Learner Prior Knowledge		Curricular saliency		What is difficult to teach		Representations		Conceptual teaching strategy	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
MJ	2	4	3	3	1	3	2	3	1	2
*ZD	3	4	3	4	1	3	1	4	2	2
WM	3	2	2	3	1	2	1	2	1	2
TM	4	3	3	3	3	3	3	3	4	3
LM	4	2	2	2	1	2	2	1	1	2
*SS	2	4	3	4	3	3	2	4	1	3
*DN	2	4	2	4	1	3	2	3	1	2
*NN	1	3	3	4	3	4	2	4	1	2
MB	2	2	3	1	1	1	2	2	1	1
SR	3	3	2	2	3	2	2	2	1	2
KK	1	3	3	2	1	1	2	2	1	2
AN	2	3	2	3	1	2	1	2	1	2

NUGTs	Learner Prior		Curricular		What is difficult		Representations		Conceptual	
TS	2	3	3	2	1	1	1	2	1	2
TC	3	4	3	2	1	3	2	2	1	2
KT	2	2	2	2	1	1	2	2	1	1

From table 7.1, it can be seen that there appears to be an overall gain in NUGTs knowledge in all the categories in the post-test as compared to the pre-test. However, when narrowing down to individual teachers, one can see the same results scored in both tests and a slight decrease in certain categories in the post-test. This kind of result may have contributed to the lower scoring of certain categories, indicating their difficulty. However, it is important to mention that evidence of gain in knowledge may further be substantiated by doing a statistical analysis as well as deeper qualitative analysis, which is shown in sections below.

7.2.2 Rasch Analysis

The raw scores generated from the NUGTs' rubric were subjected to analysis using the Rasch Winstep software. As explained in chapter four, the Rasch model is able to transform raw data from the human sciences into continuous, equal-interval scales (Bond & Fox, 2001). The raw score values for each teacher obtained from the rubric was converted into a single measure and the mean of item measure is set to zero. In using the Rasch model the following could be measured amongst others: validity of a construct, reliability indices and person measure which are shown in table 7.2.

Table 7.2: The Person Rasch & Reliability Indices scores of the Pre and Post Topic Specific PCK test

		Fit statistics for persons & items			*Fit statistics for persons & items*	
NUGTs	**Pre Rasch measures (Topic Specific PCK)**	**IN.ZSTD**	**OUT.ZSTD**	**Post-Rasch measures (Topic Specific PCK)**	**IN.ZSTD**	**OUT.ZSTD**
MJ	-2.47	-0.1	-0.2	2.83	-1.5	-1.5
ZD	-1.02	0.4	0.4	3.70	0.1	0.0
WM	-3.29	-0.6	-0.3	-1.19	0.7	0.3
TM	2.40	0.0	0.1	2.83	0.3	0.2
LM	-1.73	1.0	0.8	-0.3	1.3	1.2
SS	-0.34	1.3	1.4	5.75	-1.1	0.4

		Fit statistics for persons & items			*Fit statistics for persons & items*	
NUGTs	**Pre Rasch measures (Topic Specific PCK)**	**IN.ZSTD**	**OUT.ZSTD**	**Post-Rasch measures (Topic Specific PCK)**	**IN.ZSTD**	**OUT.ZSTD**
DN	-2.47	-0.9	-0.7	3.70	-0.8	-0.8
NN	0.30	0.3	0.3	5.75	1.2	0.7
MB	-2.47	-0.1	-0.2	-6.37	0.5	0.3
SR	-1.02	1.0	0.9	-1.19	-1.3	-1.0
KK	-2.47	-0.1	-0.2	-2.42	0.9	0.8
AN	-4.30	-1.7	-0.7	-0.01	-1.1	-0.9
TS	-3.29	0.1	0.0	-2.42	0.9	0.8
TC	-1.02	0.4	0.4	-0.01	0.8	1.1
KT	-3.29	-0.5	-0.1	-4.97	-1.1	-0.8
Summary of Reliability Indices	Mean Person Pre-Test Person Reliability Item Reliability Infit/Outfit Indices	-1.76 0.67 0.93 All ZSTD values are within +2;-2 range		Mean Person Post- Test Person Reliability Item Reliability Infit/Outfit Indices	0.22 0.89 0.90 All ZSTD values are within +2;-2 range	

Item measure mean set to zero & Units per Logit (log-odds unit) =1 for the entire test (UIMEAN=0 and USCALE =1)

Table 7.2 above shows the combination of each person's Rasch measure and fit statistics for both pre- and post-tests. It also includes the reliability indices for persons and items as well as the mean score for both tests. The first column indicates the codes assigned for each teacher. The second column shows the Rasch person measure transformed from the raw scores. The headings 'IN.ZSTD' and 'OUT.ZSTD' in the third and fourth columns refer to the standard range of parameters that measures fit statistics (Bond & Fox, 2001). As indicated in chapter four, the Rasch fit statistic values highlight validity of the construct. It can be seen in table 7.2 that all NUGTs' IN.ZSTD and OUT.ZSTD values for both the pre- and post- Topic Specific PCK fall within the +2 and -2 range. This indicates a good fit and points to a construct that is valid.

In terms of the reliability indices, the item reliability in both pre- and post- Topic Specific PCK test was found to be above 0.9, which is higher than the generally recognised standard of 0.7 for Cronbach, therefore indicating replicability of the items. Person reliability in both tests was found to be higher than 0.5 and therefore restricted to the range 0 to 1. This gives an

estimate on the ability of the person in responding to the whole test which proved to be even more reliable during the post-testing.

The Rasch person measure for Topic Specific PCK in table 7.2 above suggests that most NUGTs' Topic Specific PCK improved. This is with the exception of TM who did not to teach as indicated in chapter five and teacher MB who did not show much improvement. This can also be deduced from the mean score in the post-test which increased to 0.22 as compared to the pre-test which was initially to -1.76.

7.2.3 The Item Rank Order

The Rasch model evaluates the construct validity of an instrument by obtaining the difficulty order of the items (Wright & Masters, 1982). Table 7.3 shows the Rasch measures in terms of rank of difficulty of items for both pre- and post-tests, as found for the respondents.

Table 7.3: Categories Ranking of Topic Specific PCK for Rasch measure

Topic Specific PCK Test	Learner prior knowledge	Curricular Saliency	Representation	What is difficult to teach	Conceptual Teaching strategies
Pre-Test	-2.68	-2.02	0.52	1.26	2.93
Post-Test	-3.05	-1.15	-0.08	1.40	2.89

The results in table 7.3 show that all the categories in both pre- and post- Topic Specific PCK tests ranked similarly. According to the Rasch model, the higher the Rasch measure the more difficult the item. This implies that the category *learner prior knowledge* was found to be the easiest by the NUGTs, followed by *curricular saliency* and *representations* in both tests. The category of *what is difficult to teach* and *conceptual teaching strategy* remained difficult in both pre- and post-tests as they show high Rasch measures. Similar findings were found in experienced teachers in chapter four for the pilot. Therefore considering that NUGTs are beginning teachers, these results are justifiable. Although the category of *conceptual teaching strategy* remained the most difficult in both tests, it is important to acknowledge that there was a shift in score. It can be assumed that even though the NUGTs found it difficult, they might have engaged with the category conceptually in the post-test as compared to the pre-test. Some of the extracts from the NUGTs' teaching is discussed in the qualitative analysis of the Topic Specific PCK later in this chapter.

7.2.4 The person ability

The Rasch model can also measure the person ability in relation to item difficulty for the same metric. These two estimates for both pre- and post-test are presented in an ‘‘item-person-map” in figure 7.1 below. It should be mentioned that NUGTs’ code identifier for pre–test includes number 01 in front while the post-test has 02. This is meant to differentiate each person on the pre and post level.

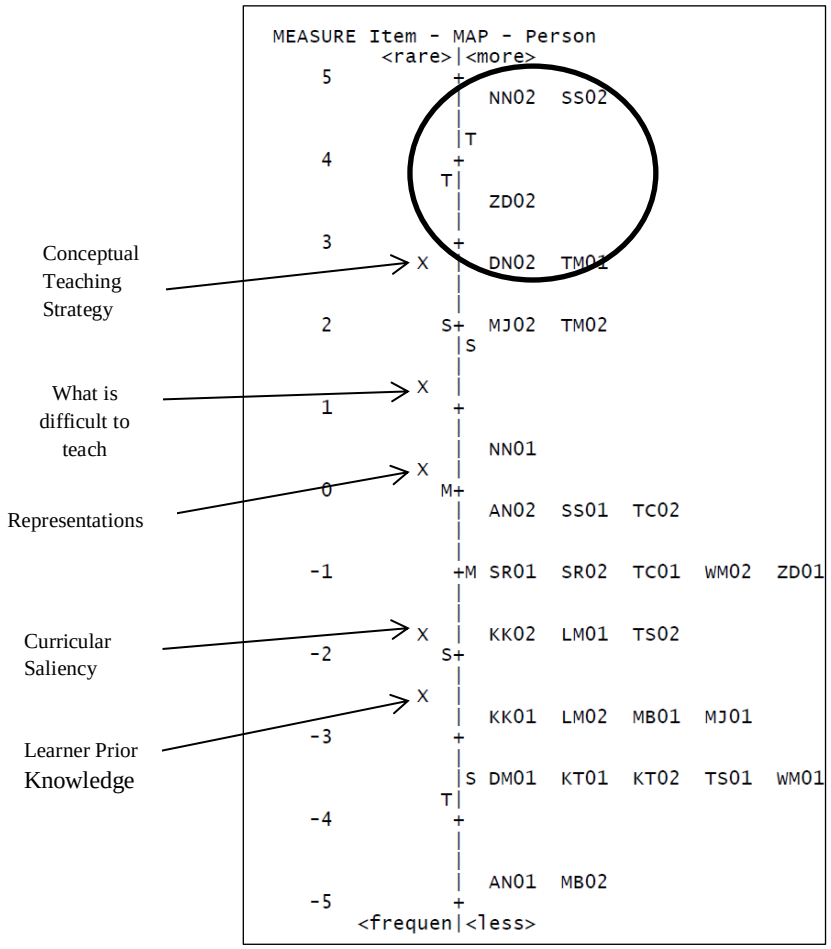


Figure 7.1: Item-person-pap for NUGTs’ pre and post Topic Specific PCK

The results in figure 7.1 shows that all the teachers except TM in the pre-test are likely to find difficult items related to *conceptual teaching strategy*. This is because all their scores are located below the category-*conceptual teaching strategy*. In the pre-test, all the NUGTs, except teacher TM01, were likely to find items on *representations* and *what is difficult to teach* difficult. TM01 is at the top level in the pre-test, implying that her person ability, in this case Topic Specific PCK, is better than the rest of the teachers and that most items were easy for her.

However, a shift in the post-test is observed. Firstly there were NUGTs (NN02, SS02, ZD02 & DN02) who moved to the top level and they are the four case study teachers. Secondly, all the NUGTs in the post-tests with the exception of LM02, KT02 and MB02 are likely to answer items relating to *learner prior knowledge* and *representations* correctly. This can be observed from the 'post' diagram in figure 7.2 where the majority of the NUGTs are no longer clustered at the bottom as shown in the 'pre' diagram. Interestingly, teachers such as LM02 and MB02 in the post-test now appear to be the least able and are likely to find all the items difficult, which contrasts with the pre-test. The same teachers were in a position to find items of *curricular saliency* easy. It was noted that teacher LM did not respond extensively and consistently as he did in the pre-test, while MB and KT appeared to be struggling as can be deduced from the pre-test map where they were slightly above the bottom category. It is worth looking qualitatively into some evidence of improvement observed.

7.2.5 Comparing Rasch person measures for significance

In the pre-test teacher TM portrayed good Topic Specific PCK. This could be explained in her case as she indicated that a year before joining the programme, she was involved in a voluntary teaching project where she taught grade 10, the class where this material is taught (see chapter five). However, her Topic Specific PCK in the post-test was not that good relative to the pre-test, as she did not teach like the rest of the NUGTs who were placed in schools. Unlike in the pre-test, teachers MB and KT portrayed poor Topic Specific PCK in the post-result compared to the rest of the NUGTs. As shown in chapter five, at the time of the study and in the first year of their teaching, teachers MB and KT were teaching grades 8 only. It can therefore be assumed that teachers were not able to engage with the topic particulate nature of matter like other NUGTs who taught higher grades including grade 9. For the teachers teaching grade 9, introduction of concepts related to the particulate nature of matter is looked into while grade 11 and 12 teachers are expected to reinforce the concepts of the topic when teaching some concepts. Teachers MB and KT did not gain such experience as they taught grade 8. The target grade in my study is grade 10.

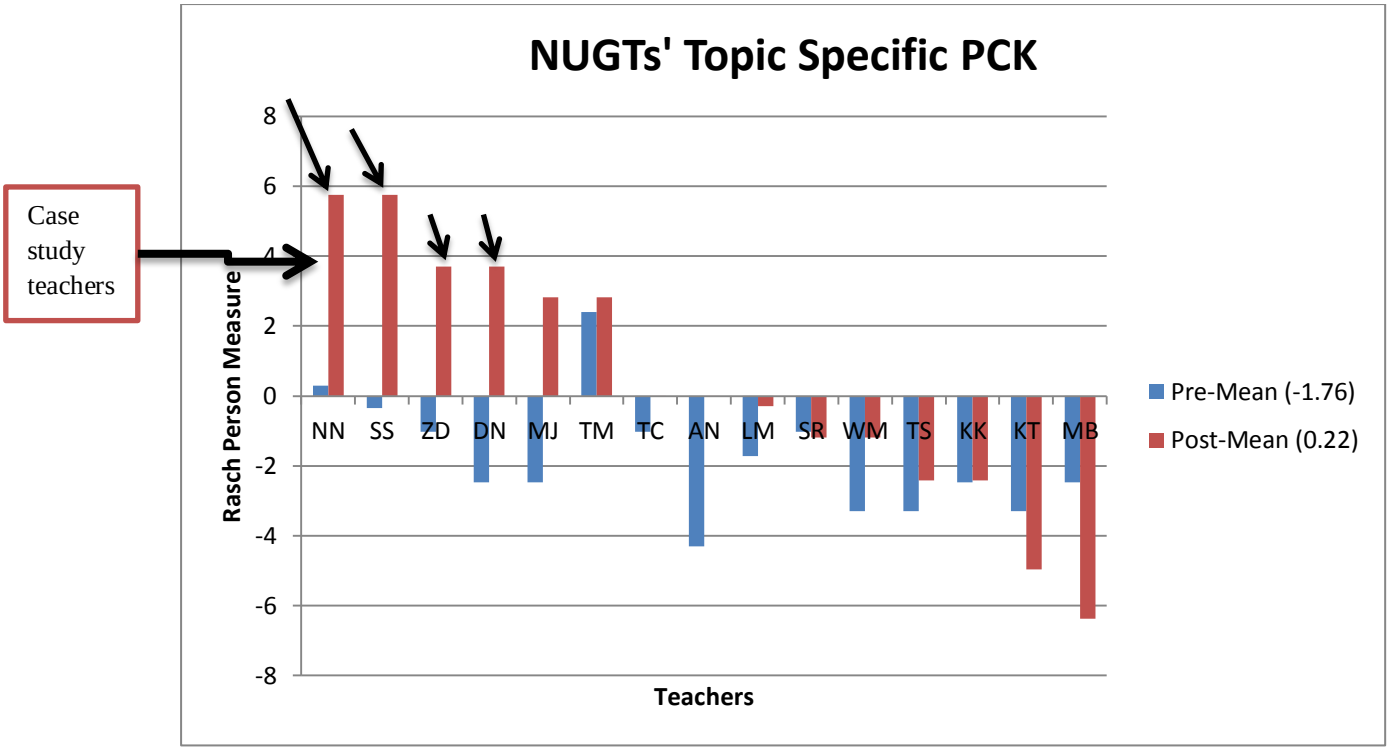


Figure 7.2: Graphical representations of NUGTs' pre and post-tests shift in Topic Specific PCK

The tests results of the Topic Specific PCK are represented in the form of a bar graph in figure 7.2. The graph represents the NUGTs in order of high to low Topic Specific PCK post test results. The first four NUGTs who displayed high Topic Specific PCK (NN, SS, ZD and DN) are case study teachers who had the opportunity to teach grade 10 particulate nature of matter teachers in my study, analysed in detail in chapter five. It can be deduced in figure 7.2 that there is good discrimination between the case study teachers and the non-case study teachers. This is attributed to the fact that the case study teachers appeared to be much more able since they have taught the topic in consideration.

In order to assess the significant difference between pre- and post-test the non-parametric Wilcoxon Signed Rank Test was applied. As indicated in chapter six, this statistic is preferred because of its design for the use of repeated measures on two occasions under different conditions. Figure 7.3 below shows the calculation relating to the statistical difference. This non-parametric statistic converts scores to ranks and compares them on specific criteria.

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Post-test TSPCK score - Pre-test TSPCK score	Negative Ranks	3[a]	6.00	18.00
	Positive Ranks	12[b]	8.50	102.00
	Ties	0[c]		
	Total	15		

a. Post-test TSPCK score < Pre-test TSPCK score

b. Post-test TSPCK score > Pre-test TSPCK score

c. Post-test TSPCK score = Pre-test TSPCK score

Test Statistics[b]

	Post-test TSPCK score - Pre-test TSPCK score
Z	-2.385[a]
Asymp. Sig. (2-tailed)	.017

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Figure 7.3: Comparison of the NUGTs' Topic Specific PCK pre and post-tests

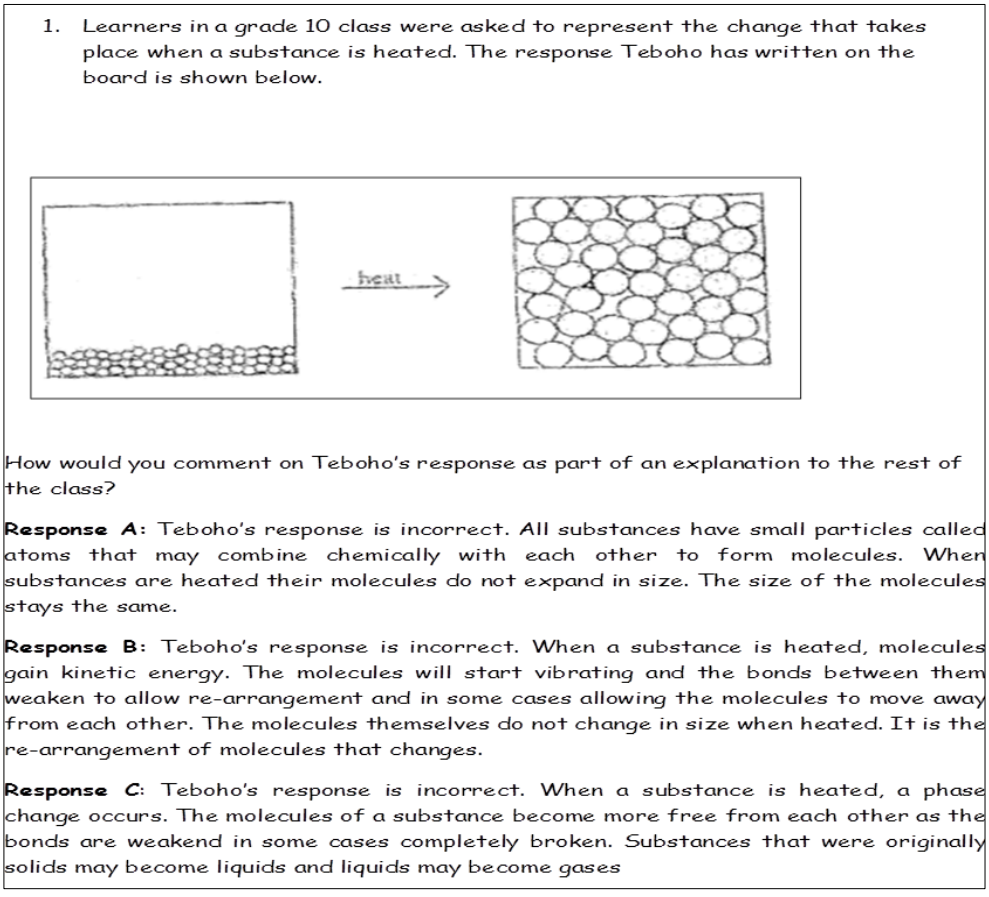
The Z value is -2.385 with a significant level p=0.017. The probability value (p) is far less than 0.05 and actually significant at the 0.02 level, indicating that the result is more significant. There is statistically significant difference in the pre- and post- Topic Specific PCK tests. This means that the NUGTs improved their Topic Specific PCK for particulate nature of matter significantly with 98% confidence level.

7.3 Qualitative analysis for investigating Topic Specific PCK

As shown in the quantitative analysis above there was a significant shift in NUGTs' Topic Specific PCK. Therefore it is important to look for the evidence to support this growth from the qualitative data. Qualitative analysis is based on teachers' written Topic Specific PCK pre- and post-tests, the initial and final CoRes, recorded video lessons on teaching particulate nature of matter, pre- and post- observation interviews and their responses from the reflective questionnaire. Different scenarios are discussed below in an attempt to support shifts in each category of Topic Specific PCK. However, it is important to emphasise that the classroom and interview data applies only in the case study teachers who were observed teaching the particulate nature of matter and made the greatest shift compared to others.

7.3.1 Evidence of emerging Topic Specific PCK when engaging with Learners' Prior Knowledge

The Rasch measurement showed that the NUGTs found the *learner prior knowledge* category to be the easiest as shown in table 7.3. Figure 7.4 shows the question asked from the pre- and post- Topic Specific PCK test with regard to the category. For this question, NUGTs were expected to confront a misconception by choosing the response and also expand their choice. According to the rubric (see Appendix H), in order for one to be placed at the *exemplary* level (score 4), the misconception has to be identified and confronted, which would include correct expansion and rephrasing of the explanation. If there is no identification and acknowledgement of the misconception, a teacher will be placed at the *limited* level (score 1) of the rubric.



1. Learners in a grade 10 class were asked to represent the change that takes place when a substance is heated. The response Teboho has written on the board is shown below.

How would you comment on Teboho's response as part of an explanation to the rest of the class?

Response A: Teboho's response is incorrect. All substances have small particles called atoms that may combine chemically with each other to form molecules. When substances are heated their molecules do not expand in size. The size of the molecules stays the same.

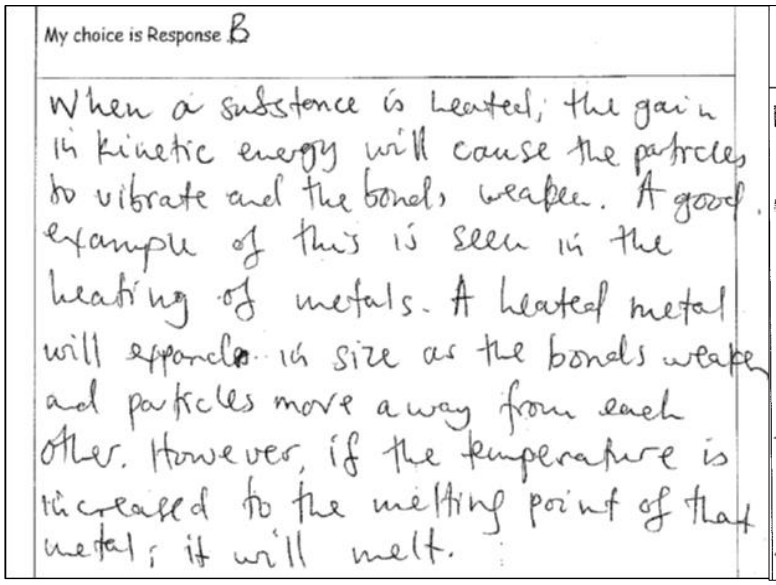
Response B: Teboho's response is incorrect. When a substance is heated, molecules gain kinetic energy. The molecules will start vibrating and the bonds between them weaken to allow re-arrangement and in some cases allowing the molecules to move away from each other. The molecules themselves do not change in size when heated. It is the re-arrangement of molecules that changes.

Response C: Teboho's response is incorrect. When a substance is heated, a phase change occurs. The molecules of a substance become more free from each other as the bonds are weakend in some cases completely broken. Substances that were originally solids may become liquids and liquids may become gases

Figure 7.4: Learner Prior Knowledge question in the Topic Specific PCK test

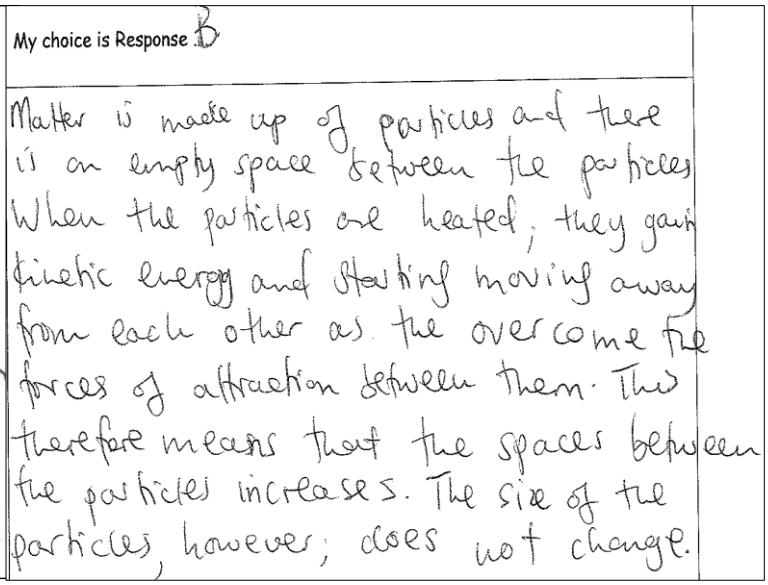
In order to explore NUGTs' growth in this category, teacher NN's response to the question is looked into. Figure 7.5 below shows both his pre- and post-test response to the question.

Pre


My choice is Response B

When a substance is heated, the gain in kinetic energy will cause the particles to vibrate and the bonds weaken. A good example of this is seen in the heating of metals. A heated metal will expand in size as the bonds weaken and particles move away from each other. However, if the temperature is increased to the melting point of that metal; it will melt.

Post


My choice is Response B

Matter is made up of particles and there is an empty space between the particles. When the particles are heated, they gain kinetic energy and starting moving away from each other as the overcome the forces of attraction between them. This therefore means that the spaces between the particles increases. The size of the particles, however, does not change.

Figure 7.5: Teacher NN's response to the first question of the category 'learner prior knowledge

Teacher NN's pre-test response does not identify and confront a misconception demonstrated by learner Teboho in figure 7.4. The first part of his expansion was a repeat of the definition from the B option. The second part given for expansion includes correct content but the example given does not relate to the example given in figure 7.4. Teacher NN has elaborated on what happens during a heating of the metals which leads to their expansion in size. This may suggest that teacher NN was looking at this example from the macroscopic point of view. He further hinted on the idea that particles move away from each other which is at the sub-microscopic level. However, he did not mention anything about the size of the particles. An assumption can be made that teacher NN might not have seen anything incorrect with learner Teboho's response in figure 7.4. This is attributed to the manner in which he explained and expanded his choice. Therefore it is for these reasons that teacher NN was placed at the *limited* level in the pre-test response.

In contrast, during the pre-test, teacher NN's response in the post-test has showed an improvement and was placed at *developing* level. The teacher did not only expand and rephrase the explanation correctly relating to the diagram on figure 7.4 but also confronted the misconceptions. The expansion made was with regard to *matter being made up of particles* and *the empty spaces between the particles*, which is not part of the answer in choice B. It is assumed that teacher NN might have seen this expansion as a pre-requisite for making learners understand that the spaces increase due to kinetic energy and not the size of the particles. This pre-requisite is supported by teacher NN's post-CoRe group response to

the big idea *the particles which make up matter are in constant motion*. The group was responding to the prompt: what else do they know about the idea that you don't intend learners to know yet. Figure 7.6 shows the response:

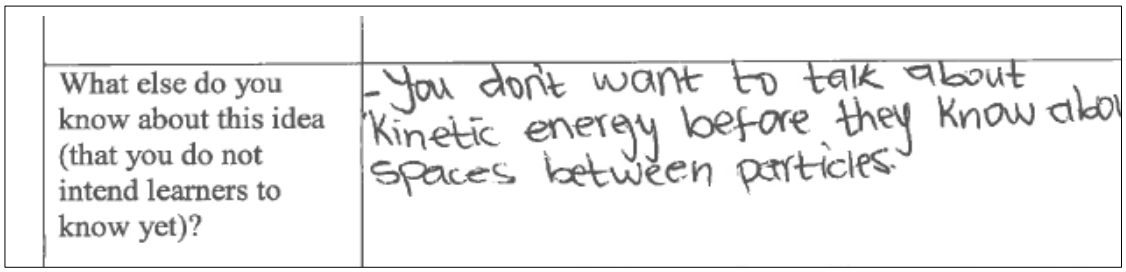


Figure 7.6: Teacher NN's group post CoRe response on the prompt 'what else do you know about the idea (that you do not intend learners to know yet)

The group's response in figure 7.6 above suggests that it is important for learners to first know about the concept of empty spaces between the particles before explaining the effects of kinetic energy on the particles. This response links with teacher NN's idea of making the concepts of empty spaces between the particles understood by the learners first as shown in his post-test response in figure 7.5. This was followed by the rephrasing that emerged, where teacher NN was explaining the effect that kinetic energy has on the particles which leads to weaker forces of attraction between the particles. However, NN's post-response fell short of the *exemplary* level because he did not make explicit the identification of the misconception. He only emphasised that *the size of the particles does not change*. It is a requirement in the rubric (see Appendix H) that the misconception has to be identified. Some of the evidence during teacher NN's teaching that included concepts such as the empty spaces between the particles and forces can be seen from excerpts shown in the category *curricular saliency* above.

Other evidence that could also support NUGTs' growth in the category *learner prior knowledge and misconceptions* can be suggested by his response in the pre- and post-observation interviews about teaching 'Atoms'. The excerpts are shown below.

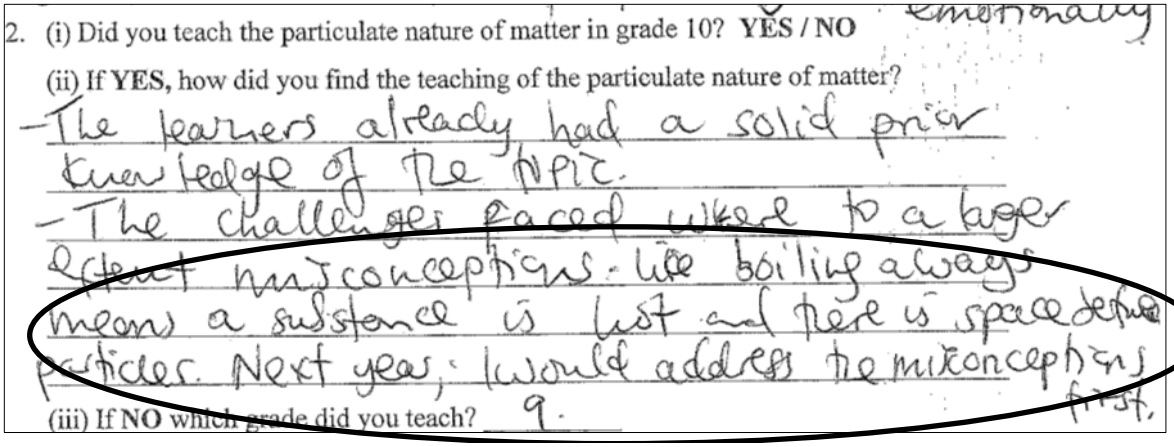
> **Me:** What kinds of students' misconceptions associated with this lesson have you noticed?
>
> **Teacher NN:** I don't know of any misconceptions maybe they will come up when I teach.

The excerpt above was taken from the pre-observation interview about the atom lesson. The response suggests that teacher NN was unable to anticipate the kind of misconceptions learners may have about the concept he was about to teach. This is not surprising because

teacher NN is an inexperienced science teacher who has never taught before. However, after teaching the same lesson teacher NN responded as follows in his post-observation interview.

> **Me:** Were there any students' misconceptions you identified during the class that you have not known?
>
> **Teacher NN**: yes, in the interview we had before the class I said I don't know of any misconceptions. Fortunately or unfortunately I don't know it did come up and one of them is the atomic number issue where most of them believe that it is the number of protons plus the number of electrons which is a huge misconception. Anyway, that's what they were taught I don't know why they were taught that but is a huge misconception. Actually that was the point that slowed down the lesson. If that misconception was not there or if I knew of the misconception before I probably would have planned my lesson differently. But unfortunately it only came up in the lesson and we had to do things that I thought where straightforward they knew them
>
> **Me:** Would you make any changes in the class that I just observed differently from the other class periods or lesson plan?
> **Teacher NN**: Of course
> **Me: Why?**
> **Teacher NN**: Now that I know that there is a misconception I think I would first address that and make sure that they were on the same page. Not being aware of the misconceptions really affected the flow of the lesson. We ended up spending more time on something that I did not know so of course I will do things differently

Teacher NN's response suggests that he is now aware of the misconceptions learners have about the concept he has just taught. He not only acknowledged that by not knowing misconceptions learners have about the atom prior to teaching had slowed down the lesson but also showed that he would have planned the lesson differently. This reflection supports the finding of Geddis et al. (1993) that the knowledge of the alternative conceptions learners are likely to bring to science class could be extremely useful in deciding how to reformulate the content knowledge for teaching. He also indicated that in future he would address the misconception prior to teaching the next grade 10 class and also in teaching in future. Teacher NN shared the same sentiment in his response in the reflective questionnaire alluded to below. He acknowledged facing challenges, including misconceptions in particular as shown in the reflective questionnaire below.


2. (i) Did you teach the particulate nature of matter in grade 10? **YES / NO**

(ii) If **YES,** how did you find the teaching of the particulate nature of matter?

- The learners already had a solid prior knowledge of the topic.
- The challenges faced where to a large extent misconceptions like boiling always means a substance is lost and there is space between particles. Next year, I would address the misconceptions first.

(iii) If **NO** which grade did you teach? 9.

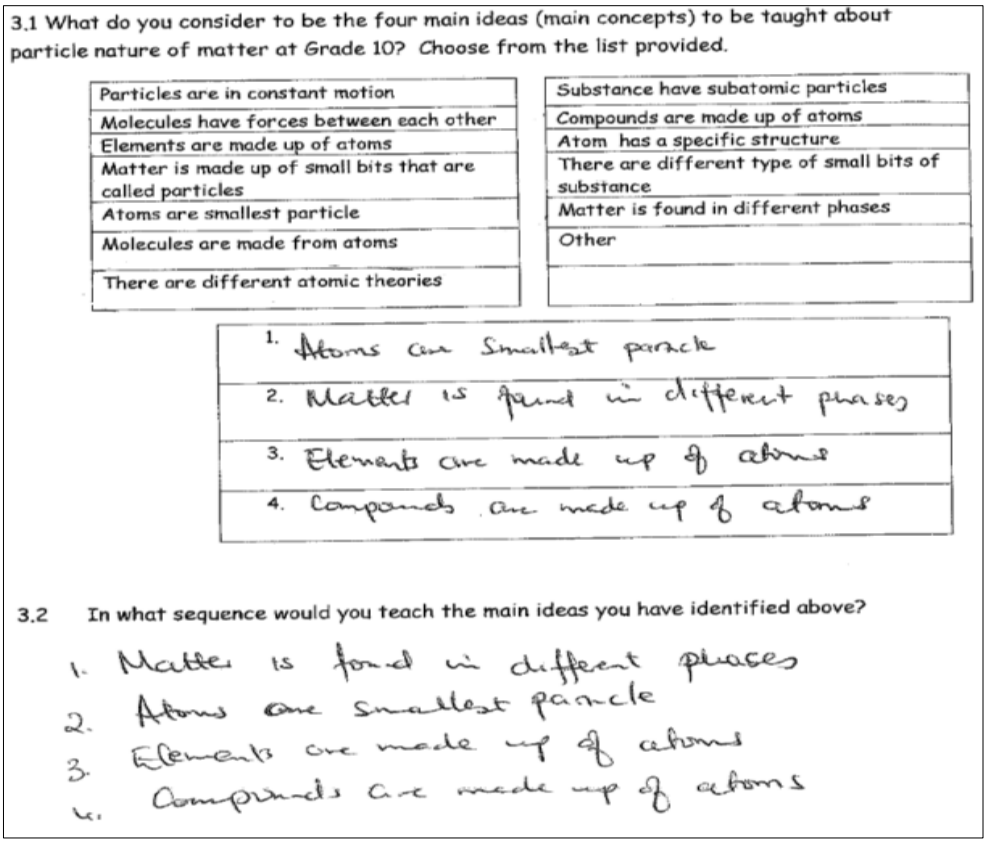
Figure 7.7: Teacher NN response from the reflective questionnaire about the experience of teaching the particulate nature of matter

In the circled response in figure 7.7 teacher NN made explicit that addressing misconceptions learners might have with regards to spaces between particles would be his priority in his future teachings. This suggests that the teacher sees the importance of remediating learners' misconceptions during the teaching.

7.3.2 Evidence of emerging Topic Specific PCK when engaging with Curricular Saliency

Geddis, Onslow, Beynon, & Oesch (1993) expanded Shulman's (1987) conceptualisation of PCK included amongst others knowledge of the *curricular saliency* as broad category of PCK. The authors described the *curricular saliency* as taking into consideration learning the importance of different topics relative to the curriculum as a whole. Therefore, in the Topic Specific PCK test, NUGTs were asked about the questions that relate to planning and sequencing of concepts which relates to the *curricular saliency*. The Rasch results for categories in table 7.3 shows that the NUGTs have found *curricular saliency* second easiest as it comes after the *learner prior knowledge*. For the items relating to this category, the teachers had to identify four main/big ideas and also indicate the sequencing in terms of how they would teach the main concepts identified. Developing big ideas for a specific topic is an important aspect of articulating teachers' PCK, as it indicates the path with which science teachers frame the topic and it is seen as being at the heart of understanding that topic (Loughran et al., 2006)

The extracts from teacher NN and ZD showing how they responded to different questions with regards to the category of *curricular saliency* are shown below. In the pre Topic Specific PCK test, teacher NN responded as follows (see figure 7.8) when asked about what he considers to be the four main ideas:



3.1 What do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10? Choose from the list provided.

Particles are in constant motion	Substance have subatomic particles
Molecules have forces between each other	Compounds are made up of atoms
Elements are made up of atoms	Atom has a specific structure
Matter is made up of small bits that are called particles	There are different type of small bits of substance
Atoms are smallest particle	Matter is found in different phases
Molecules are made from atoms	Other
There are different atomic theories	

1. Atoms are Smallest parcle
2. Matter is found in different phases
3. Elements are made up of atoms
4. Compounds are made up of atoms

3.2 In what sequence would you teach the main ideas you have identified above?

1. Matter is found in different phases
2. Atoms are smallest parcle
3. Elements are made up of atoms
4. Compounds are made up of atoms

Figure 7.8: Teacher NN's pre-test response to the question of curricular saliency

In his response above teacher NN suggested mixed concepts that consist of a combination of mostly subordinate concepts and one main idea 'matter is found in different phases'. His response has also affected the answer to the question about the sequence due to the identification of sub-ordinates concepts instead of the main concepts. However, it is important to mention that even though they are not all main ideas, the sequence is logical.

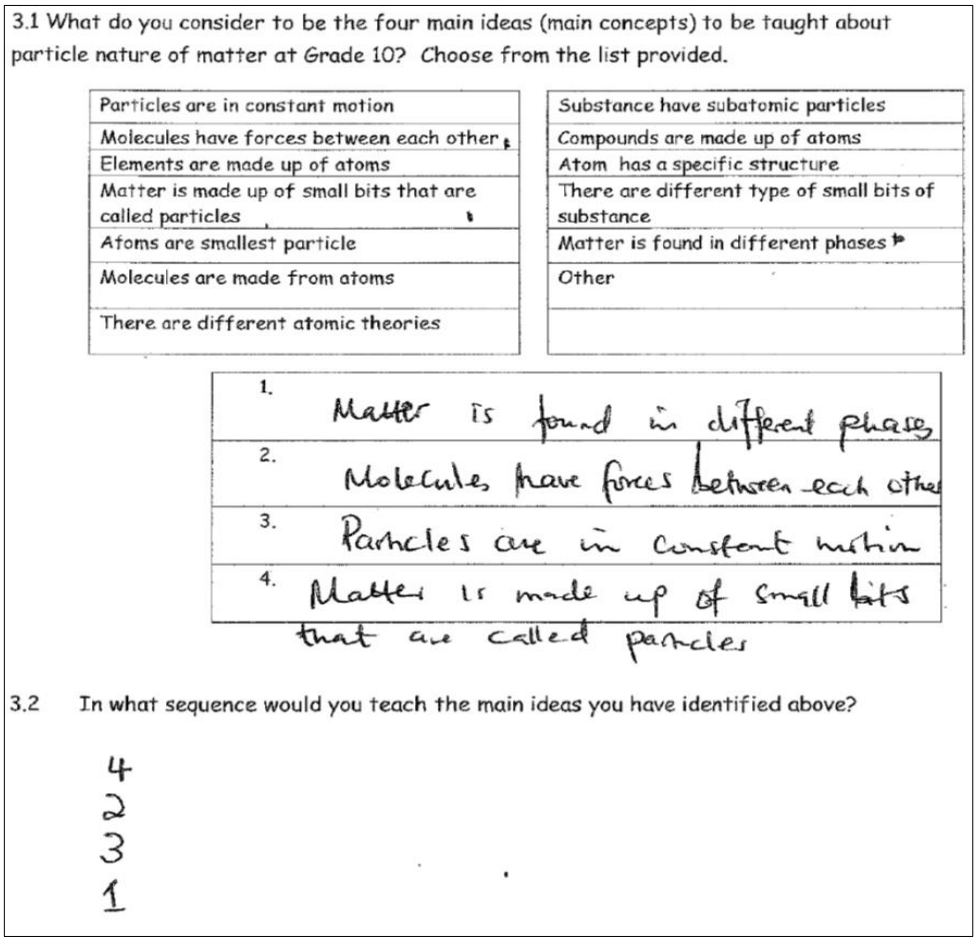
Loughran et al. (2006) have identified, amongst others, the first three big ideas (below) and 'matter is found in different phases' was also considered a big idea in my study. This is mainly because for learners to understand the motion of particles and forces between them, a pre-requisite knowledge of phases of matter is important. During the pilot stage most teachers (experienced) identified it as big idea as well. It is for this reason that this big idea is included.

The suggested four main concepts which are considered as being the heart of understanding in the topic in figure 7.8 are:

- Particles are in constant motion
- Molecules have forces between each other

- Matter is made up of small bits called particles
- Matter is found in different phases

However, in his post-test response teacher NN responded as follows, shown in figure 7.9 below:


3.1 What do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10? Choose from the list provided.

Particles are in constant motion	Substance have subatomic particles
Molecules have forces between each other	Compounds are made up of atoms
Elements are made up of atoms	Atom has a specific structure
Matter is made up of small bits that are called particles	There are different type of small bits of substance
Atoms are smallest particle	Matter is found in different phases
Molecules are made from atoms	Other
There are different atomic theories	

1. Matter is found in different phases
2. Molecules have forces between each other
3. Particles are in constant motion
4. Matter is made up of small bits that are called particles

3.2 In what sequence would you teach the main ideas you have identified above?

4
2
3
1

Figure 7.9: Teacher NN's post-test response to the question of curricular saliency

The response shows an improvement in understanding the difference between main ideas and sub-ordinate concepts. Teacher NN was able to correctly identify all the main ideas. In addition to that, the sequence shown in figure 7.9 makes sense. This is evident in teacher NN's lesson of the kinetic molecular theory. The excerpts from his lesson on the kinetic molecular theory are shown below. Teacher NN was doing a recap of the lesson he delivered a day before on the kinetic molecular theory. Although there might be some misconceptions in this excerpt and some data in the category discussed, it is important to emphasise that it is only meant to show evidence of the category *curricular saliency*.

***Teacher NN**: guys, anyone who knows what kinetic molecular theory says?*

***Learner Naku**: molecules are always in motion*

***Teacher NN**: guys, anyone who knows what kinetic molecular theory says?*

***Leaner Xoli**: kinetic molecular theory is how particles move in a state of a matter*

***Teacher NN**: ok. That is good enough but we can have a different answer to that one?*

Main idea 4

Main idea 3

***Learner Mbosi:** all matter is made of molecules and atoms and they are always in motion*

***Teacher NN**: guys, you need to say <u>they are always in motion</u>. It is not enough to only say <u>matter is made up of molecules and atoms</u>. You have to include the kinetic part because that phrase has two important parts. The kinetic part standing for the motion the movement you know the kinetic energy is moving so you have to mention the kinetic part and the molecular part which is the particles and the atoms.*

It appears from the excerpt above that teacher NN was not entirely satisfied with learner Xoli and Naku's response to the question though to some extent he indicated that the response is good enough. The comment made by teacher NN after learner Mbosi's response suggests that he might have been after a certain sequence in terms of learner reporting. Hence the last comment suggests that he needed learners to firstly know that *'matter is made up of molecules and atoms'*, which is exactly what he emphasised as the first main idea to be taught in his post-test as shown in figure 7.9. This was followed by the main idea 3 which says the particles (molecules and atoms) '*are always in motion'*, which was also highlighted as a main idea. As the lesson progressed teacher NN asked learners further questions that relate to the main idea 2 & 1 identified in figure 7.9. This is shown in the excerpt below:

Main idea 1

***Teacher NN:** Why <u>solids</u> have a fixed size and a fixed shape? (Sic) Again you have to mention how the particles are packed and the kinetic energy*

***Ngozi:** sir, their molecules are so close together, they are close to each other. Their energy is lesser.*

***NN:** ok*

***Kamo:** their molecules are attracted to one another by force of attraction*

Main idea 2

***Teacher NN**: you talked about the forces of attraction but not about the kinetic energy of the <u>molecules themselves</u>. You need to mention that they don't have enough kinetic energy to move away from that <u>attractive force</u>. So guys always mention the energy of the particles and probably the attractive forces.*

In order to bring up the main idea of forces of attraction between the molecules, teacher NN asked the learners about the shape of solids. For learners to understand the main idea of phases of matter, knowledge about the strength of attractive forces is needed. Hence teacher NN had emphasised the idea of attractive forces which would assist them in explaining how

the particles are arranged. These two main ideas were also identified in teacher NN's post-test response as shown in figure 7.9.

Other evidence of a shift in *curricular saliency* was evident from teacher ZD, where the NUGTs were asked about the topics in chemistry that require the understanding of particle nature of matter. Teacher ZD responded as follows in both tests as shown in figure 7.10 below:

Pre

3.4 What other topics in chemistry do you think require the understanding of particle nature for teaching them?

Chemical reactions & equations.

Phases of matter.

The mole concept.

Post

3.4 What other topics in chemistry do you think require the understanding of particle nature for teaching them?

Other topics that require the understanding of particle nature are chemical reactions, bonding theories, ~~and~~.

Redox reactions and

Figure 7.10: Teacher ZD's pre and post-test response to the question of curricular saliency

All the topics suggested by teacher ZD above in both pre and post-tests are correct. This was made easy because the particulate nature of matter is a basic category of the chemistry curriculum and a precursor for all later learning in chemistry. It can therefore be safely assumed that it is for this reason that the NUGTs found the category 'curricular saliency' the least difficult relative to others as shown table 7.3 In her pre-test response teacher ZD did not include 'bonding' as the topic that requires the understanding of the particulate nature of matter. However, 'bonding' was included in her post-test response. What makes 'bonding' topic exceptional in this case is that it is the only topic within all those selected in figure 7.10 that teacher ZD referred to during her teaching of the particulate nature of matter as part of the category *curricular saliency*. An excerpt below shows evidence of the curriculum awareness from teacher ZD.

***ZD**: let's look at H. What is the atomic number for hydrogen?*

***Learner Nxobi**: one*

***ZD**: one ok the atomic number. Guys look at the things-when I say look at it look at it. So how many protons does hydrogen have?*

***Learners (chorusing)**: one*

***ZD**: how many electrons?*

***Learners (chorusing)**: one*

***ZD**: what is the charge here?*

***Learners (chorusing)**: neutral*

***Teacher ZD**: so hydrogen uses an electron. It decided to give away its electron to another element*

***Learner Maggie**: why?*

***Teacher ZD**: because it can. It only has one valence when we get to the electron configuration. We will get to the why when we do bonding you will understand how you place the electrons. And why it is easier for some elements to give away and some to take. We will still get there ok. For the sake of avoiding confusion, just take my word as is for now. We are getting there guys as to why hydrogen gives away its electron instead of taking something else. Just keep it at the back of your head we will get there.*

In the excerpt above teacher ZD was teaching learners about atomic number. It happens that she mentions that hydrogen could give away the one electron and learner Maggie needed to know why. In her response, teacher ZD illustrated her understanding of curriculum awareness with regard to the depth to which a topic should be covered. This was evident in her response to learner Maggie that says *'we will get to it when we do bonding…'.* This response suggests that teacher ZD was aware that explaining what bonding is at this stage might confuse the learners. According to Geddis, Onslow, Beynon, & Oesch (1993), *curricular saliency* shows how important a particular science concept is to the overall curriculum. Therefore one might argue that teacher ZD included 'bonding' as a topic that requires the understanding of the particulate nature of matter in her post-test because of her teaching experience illustrated in the above excerpt.

7.3.3 Evidence of emerging Topic Specific PCK when engaging with Representations

The category of *representations* was found to be the middle category according to the Rasch scores. This implies that the NUGTs found it neither easy nor difficult. However, it is important to present qualitative evidence to support the Rasch measurement. Figure 7.11 shows the models/representation that the questions were based on. This category consisted of three questions. The first question required the NUGTs to explain what they liked and didn't like about each of the representations. Secondly, they had to indicate which one of the representations they like most. Finally the NUGTs had to explain how they would use the representation they like most when teaching. In the discussion to follow, a case of teacher ZD's pre- and post-test responses to the questions on the *representations* category will be looked into.

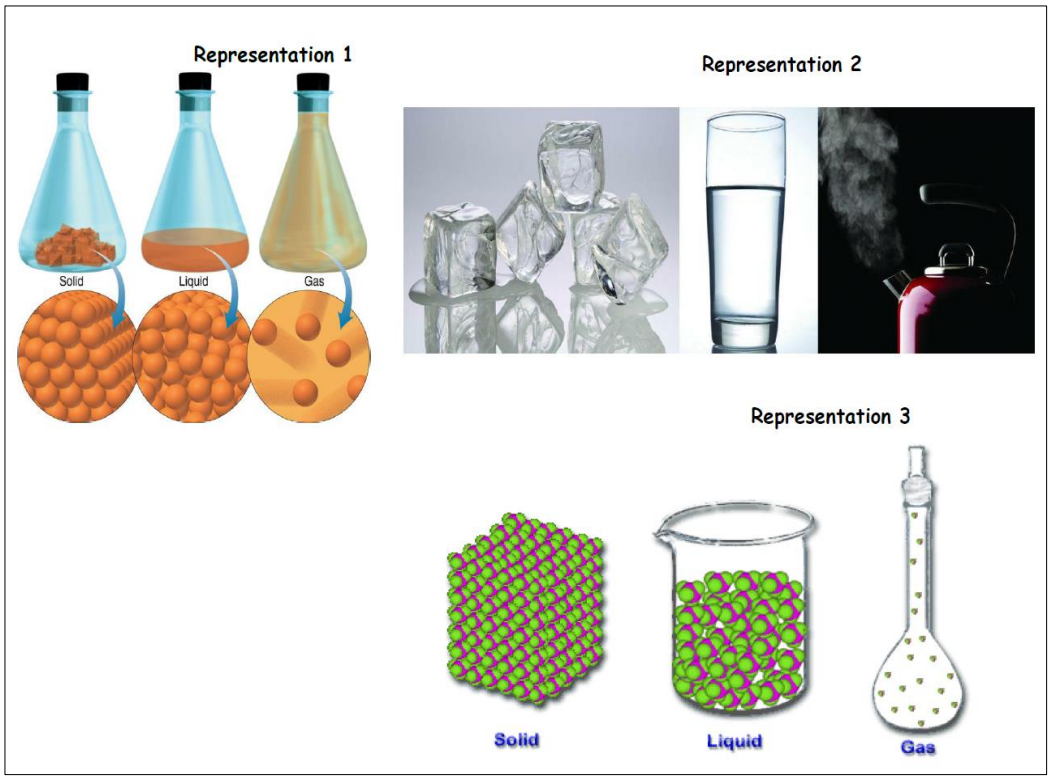


Figure 7.11: A list of representations from both the pre- and post-test given to the NUGTs to choose from

Teacher ZD's responses in all three questions suggests that there was a shift in her knowledge and understanding of *representations*. I will firstly look at her response to the first question which suggests that there were cases in the pre-test where she was unable to respond because she did not attempt to complete and were left blank as shown in figure 7.12 below. It can therefore be assumed that teacher ZD did not know about them, hence she portrayed poor understanding of types of representations. However, she responded to all the parts that needed to be completed in her post-test.

Pre

Representation No.	What I Like	What I do not like
1	The different phases are well represented in each flask. There is no room for confusion.	
2	It is done using water, Something we encounter on a daily basis. It is easy to relate to since we see these phase changes almost everyday.	
3		The pictures are misleading might end up thinking that when moving from solid to liquid the particle size increases and decreases when moving to the gas phase.

Post

Representation No.	What I Like	What I do not like
1	The phases are represented in a way that we normally see them. There is also a representation of the different phases of the particles.	There is not that much difference between the particles of the solid & liquid phase. The number of particles is not the same which will create confusion.
2	Water is easy to relate to and everyone has seen the phase changes of water.	No particle representation. This makes it hard for learners to fully grasp what is happening in a subatomic level.
3	The spacing between the particles in the 3 phases is nicely represented.	It does not seem like the same substance is being represented because the particles are different sizes. It will lead learners to think that particles expand when the phase becomes liquid & shrink when it is gas.

Figure 7.12: Teacher ZD's response to the first question of the category 'representations'

Another difference that may provide evidence of teacher ZD's growth is that in her pre-test the responses to the first question were general. This means that they were not displayed in a learner context as she has done in most of her circled responses in the post-test. In her post-test response teacher ZD has mentioned and related to the learners explicitly, while in her pre-test words such as 'we' and 'you' were often used as shown in figure 7.12 above. One may assume that while responding to the pre-test teacher ZD might not have seen herself as a teacher. However, the post-test response suggests that teacher ZD was responding more like a teacher.

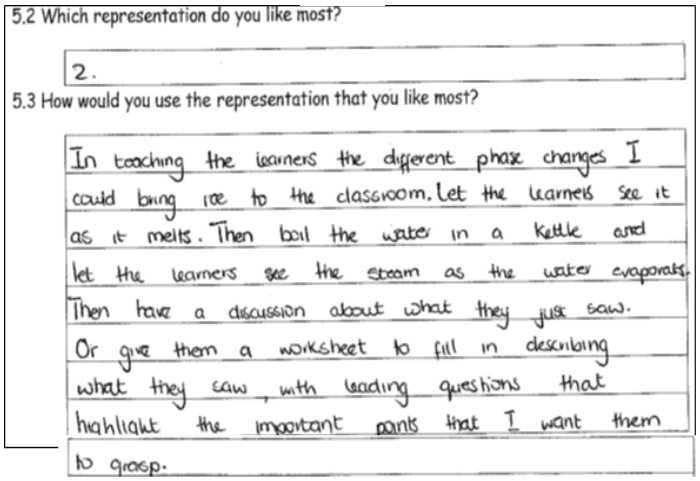
The main finding that came out of figure 7.12 is with 'Representation number 2'. In the pre-test teacher ZD did not comment on what she did not like about the representation. This suggests that she liked the representation that is macroscopic in nature, which was also her choice in question two and ultimately the third one, which is discussed later. It must be acknowledged that teacher ZD's comment on particles in Representation number 3 in the pre-test response was a good one in that she realised that the size of particles are not the same in different phases.

However, after going through the PDI (in particular teaching the lessons on the particulate nature of matter), teacher ZD had something to say about her dislikes. Her post-test response suggests that she now realised that representation number 2 has no representation representing the particulate level, which could assist learners in understanding what is happening at the sub-microscopic level. This response provided by teacher ZD is what the particulate nature of matter is really all about, as understanding the concepts at the particulate level is that core. The other findings from teacher ZD that showed evidence of growth is the following that has emerged from the dislikes in Representation 1 and 3 of her post-test response which were not identified in the pre-test response:

- Representation 1 should show an equal number of particles in all the three state
- Representation 3 should show all the particles equal in size irrespective of the phase they are found in

In terms of question two of the representation, her choice in the pre-test was a macroscopic representation of the phases of matter which is the second representation as shown in figure 7.13 below. This is not surprising taking into account that she could not comment about the dislikes on the representation in figure 7.12.

Pre

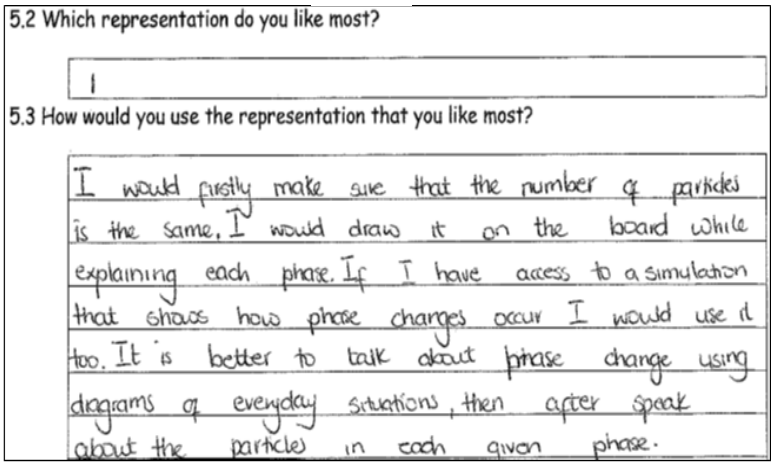

5.2 Which representation do you like most?

2.

5.3 How would you use the representation that you like most?

In teaching the learners the different phase changes I could bring ice to the classroom. Let the learners see it as it melts. Then boil the water in a kettle and let the learners see the steam as the water evaporates. Then have a discussion about what they just saw. Or give them a worksheet to fill in describing what they saw, with leading questions that highlight the important points that I want them to grasp.

Post


5.2 Which representation do you like most?

1

5.3 How would you use the representation that you like most?

I would firstly make sure that the number of particles is the same, I would draw it on the board while explaining each phase. If I have access to a simulation that shows how phase changes occur I would use it too. It is better to talk about phase change using diagrams of everyday situations, then after speak about the particles in each given phase.

Figure 7.13: Teacher ZD's response to the second and third question of the category 'representations'

Teacher ZD's explanation on how she would use the representation is limited to the use of macroscopic representation only. The preferred representation is not linked to the sub-microscopic explanation. However, in the post-test teacher ZD acknowledged that both macroscopic and sub-microscopic representations should be used when teaching phase change. This is suggested by her idea of using diagrams learners can relate to and also explaining the arrangement of particles in each phase. Evidence that showed that teacher ZD emphasised the sub-microscopic representation is the idea of using simulations. In most cases simulations are representations of what cannot be seen directly. Based on the reasons alluded to, it can be assumed that teacher ZD was able to link the two representations. However, it is important to investigate what might have contributed to teacher ZD's growth in terms of making use of multiple meanings in chemistry that is seen on her post-test's response. The following excerpts below highlight an instance where teacher ZD incorporated multiple levels of representations.

> ***Teacher ZD:*** *before we went to the lab (writing on the board-Phase changes). We talked about the rise in and decrease in temperature. And I have asked you guys what is so important about temperature*
>
> ***Learner Sisipho:*** *Kinetic energy increases*
>
> ***Teacher ZD:*** *(capture on the board -increase in kinetic energy of the particles). I want you to be able to explain the motion of particles when you increase temperature when you have a solid what happens to the particles in there. What happens when you have a phase change, when you move from solid to gas? So with solid they were vibrating about their rest position neh (ok)? So say now we add some heat to that. Say there its block of ice neh (ok) all the particles are vibrating there and we take a block of ice we put it a block on a stove and we switch on a stove. So heat is getting on to that (drawing a representation on the board). So*

<u>when you add heat to the pot, the pot heats up the ice. So what actually happens to the particles?</u> What is the first thing that will happen?

Learners (chorusing): *Miss they will be separate*

Teacher ZD*: (capturing separation on the board). If you say there is separation between the particles, what do you say about the forces now? The intermolecular forces are they strong as they were when they were still solid*

Learners (chorusing: *No Miss*

Teacher ZD*: what can you say about the forces that were holding them together?*

Learner Sisipho*: they are no longer strong Miss*

Teacher ZD*: they are not as strong. Forces are not as strong as they become liquid. These are the intermolecular forces neh (ok). We are talking about the intermolecular forces. If I ask you what are the forces in between the molecules you must be able to give me the name. The particles in solid start to separate because they are no longer held together as strong.*

In the excerpt above teacher ZD used both the macroscopic and sub-microscopic representations. A macroscopic representation was represented by the block of ice to be heated. This is something that learners are able to see directly. The teacher further introduced the sub-microscopic representation when indicating to the learners the particles (which a learner did not mention in the excerpt above) of the ice vibrates and also the presence of intermolecular forces. Learners are not able to see both the particles and forces in this regard, but might be able to imagine them based on the macroscopic representation. Teacher ZD also showed the learners a sub-microscopic representation of different phases of matter. Figure 7.14 shows how teacher ZD represented the block of ice in a sub-microscopic representation.



Figure 7.14: Teacher ZD's sub-microscopic representation of a solid

Teacher ZD further used this representation to show the learners that even in solids there are small spaces in between the particles. In order to assist learners to see the spaces in the representation, she shaded the area in red as shown in figure 7.14. Another sub-microscopic

representation used was in the form of a PHET simulation in figure 7.15 (www.phet.colarado/edu/)

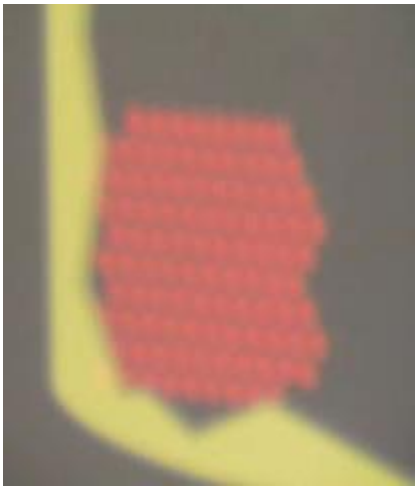


Figure 7.15: Teacher ZD's sub-microscopic representation of a solid (simulation)

Teacher ZD utilised the simulation because she needed to show the learners that the solid particles also move just like the liquids and gases. Although this cannot be observed clearly from figure 7.15, the simulation shows the solid particles vibrating (http://phet.colarado/edu/en/simulations/states-of-matter). The use of illustration was also acknowledged as important by teacher ZD in the respond about her experience in teaching the particulate nature of matter. Her response from the reflective questionnaire is shown below in figure 7.16:

(iv) How did you find the teaching of the topics you mentioned above?

Teaching concepts of things that can not seen is hard, you need to have models and a lot of visual aid. The more visual the lesson the better.

Figure 7.16: Teacher ZD's response from the reflective questionnaire about the experience of teaching the particulate nature of matter

She has emphasised the use of visuals in order to assist learners in conceptualising abstract concepts. This was evident in her teaching as she has utilised the sub-microscopic representations which included both diagrams and simulations.

7.3.4 Evidence of emerging Topic Specific PCK when engaging with 'what is difficult to teach'

Although there was a slight improvement in this category in the post-test, it has still proven to be difficult for NUGTs as shown in the Rasch measure category ranking in table 7.3. This may be attributed to NUGTs' lack of teaching experience. But there was observed evidence which may account for the slight shift in this category. This evidence is drawn from different case study teachers' responses. The question asked for this category was: *what is difficult to teach*. This was followed by a list of possible concepts. Teachers were expected to choose a concept and make explicit what makes that concept difficult to teach. Teacher DN responded as follows in both her pre- and post-test:

Pre

Concept	✓	What exactly makes it difficult?
There is an empty space between particles of matter		

Post

Concept	✓	What exactly makes it difficult?
There is an empty space between particles of matter	✓	Learners believe that in a solid state there is no empty space between the particles therefore they assume that the only place where the particles have space between the particle is when they are in a gaseous state.

Figure 7.17: Teacher DN's pre and post-test response to the category 'What makes the topic difficult to understand'

In her pre-test response teacher DN did not anticipate that the concept of 'empty spaces between particles of matter' could be a difficult concept to teach. This is suggested by her response in figure 7.17 in the pre-test which is not ticked nor completed. However, in her post-test response teacher DN recognised the difficulty learners have in terms of understanding the existence of empty spaces between particles and particularly in solids as she has identified. It is evident that this is what teacher DN experienced during her teaching as shown in the excerpt below:

> ***Learner Dumi****: Miss I learn this from primary and some people like to say solid is something that is….. (not clear) purely how can it have spaces?*
>
> ***Teacher DN:*** *Ok she is saying a solid is something that is…I think I get what you saying. Like this (touching a table) is a solid, if you can't see the spaces in between the particles that makes up this thing. But if you have to break it down to a very small small small small small small small small small small (learners and teacher DN laughing) small size you know we normal people have no privilege to see. There are actually spaces in between the particles. (Sic)*

It can be deduced from the excerpt above that teacher DN is making learners aware that the spaces between particles do exist. However, they are at microscopic level. This implies that they can't see them with their naked eyes. Teacher DN further indicated this learner difficulty in her after observation interview shown below:

> ***Me:*** *Were there any students' misconceptions you identified during the class that you have not known?*
> ***Teacher DN:*** *Yes. The learner' thinking that particles are squashed together and there is no space between the particles of the solid*
> ***Me:*** *If yes, how did you respond to challenge the misconceptions?*
> ***Teacher DN:*** *I corrected them and told them that the spaces are too small they can't see but are there*

The interview excerpts show that teacher DN did not only see that this concept is not easily understood by the learners but as also carrying a misconception. It can be assumed that although learners may understand that there are spaces in between the particles, they tend to think that those spaces don't exist in the solid phase due to the particles being closely packed.

The concept of 'an empty space between particles' being difficult to teach was also confirmed in the post-CoRe that was done by teacher DN with members of her group. The group was responding to the prompt "what do you consider easy or difficult in teaching the big idea": there are empty spaces between particles that makes up matter. Teacher DN's group responded as follows:

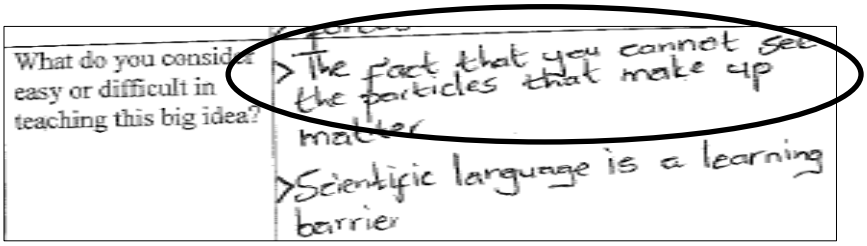


Figure 7.18: Teacher DN's group's post response on the prompt 'what do you consider easy or difficult in teaching this big idea

The circled response from teacher DN's group in figure 7.18 above confirms what was already seen from her lesson and the post observation interview. However, it should be acknowledged that although this response does not come entirely from teacher DN, the fact that she was part of the group may suggest that she might have contributed to the response given in the prompt in figure 7.18.

Other evidence on '*what makes the topic difficult to understand'* was observed from teacher ZD. In both her pre- and post-test responses she identified the concept of 'finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$' as difficult to teach or understand by the learners. Figure 7.19 displays how she responded in both tests with regard to the concept.

Pre

Concept	✓	What exactly makes it difficult?
Finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$	✓	If the learner does not know how to calculate the number of electrons from information given or knowing what the numbers at the top and bottom mean, then it will be hard to do the calculations.

Post

Concept	✓	What exactly makes it difficult?
Finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$		It tends to be hard to understand why there are less electrons when the charge is positive. The learners link the "+" sign with the idea that there is more of the particle in question (electron).

Figure 7.19: Teacher ZD's pre and post-test response to the category 'What makes the topic difficult to understand' for the concept 'finding number of electrons in an ion'

The way in which ZD explains what is difficult about the concept in her pre-test was not explicit. ZD indicates only the procedural processes that involve calculation of number of electrons with little elaboration on conceptual issues, hence it is mechanical. It is for this reason that ZD was scored "limited" because the reason for the selected concept was neither clear nor abstract, which could have placed her under level 2 or "basic" (see appendix H).

However in her post-test, ZD's response was classified at the developing level. As required by the rubric , ZD was not only able to indicate that learners found difficulty in understanding why there are fewer electrons when there is a positive charge but also justified why this may be the case based on their prior knowledge. She indicated that learners tend to link the positive sign to the word 'more' or 'many', which they use everyday life. This kind of response portrays good PCK of a teacher. It shows that ZD has engaged in some kind of teaching which might have influenced her response. Shown below is evidence in the form of an excerpt of ZD's lesson on 'Atoms'.

***Teacher ZD**: so hydrogen has one it gives away its electron how many electrons does it have*

***Learners (chorusing)**: Zero*

***Teacher ZD**: so what is the charge now?*

***Learners (chorusing)**: some negative and other positive*

***Teacher ZD**: so the charge is positive (capturing + on the board). So if you lose an electron you are left with a positive charge. If you gain an electron, you are left with a negative charge. For you to be charged is either you gain an electron or lose an electron. If you gain it, now you have more electrons than protons. If we were to add an electron to say Cu, which has 29 electrons and 29 protons if you add one electron, how many electrons will be there?*

***Learners (chorusing)**: 30*

***Teacher ZD**: you have 30 now. Is less or more than 29?*

***Learners (chorusing)**: more*

***Teacher ZD**: so what will the charge be?*

***Learner**: negative*

***Teacher ZD**: so if you gain an electron, your charge becomes negative. It you lose, you become positive*

The excerpt above shows that ZD had encountered the concept as difficult in her teaching. This is supported by the learners' response when asked about the charge of hydrogen where some of them said positive while others said negative. It can be assumed that it is from this response where ZD realised that this concept is not easy for learners, therefore confirming her choice of concept in her post-test. However, what is interesting is that the manner in which she took learners through in making them understand the concept has nothing much to do with how she responded in her pre-test but resonates more with her explanation in her post-test. For example, it can be deduced from the excerpt above that learners seem to have a problem with the charge type, as in when it becomes a positive or a negative. ZD's explanation to the learners about the charge type was more on the gaining and losing electrons which results in either negative or positive charges. She even went on to give examples using learners themselves as atoms first and later using Cu so that they can understand the charges.

The concept 'particles are in constant motion' also contributed to the slight shift observed in this category. A case of teacher ZD is looked into for this concept. There were other case study teachers who chose this concept but did not elaborate more on it in their teaching, unlike ZD. The reason for choosing ZD is that in her pre-test she did not identify this category as difficult. However, the concept was identified in her post-test as difficult to the

extent that she emphasised it in her lesson, the CoRe and in her reflection questionnaire. Figure 7.20 below shows her responses for both the pre- and post-test.

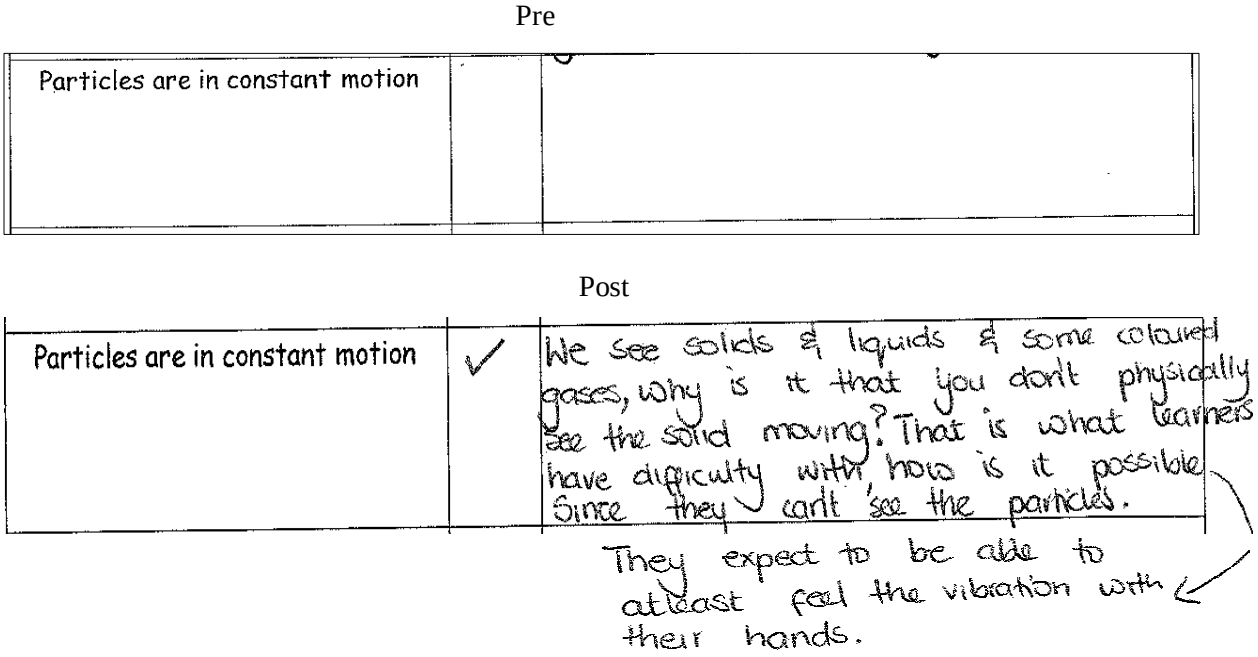


Figure 7.20: Teacher ZD's pre and post-test response to the category 'What makes the topic difficult to understand' for the concept 'particles are in constant motion'

Teacher ZD' response suggests that it was not easy for her to teach and demonstrate to the learners the solid particles that are in motion. She further acknowledged that the movement of liquids and gases is easier to notice; solids appear to be more stable in position at the macroscopic level.

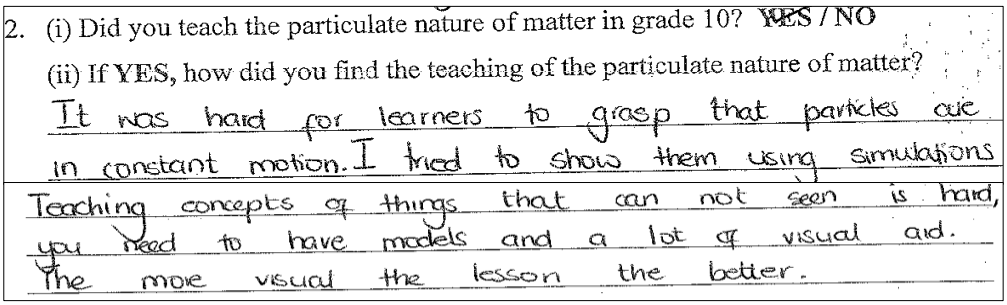
The excerpt below shows teacher ZD teaching about the kinetic molecular theory. She has divided learners into three groups of 10 to act as liquids, solids and gases. Learners were requested to come in front to simulate the particles of each state. Prior to the solids, the liquids and gases had demonstrated correctly in terms of spacing, ordering and movement of the particles. The excerpt below shows what has unfolded in her lesson in terms of the solid simulation.

> ***Teacher ZD:*** *ok so now let's start the solid. Where are the solids? It is not just one solid (phela) in fact (Sic)*
>
> ***Solids Learners****: (are preparing to come in front to demonstrate the movement of solid particles).*

(Solid representation-Simulation)-The ten learners are holding each other's hand and tightly leaning against each other.

***Teacher ZD**: Move phela (in fact) particles are never just constant - (learners started to vibrate the bodies while holding on to each other).*

From the excerpt above it can be deduced that for the solid simulation learners were not showing any kind of movement. The learners started shaking their bodies as soon teacher ZD intervened and reminded them that 'particles are never just constant'. It should be mentioned that while demonstrating the liquids and gases, although not included, the movement was visible and teacher ZD did not remind them. Although in the beginning of the lesson teacher ZD has emphasised the concept of particles always being in constant motion regardless of the phase they are found in, learners were unable to grasp and incorporate that concept when simulating the solid particles. Teacher ZD did not only identify this concept in her post-test but also stated it in the reflective questionnaire shown below:


2. (i) Did you teach the particulate nature of matter in grade 10? ~~YES~~ / NO

(ii) If YES, how did you find the teaching of the particulate nature of matter?

It was hard for learners to grasp that particles are in constant motion. I tried to show them using simulations

Teaching concepts of things that can not seen is hard, you need to have models and a lot of visual aid. The more visual the lesson the better.

Figure 7.21: Teacher ZD's response from the reflective questionnaire about the teaching of the particulate nature of matter

Teacher ZD's answer to the question above in figure 7.21 confirms what she has experienced during her lesson as well as her response to the post-test in figure 7.20. The answer shows explicitly that she found teaching concepts that learners cannot see as not easy. However, she acknowledged that the use of representations (which is shown in her teaching excerpt above) was useful.

The difficulty of the concept was also confirmed in teacher ZD's group post-CoRe in figure 7.22. The group was responding to the CoRe prompt 'what do you consider difficult or easy in teaching the big idea-particles are in constant motion'.

	Pre	Post
What is difficult to teach		
What do you consider **easy or difficult in teaching this big idea?**	Difficult that a lot of factors causes the molecules to move and not just energy. That there are also forces involved also the average distances between solids + liquids is relatively the same but the major jump is in gases have a significant difference due to these forces.	- Hard to understand the idea that particles are always in constant motion when the object is stationary especially if the particles are in a solid state.

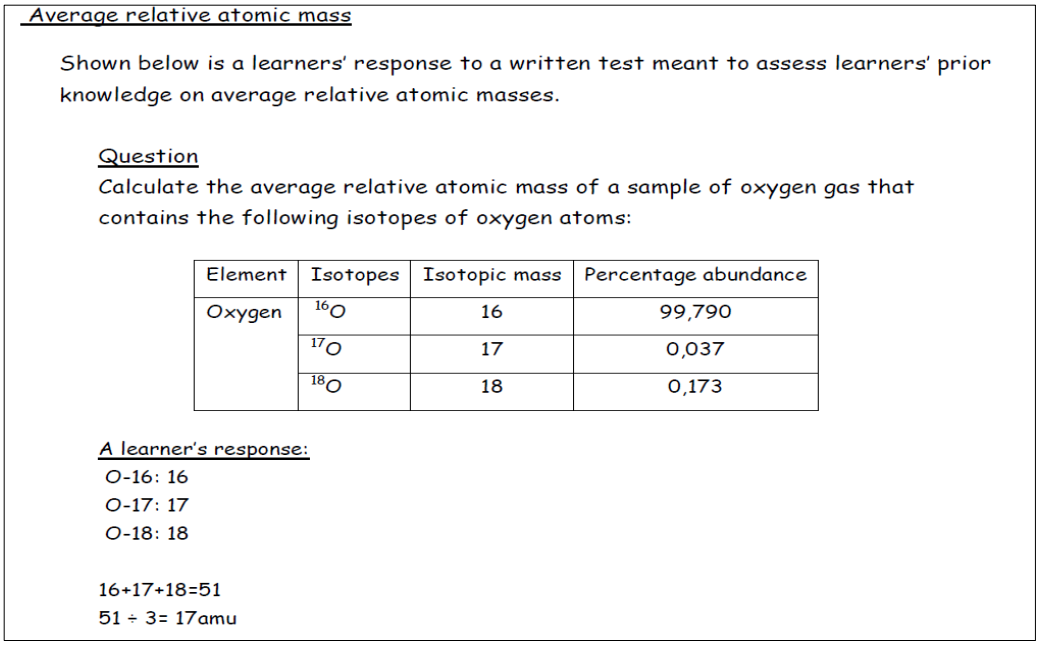
Figure 7.22: Teacher ZD's group pre and post CoRe response on the prompt 'what do you consider easy or difficult in teaching the big idea'

There was an improvement from the pre-CoRe's response to the post-CoRe. In the pre-CoRe the group had assumed that factors such as energy and forces would be difficult when teaching this big idea. However, in their post-CoRe that turned out to be completely different. Their response to the prompt supported and confirmed the concept teacher ZD has identified as difficult, making learners understand that particles are always in constant motion. The group also state it explicitly particularly the solid particles, since they don't appear to be moving even from the macroscopic point of view.

7.3.5 Evidence of emerging Topic Specific PCK when engaging with the conceptual teaching strategies

The category *conceptual teaching strategies* remained the most difficult for NUGTs in both pre- and post-Topic Specific PCK test. Unlike the other four categories the *conceptual teaching strategies* showed only a slight improvement in the post-test relative to the pre-test as shown in table 7.3. The Rasch measure in NUGTs' pre-test for this category was 2.93 while the post-test improved to 2.89 According to the Rasch model, the higher the Rasch measure the more difficult the category. The slight improvement may suggest that most NUGTs struggled in terms of understanding and engaging with this category. Most of the NUGTs in the pre-test scored *limited* and some shifted slightly to the *basic* level in the post-test. In the discussion to follow evidence of cases where slight growth took place will be looked into. However, it is equally important to also look at the cases where NUGTs struggled as this category has proven to be the most difficult as compared to others in both tests. In the question on the *conceptual teaching strategies*, NUGTs were asked about how they would teach the lesson on the concept of average relative atomic mass of a sample of

oxygen gas that contains certain isotopes of oxygen atoms. They had to take into account a learner response given in figure 7.23.



Average relative atomic mass

Shown below is a learners' response to a written test meant to assess learners' prior knowledge on average relative atomic masses.

Question

Calculate the average relative atomic mass of a sample of oxygen gas that contains the following isotopes of oxygen atoms:

Element	Isotopes	Isotopic mass	Percentage abundance
Oxygen	^{16}O	16	99,790
	^{17}O	17	0,037
	^{18}O	18	0,173

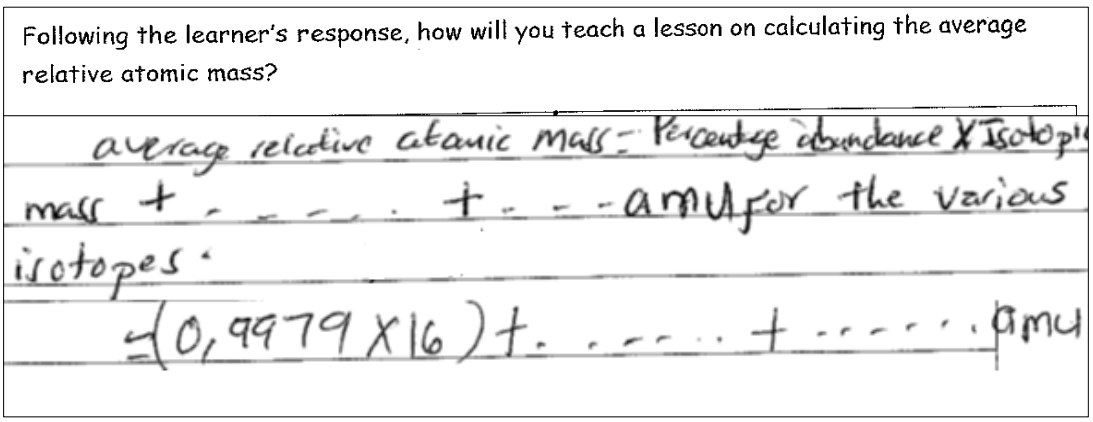
A learner's response:

O-16: 16
O-17: 17
O-18: 18

16+17+18=51
51 ÷ 3= 17amu

Figure 7.23: Learner response to category Conceptual Teaching Strategy question in the Topic Specific PCK test

Shown in figure 7.24 is teacher SS's pre-test response to the question. The response suggests that teacher SS has an idea of how average relative atomic mass is calculated. He is aware that the average relative atomic mass takes into account the percentage abundance and the isotopic mass. But it appears as if teacher SS has found it difficult because he has not shown explicitly how he can teach the concept. It is for this reason that he was scored at *limited* level of the rubric (see Appendix H).



Following the learner's response, how will you teach a lesson on calculating the average relative atomic mass?

average relative atomic mass = Percentage abundance X Isotopic mass + ... + ... amu for the various isotopes:

= (0,9979 X 16) + ... + ... amu

Figure 7.24 Teacher SS's pre-test response to the question of category 'conceptual teaching strategies'

However, there was some improvement in his post-test response shown in figure 7.25 below. He was able to acknowledge and confront a misconception by indicating that learners were not supposed to divide by 3 as done in figure 7.23. The teacher also explained how the learners should go about correcting the error. An aspect with regard to *curricular saliency* is with regards to the sequencing. The teacher suggested that learners' should have an understanding of what an isotope is prior to doing the questions asked.

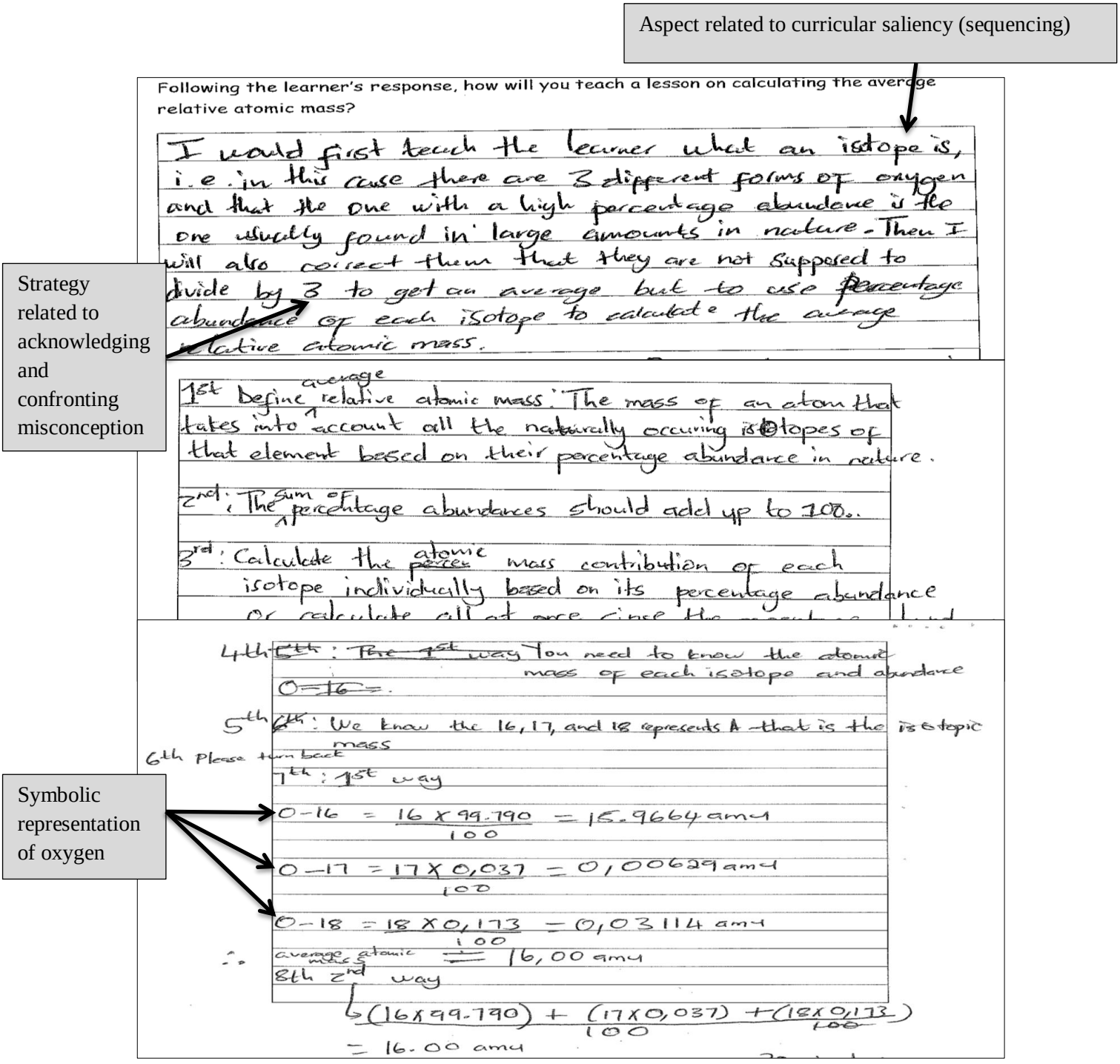


Figure 7.25 Teacher SS's post-test response to the question of category 'conceptual teaching strategies'

The use of representation also emerged in teacher SS' response but was only limited to symbolic representation, which is not considered conceptual. The fact that teacher SS reinforces the concept of relative atomic mass by considering an aspect related to *curricular saliency* and taking learners' *misconception* as well as the use of symbolic *representation* indicates that he was approaching the answer conceptually. Taking into consideration all his responses, teacher SS was placed at the *developing* level of the rubric. This implies that the overall strategy was workable. But what had prevented teacher SS from being placed on the *exemplary* level is that he did not incorporate the use of sub-microscopic representations and also failed to show how he would engage the learners during the teaching of the concept.

For NUGTs who obtained a slight improvement, a case of teacher NN's pre- and post-test response is considered below. In both the pre- and post-test responses teacher NN clearly shows the steps that a learner should follow in order to get the question correct. However, in his pre-test response, there is no (i) acknowledgement or confirmation of prior knowledge and misconceptions (ii) evidence of the use of two levels of representations (iii) aspect related to *curricular saliency* and (iv) learner involvement needed to understand the concept of average relative atomic mass as required by the rubric. Thus teacher NN was scored as "limited" in the pre-test.

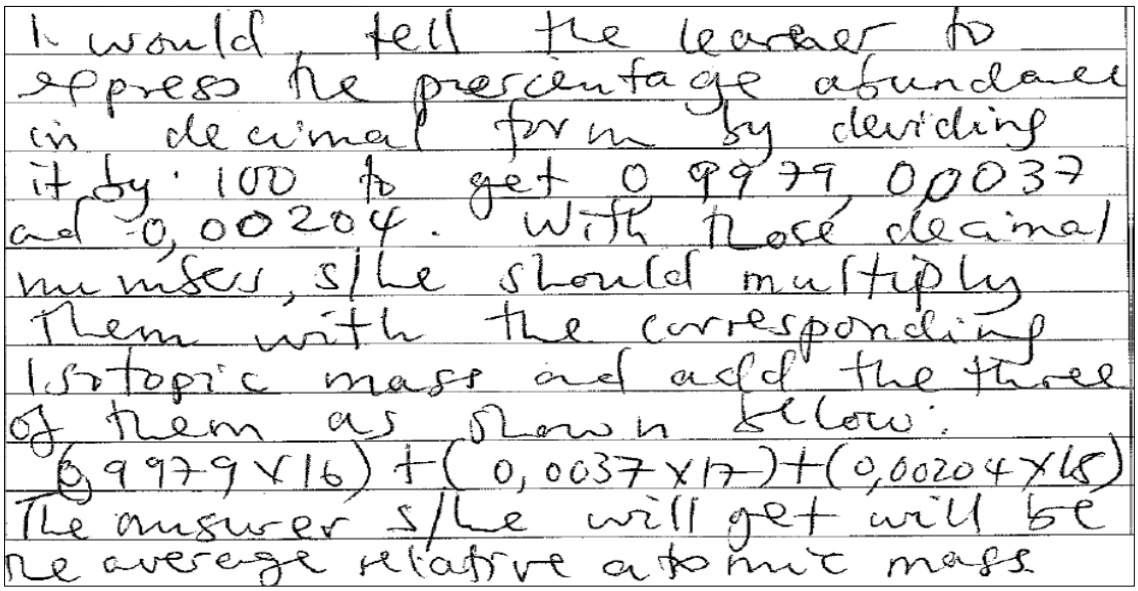

I would tell the learner to
express the percentage abundance
in decimal form by dividing
it by 100 to get 0,9979, 0,0037
and 0,00204. With those decimal
numbers, s/he should multiply
them with the corresponding
isotopic mass and add the three
of them as shown below:
(0,9979 x 16) + (0,0037 x 17) + (0,00204 x 18)
The answer s/he will get will be
the average relative atomic mass

Figure 7.26 Teacher NN's pre-test response to the question of category 'conceptual teaching strategies'

The post-test response, however, is almost similar to the pre-test response as the teacher also resorted to the calculations. However, the only difference is that teacher NN acknowledges *learners' prior knowledge* in that, learners should recall that 'percentage means out of 100'

and the use of symbolic representation as shown in figure 7.27 below. But there was still lack of evidence on the use of sub-microscopic representation, aspects of *curricular saliency* and learner involvement. It is for this reason that teacher NN was placed at the *basic* level in the post-test.

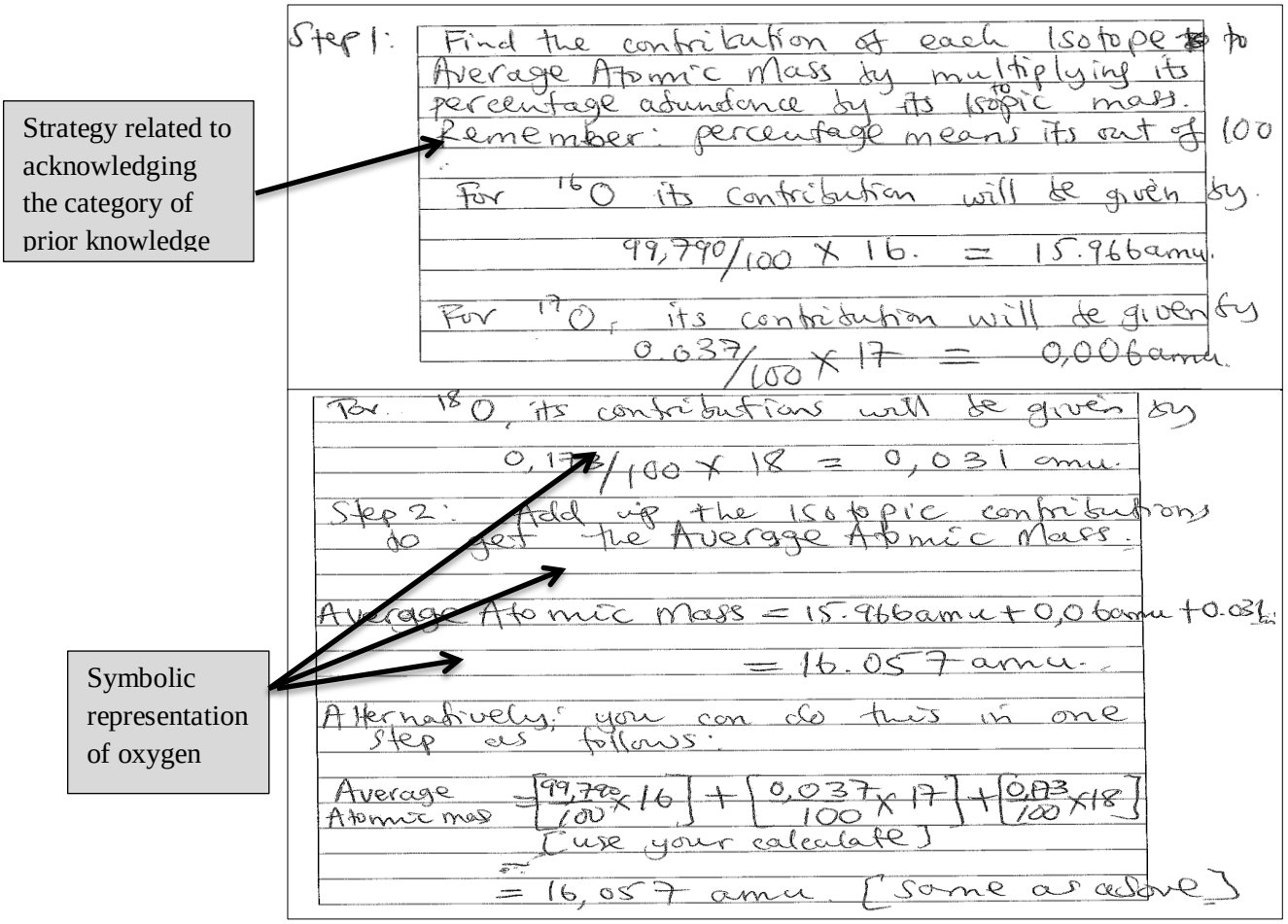
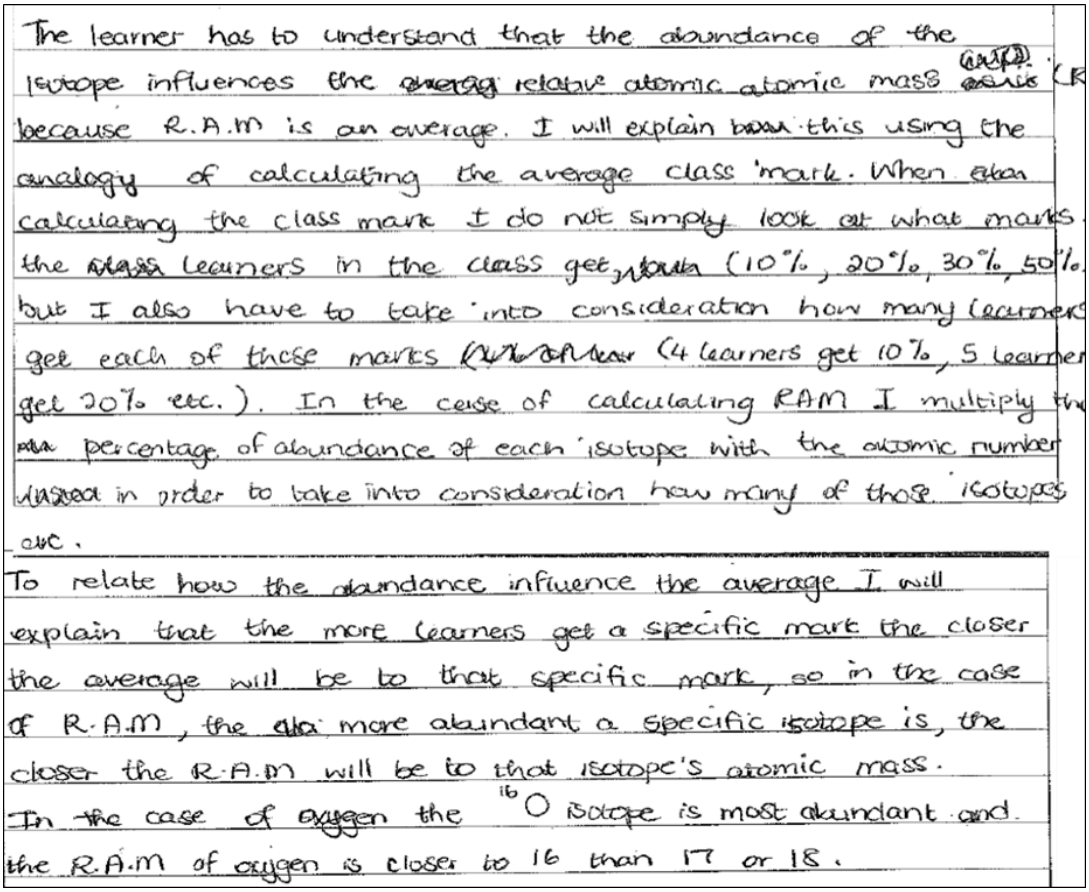


Figure 7.27 Teacher NN's post-test response to the question of category 'conceptual teaching strategies'

In both tests, the type of response given by teacher NN is merely mechanical and procedural rather than emphasising the concepts. Therefore this type of response has accounted for a negligible improvement seen in NUGTs in terms of *conceptual teaching strategies* category.

Both teacher SS and NN's response is contrasted with teacher TM who scored 4 (exemplary level) as shown in Appendix H. Although teacher TM is not a case study teacher, the idea here is to show how she conceptually answered the question. Her response on the *conceptual teaching strategy category* is shown in figure 7.28.


The learner has to understand that the abundance of the isotope influences the relative atomic mass because R.A.M is an average. I will explain this using the analogy of calculating the average class mark. When calculating the class mark I do not simply look at what marks the learners in the class get, (10%, 20%, 30%, 50%) but I also have to take into consideration how many learners get each of those marks (4 learners get 10%, 5 learners get 20% etc.). In the case of calculating RAM I multiply the percentage of abundance of each isotope with the atomic number instead in order to take into consideration how many of those isotopes etc.

To relate how the abundance influence the average I will explain that the more learners get a specific mark the closer the average will be to that specific mark, so in the case of R.A.M, the more abundant a specific isotope is, the closer the R.A.M will be to that isotope's atomic mass. In the case of oxygen the ^{16}O isotope is most abundant and the R.A.M of oxygen is closer to 16 than 17 or 18.

Figure 7.28 Teacher TM's post-test response to the question of category 'conceptual teaching strategies'

In her response, TM was able to consider *learners' prior knowledge* such as the need for them to have a clear understanding of isotopes. An aspect with regard to *curricular saliency* was shown by teacher TM in that learners' should understand that abundance of isotopes influences the relative atomic mass. She used a representation in the form of an analogy involving calculating the average class mark which was linked to the symbolic level of representation only. The teacher also confirmed that there is a misconception on how learners responded to the question. The fact that teacher TM reinforces the concept of relative atomic mass using the different levels of representations as well as taking into account *learners' prior knowledge* and *curricular saliency* indicates that she was approaching the answer conceptually, which is in contrast with teacher SS and NN who were approaching it procedurally and mechanically. Taking into consideration all her responses, TM was placed at the exemplary level of the rubric.

7.4 Concluding Discussion

The findings in terms of the Topic Specific PCK test confirm that both the reliability and validity indices are well within the acceptable ranges. For reliability, this was evident from both the persons and items, where high statistical values were obtained in both the pre- and post-test. The infit and outfit indices values for each NUGTs were found to be within the +2;-2 ranges, therefore indicating a valid construct. The quantitative analysis revealed that there was significant difference statistically with 98% confidence level in both the Rasch measure for the pre- and post- Topic Specific PCK tests. This observed difference indicates that there is evidence of developing Topic Specific PCK of the NUGTs. The quantitative results from Rasch measure order showed that NUGTs found *what is difficult to teach* and *conceptual teaching strategies* categories more difficult than *representations*, *curricular saliency* and *learners' prior knowledge*, which were the least difficult. Similar to Mavhunga (2012)'s findings, the *teaching strategy category* was found to be the most difficult. Like Mavhunga (2012), I attribute this to the cumulative nature of the *conceptual teaching strategies category* making it the most difficult.

The NUGTs' initial knowledge (in the pre-test) about the teaching and learning of the particulate nature of matter was poor. This is based on their Topic Specific PCK scores which were generally low. These results are not surprising because other than not having a teaching qualification, NUGTs did not have appreciable teaching experience at the time, hence it might be expected that they would find the test items difficult. However, an improvement after engaging in the professional development was seen from the mean score, which increased from -1.76 (pre-test) to 0.22 (post-test). This implies that NUGTs' Topic Specific PCK was developing after engaging in the PDI. As expected, the NUGTs who portrayed high Topic Specific PCK are the ones who taught the particulate nature of matter in grade 10, which are the case study teachers, and this is the major finding. The first two teachers (NN and SS) who displayed high PCK after engaging in the PDI are out of field specialists - they are biology majors.

In the categories of *curricular saliency* and *learner prior knowledge*, which remained the least difficult, NUGTs showed even more understanding, hence the refined post-test responses in the cases that were looked into. In terms of the *curricular saliency* there was an improvement in identifying the big ideas in their post-test responses which talks to sequencing. The teachers were also able to recognise the depth to which the particulate nature

of matter should be covered. For the *learner prior knowledge* the NUGTs confidently identified and confronted the misconceptions which was not explicitly done in their initial responses. This was evident in their teaching, the post-CoRe as well as the response from the questionnaire with regard to the particulate nature of matter. The NUGTs' knowledge on the category *representation* has also improved. Initially the use of representation was limited to the macro; however, in the post-test there was evidence of the use of sub-microscopic representation. It was also evident to some extent in their teaching, with teachers showing learners simulations on how the particles move in different phases. The last two categories *what is difficult to teach* and *conceptual teaching strategies* remained the most difficult. This finding is not surprising, considering that NUGTs do not have sufficient teaching experience. Most of the NUGTs would choose a concept they think would be difficult to teach but struggle to conceptually elaborate exactly what learners' would find difficult about it. But with little teaching experience gained, there was some development with regard to the category.

The *conceptual teaching strategy* category has proven to be a challenge for the NUGTs. In both the tests, learner engagement seemed to be missing as well as utilisation of the sub-microscopic representation and more aspects on *curricular saliency* category. It needs to be made explicit to teachers what constitutes topic specific teaching strategies, in order to improve their competence in each category. An improvement in *conceptual teaching strategy*, *what is difficult to teach* and *curricular saliency*, may result in improvement and have a positive effect on their Topic Specific PCK, but this needs to be done topic by topic.

Finally, since the status of NUGTs' CK and Topic Specific PCK before and after the PDI is known, it is worthwhile investigating the relationship that exists between them. Mavhunga (2012) established that there is a close link between these two constructs in pre-service teachers and that teachers with good CK are likely to develop high PCK level, whilst low CK levels lead to low PCK. In my study the relationship between these constructs are investigated quantitatively. A scatter plot for NUGTs was produced from their Rasch person measures for Topic Specific PCK as shown in table 7.2. According to Bond and Fox (2001), the positive or higher the person measure values, the more able the person is and the more negative or lower the person measure values, the less able the person is. Thus NUGTs were defined as having "high" Topic Specific PCK if they obtained the positive Rasch person measure value and "low" Topic Specific PCK when they obtained the negative value. This

implies that zero is considered a cut-off point for NUGTs' Topic Specific PCK. In terms of CK tests, a 50% and above (also considered the cutoff point) was considered a reasonable score for indication of a "high" CK in both pre- and post-tests. However, the NUGTs with the score below 50% were defined as having "low" CK. I should firstly acknowledge that the cut-off point was a sensible decision as it assists in looking into the relationship between NUGTs' Topic Specific PCK and CK and therefore should not be mistaken for a finding. Figure 7.29 shows in the form of scatterplot, the distribution of teachers' Topic Specific PCK and CK with regard to strength before and after the PDI.

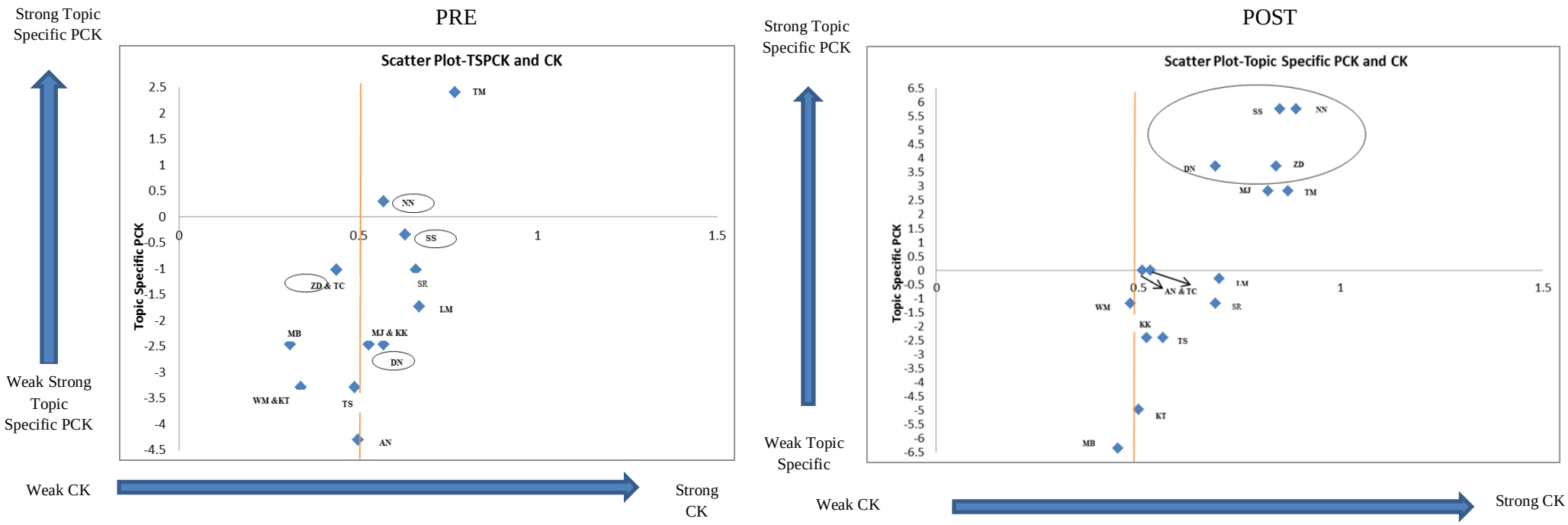


Figure 7.29: Scatterplot for pre and post CK and Topic Specific PCK

The major finding that emerges from the pre and post scatter plots is that the NUGTs who portrayed high Topic Specific PCK were all the case study teachers (circled) excluding TM and MJ as shown in figure 7.29. The improvement in Topic Specific PCK of TM and MJ is justified by the fact that they were engaged with the grade 10 teaching. As I indicated in chapter five, that teacher MJ taught some topics in grade l0 and TM was also involved in a community teaching project which also involved grade 10 teaching. This finding shows that explicit engagement (in particular teaching) with the topic in consideration and some topics that need an understanding of it, yield quality PCK of that topic. It is certain that PCK develops with teaching experience (Van Driel et al., 2002; van Driel et al., 1998).

In considering both scatterplots, NUGTs with high CK, two of them in the pre-scatter (TM, and NN) and six in the post (NN, SS, ZD, DN, MJ, TM) were positioned above the cut-off Topic Specific PCK, while others although with high CK (SS, SR, LM, MJ, and DN) in the pre and (AN, TC, LM, SR, KK, TS and KT) in the post portrayed low Topic Specific PCK. This means that it is possible that some NUGTs with reasonably high CK relative to each other may or may not yield high Topic Specific PCK. Therefore it can be deduced from the scenarios that a teacher with high CK in relation to others is likely to present a strong Topic Specific PCK. This finding is supported by Kind (2009) who argues that good CK enables a teacher to develop appropriate Topic Specific PCK. However, to have high CK does not always imply that a teacher will display high Topic Specific PCK. This may simply be a sign of lack of teaching experience, as is evident in my study taking into consideration the unqualified science graduate status. Kind (2009) argues that over-confidence in one's CK might result in teacher's enacting poor quality lessons, which could ultimately negatively impact one's Topic Specific PCK.

As a result of the selected cut-off, figure 7.29 of the pre- and post-scatter shows that some teachers possessed low CK relative to others. Of these teachers, some of them portrayed low Topic Specific PCK when compared to others in the sample. The findings showing that a low CK leads to low PCK is consistent with Kind (2009) and Rollnick et al. (2008), in that CK is a prerequisite to PCK and that if teachers have limited CK, they may resort to more transmission-based instructional strategies and this impacts negatively on their teaching.

However, some NUGTs who portrayed low CK in the pre-scatter showed some improvement in the post diagram. They portrayed strong CK in the post-scatter except for teacher WM and

MB, as shown in figure 7.29. It is important to highlight that portraying low CK even after engaging in the PDI does not imply that teacher WM and MB's CK has not improved. Their CK has improved but not enough to be at 50% or above which is considered a reasonable score and cut-off point. The same applies to teacher WM with regards to the Topic Specific PCK score - the improvement was not enough to be in the positive value range. However, an observation in teacher MB showed a decrease in the person measure value in the post-scatter relative to the pre. This implies that her Topic Specific PCK was poor after the PDI, which is in contrast to other teachers. This was attributed to the manner in which she responded to the post-test questions, which was inconsistent as compared to the pre-test. Some of the responses in the post-test were not as conceptual as in the pre-test.

Lastly, the findings confirm that there is a relationship between CK and Topic Specific PCK in both pre- and post-tests. Quantitatively, the Spearman's Rank Order Correlation (non-parametric) was used because it calculates the strength of the relationship between two continuous variables. In the pre-CK and Topic Specific PCK tests, the coefficient (rho) was 0.56 indicating a moderate relationship. The probability value (p) 0.028 (which is below 0.05) was found indicating the significance in the result. The post-CK and Topic Specific PCK tests showed a strong relationship with the coefficient (rho) 0.81 and the probability value (p) 0.000- indicates that correlation is more significant at the 0.01 level. I am assuming that higher number of NUGTs with high CK and high Topic Specific PCK (mostly case study teachers) may have attributed to stronger relationships found in the post-scatterplot.

In concluding, the findings from this chapter suggest teachers such as NUGTs' have the potential to be good science teachers and develop the Topic Specific PCK. It is important to indicate that the slight improvement in their Topic Specific PCK is acceptable considering that they only had a period of 8 months which yielded these changes. Chapter eight draws on all the findings presented in Chapters five to seven together, and highlights issues of importance identified.

CHAPTER 8

8. DISCUSSIONS AND IMPLICATIONS

This chapter gives a critical overview of my study which draws on the discussions from the previous chapters. It starts with an introduction relating to the theoretical framing of my study. This is followed by reflections on both methodological and empirical findings including answers to the research questions. Furthermore, based on the empirical findings the implications of Professional Development Intervention (PDI) within a South African context are drawn. A reflection on the research methods used as well my personal reflection is highlighted with suggestions for future research. The chapter concludes with the recommendations from the study.

8.1 Introduction and overview of the study

Since Shulman's article nearly three decades ago (Shulman, 1987), there have been researchers who have extended the notion of PCK (Cochran et al., 1993; Geddis & Wood, 1997; Grossman, 1990; Magnusson et al., 1999). Despite debates about its tacit and elusive nature, there is general agreement amongst these researchers that PCK is a useful construct. Veteran teachers have the capacity to transform conceptual comprehension to forms accessible by learners, which is the benefit of PCK. Some researchers such as Luft (2009) suggest that there is a need for programmes that investigate PCK at a topic level particularly in novice teachers. It was for this reason that I decided to investigate novice science teachers' Topic Specific PCK and CK in my study.

The NUGTs consisted of two groups: case study and non-case study teachers. They were all engaged in the PDI programme which is defined in my study as: encompasses all NUGTs' experiences in relation to knowledge and teaching in general and to that of a topic in consideration. It began at the beginning of the intensive training and ended after 9 months of teaching. The PDI consisted of the following:

(i) Two weeks intensive training which included:

- Administration of the CK and Topic Specific PCK pre-tests
- Generic information about teaching, science content related topics including a session on re-visitation of the particulate nature of matter
- explicit engagement on the five knowledge categories of Topic Specific PCK using Particulate Nature of Matter (Grade10)

- Initial CoRe development

(ii) Teaching experience in schools where they were placed

(iii) Mentoring sessions given by either myself or the Teach South Africa's mentor

(iv) In-service science teachers' workshops

(v) Final CoRe development

(vi) Administering the CK and Topic Specific PCK post-tests

The only difference between the groups is that for case study teachers, there was direct experience of both knowledge and practice with regards to particulate nature of matter while for the non-case study teachers; there was only experience of knowledge about the topic. Although they may have acquired some teaching experience from teaching grades such as 8, 9, 11 & 12, where either pre-knowledge of the topic is dealt with or implicit knowledge of the topic is required for subsequent topics, but no direct experience of practice was gathered as they were not teaching grade 10 which is where the topic under consideration is taught.

The aim of the study was to investigate the extent to which the NUGTs' Topic Specific PCK and CK were influenced by the PDI.

The thesis set out to answer the following research questions:

1. How can NUGTs' Topic Specific PCK, with regard to the particulate nature of matter, be measured?
2. What effect did a targeted PDI have on the NUGTs' CK for the particulate nature of matter?
3. To what degree did the PDI influence the development of NUGTs' Topic Specific PCK?
4. What is the relationship between the NUGTs' CK and Topic Specific PCK of particulate nature of matter?

It is implicit in the aim stated above that my study acknowledges Shulman (1987)'s fundamental tenet that the key to distinguishing the knowledge base for teaching lies in teachers' ability to transform Content Knowledge (CK). It is for this reason that the theoretical construct of Topic Specific PCK by Mavhunga (2012) was used in my study. As indicated in chapter two, the construct builds on Geddis and Wood (1997) and Ball, Thames, and Phelps (2008), who extended the notion of pedagogical transformation. Mavhunga

(2012) identified five necessary knowledge categories related to the teaching of content in order for transformation to emerge. The categories are as shown in figure 8.1: *learner prior knowledge, curricular saliency, what is difficult to teach, representations* and *conceptual teaching strategies.*

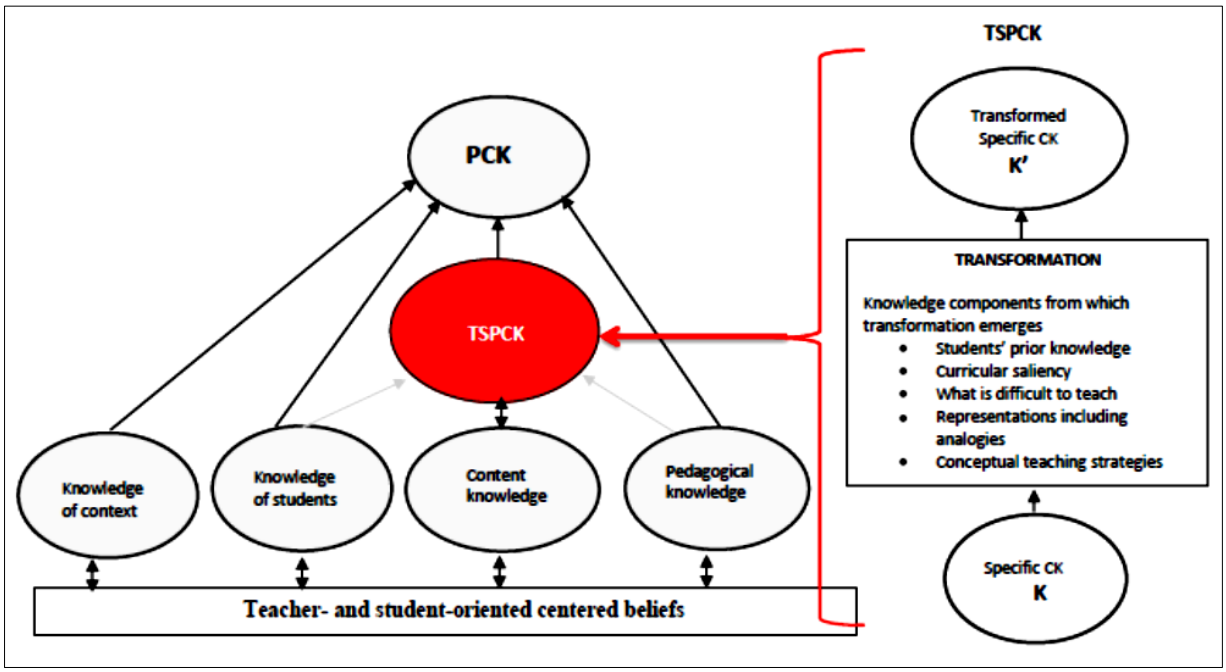


Figure 8.1: A model of Topic Specific PCK from Mavhunga (2012)

The amalgam of all the five categories enables transformation of content for the purpose of teaching. Mavhunga (2012) argues that if PCK is linked with the benefit of transforming comprehension, the benefit of transformation at a topic level is associated with PCK for that specific topic.

According to Mavhunga (2012) these knowledge categories have a specific order in terms of differentiating the difficulty of engaging in each category. In the chemical equilibrium topic, the category *learner prior knowledge* was found to be the least difficult whilst *conceptual teaching strategies* the most difficult, as it integrate all the other categories (Mavhunga, 2012). Although Mavhunga acknowledged that the above hierarchal expectations were limited to chemical equilibrium, the same hierarchy (in the middle order) was found in this study involving a different topic-particulate nature of matter.

My thesis has highlighted aspects relating to how NUGTs' Topic Specific PCK can be measured and what can be deduced from these measurements. It has also highlighted shifts in

both NUGTs' Topic Specific PCK and CK after engaging in PDI. The discussion of my findings is presented in the following sections:

- The methodological contribution to new knowledge
- Empirical contribution to new knowledge
- Answers to research questions

In the following discussion I examine each of the above issues, taking into consideration both empirical and methodological contributions. Finally, I demonstrate how the findings in previous chapters helped in answering my research questions.

8.2 Contribution to New Knowledge

The study contributes to the knowledge base of science education both methodologically and empirically. One aspect of the uniqueness of my study lies in the creation of the tool for measuring Topic Specific PCK of the particulate nature of matter. The tool served the purpose of the study and contributes to the literature on Topic Specific PCK instruments. The findings deduced from the analysis on the improvement in NUGTs' Topic Specific PCK and CK as well as their relationship contributed empirically. The discussion below gives a reflection on these findings and how they contributed to new knowledge.

8.2.1 Methodological contributions to new knowledge

The starting point is to link the findings to that of Mavhunga (2012). Firstly, the construct of Topic Specific PCK in Mavhunga's study was seen to develop in pre-service teachers and found to be valid only for the topic-chemical equilibrium. Mavhunga suggests that the proposed theoretical framework be adapted and tested with other topics of school science. Mavhunga (2012, p. 217) indicated that 'the idea of exploring the concept piece by piece through the topics of school science has promise for understanding the nature of the whole (PCK) better'. Taking this suggestion into consideration, my study has further confirmed the validity of the Topic Specific PCK construct by investigating it in the case of a different topic, the particulate nature of matter. In addition to that, my study took the construct further by investigating it in a different group of teachers, graduate unqualified science teachers.

Secondly, Mavhunga suggests that more instruments for measuring Topic Specific PCK in different school science topics are necessary. An instrument for measuring the topic-particulate nature of matter was developed in my study, thereby expanding the literature base in this area.

The instrument contributes to the literature for measuring the Topic Specific PCK in the particulate nature of matter. Similar to Mavhunga (2012), the instrument was designed in such a way that it includes the five categories of Mavhunga's Topic specific PCK construct. As argued above it is assumed that the integration of all five categories produces a single kind of knowledge - Topic Specific PCK. Secondly, the Topic Specific PCK test items created were those that required the application of pedagogical knowledge to specific content areas (Carlson, 1990). The emphasis was on producing the test items that assess teachers' Topic Specific PCK rather than testing pedagogical and content knowledge separately. All the questions were asked in such a way as to allow NUGTs to show their pedagogical reasoning. The test consisted of a combination of multiple choice and open-ended questions. As indicated in chapter four, these open- ended items were exposed to a reference team for judgment, confirming the characteristics of items fitting topic specific PCK and at the same time validating the content.

According to Golafshani (2003) construct validity determines which data is to be gathered and how is to be gathered. The process of test development including its refinement discussed in chapter four highlights the measures of construct validity. Furthermore, the fit statistics range of (+2;-2) of the Rasch model confirmed the construct validity (Wright & Masters, 1982). This implies that the test items with all five knowledge categories work well together to measure a single construct, Topic Specific PCK.

8.2.2 Empirical findings contributing to new knowledge

Firstly, the overall findings show that most NUGTs gained from the PDI. Since research shows that CK is a prerequisite for quality PCK (Kind, 2009), the improvement in their CK, accompanied by acquired teaching experience, may have possibly influenced their Topic Specific PCK. This finding is in line with the Consensus model for PCK (http://pcksummit.bscs.org) that shows a close relationship between the Teacher Professional Knowledge Bases and Topic Specific Professional Knowledge. The model displays teachers drawing on Professional Knowledge Bases (such as assessment, pedagogical knowledge, CK (in particular), knowledge of students, and curricular knowledge) to produce Topic Specific Professional Knowledge which, according to Rollnick and Mavhunga (2014) aligns closely with the construct of Topic Specific PCK and its five categories as articulated in figure 8.1. This is confirmed in my study where NUGTs' draw on their improved CK to yield better Topic Specific PCK.

Secondly and most importantly, my study further showed that the case study teachers who had direct classroom practice experience on the topic, the particulate nature of matter, gained higher quality Topic Specific PCK of that topic than those who did not teach it. This can be deduced from their superior performance in their Topic Specific PCK in figure 8.2. This finding provides a useful way of understanding that the Topic Specific Professional Knowledge (which aligns to Topic Specific PCK) influences classroom practice or vice versa, as shown in the Consensus model for PCK (http://pcksummit.bscs.org). Therefore, my study suggests that classroom practice of the case study teachers had great influence on their knowledge - Topic Specific PCK. This implies that through their personal PCK experience (which included knowledge and enactment) and classroom resources such as curriculum (http://pcksummit.bscs.org), the case study teachers were able to articulate categories of Topic Specific PCK effectively. However, the non-case study teachers who had indirect classroom practice experience (such as teaching the pre-requisite concepts of the topic) also showed some improvement in their knowledge but not to as great an extent as the case study teachers. This finding shows that although related classroom practice experience may improve teachers' Topic Specific PCK, direct classroom practice of the topic under investigation leads to higher quality Topic Specific PCK. This evidence confirms the idea that PCK is generally to be gained in practice (Kind, 2009; Van Driel et al., 2002) and also suggests it is possible to achieve quality Topic Specific PCK of beginning unqualified graduate teachers, provided they get an opportunity to gain direct classroom practice experience on the topic under investigation.

a) The improvement of Topic Specific PCK within the particulate nature of matter

The Topic Specific PCK tests were administered at two different stages. The pre-tests were completed at the beginning of PDI while the post-tests were administered at the end. The reason for this was to determine whether the PDI had influence on NUGTs' Topic Specific PCK. Both tests scores were analysed using the Rasch Statistical software. Quantitatively using Wilcoxon Signed Rank Test, the Rasch measures of pre- vs. post-Topic Specific PCK tests analysis showed a significant difference at the 2% level for all teachers. This showed that the level of NUGTs' Topic Specific PCK improved considerably after engaging with the PDI. This finding suggests that most NUGTs were able to integrate the Topic Specific PCK categories collectively, which enabled the transformation of CK of the particulate nature of matter. Figure 8.2 below reproduced from chapter seven shows where each NUGTs' Topic Specific PCK was before and after engaging in the PDI.

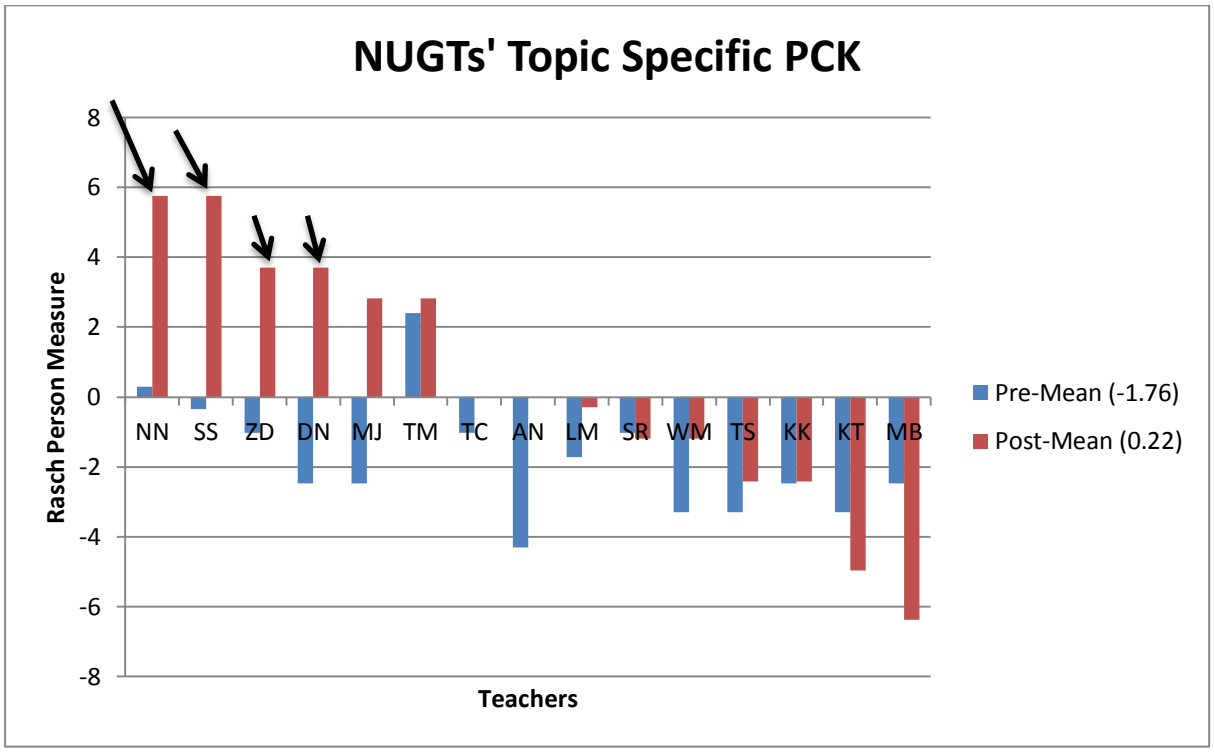


Figure 8.2: Graphical representations of NUGTs' pre and post-tests shift in Topic Specific PCK

The case study teachers (indicated by arrows in Figure 8.2) showed the greatest improvement in Topic Specific PCK. Therefore the success of improvement in Topic Specific PCK in the case study teachers relative to the non-case study teachers is a key finding in my study. These are teachers who taught the particulate nature of matter and were observed and assisted while teaching it. The fact that there is a clear difference between case study and non-case study teachers show that PCK of a certain topic can best be advanced through practice in teaching the topic itself (Mavhunga, 2012). As I mentioned earlier, despite the fact that the non-case study teachers' PDI was limited, as they did not teach the topic in grade 10, their improvement of Topic Specific PCK could be attributed to the fact that they taught either grade 8 or 9 natural science which includes the underpinning pre-requisite concepts of the particulate nature of matter, or higher grades where particulate nature of matter is a pre-requisite.

Based on the nature of the intervention, this finding suggests that most NUGTs' understanding of combined knowledge categories that yield transformation of CK has improved. This means that the NUGTs' thoughts on aspects related to the particulate nature of matter such as *learner's prior knowledge*, *curricular saliency*, concepts that are *difficult to*

teach, *representations* and *conceptual teaching strategies*, improved. The NUGTs' improvement on Topic Specific PCK emerged after the actual teaching of the topic for case study teachers and after teaching of grade 8 or 9 for non-case study teachers.

Evidence of emerging Topic Specific PCK was also collected qualitatively during the PDI from the case study teachers' Topic Specific PCK pre- and post-test responses, pre- and post-observation interviews and lessons observations. It is important to mention that these two instruments are the main indicator of the quality of Topic Specific PCK as shown through the analysis in chapter seven. The analysis was done in an attempt to find evidence in practice of the categories of Topic Specific PCK. Although the Rasch ranking of item difficulty showed that some categories were more difficult than others, there was evidence of use of all categories in some of their lessons.

More evidence of emerging Topic Specific PCK was observed from case study teachers' responses to the test question on *learner prior knowledge* in the post-test and through the lessons, which revealed integration of categories. The responses revealed that while engaging with this category of *learner prior knowledge*, references to other categories were made. For example, when confronting the learners' misconception about 'the particles size increasing when heated', the teacher response included aspects of *curricular saliency*. It was based on the idea of understanding a pre-concept that would able learners to understand that 'matter is made up of particles' and the 'empty spaces between the particles'. These are the concepts learners need to grasp prior to understanding that the spaces increase due to kinetic energy and not the size of the particles. Data showed that teachers demonstrated the understanding of what comes before and after the topic at hand (Rollnick et al., 2008) while at the same time engaging with learners' misconceptions. The blending of these categories shows conceptual understanding of the topic by the NUGTs.

A similar finding was seen from the categories *what is difficult to teach* and *representations*. Prior to engaging with the PDI, in particular during teaching, some NUGTs' choices of representations in the pre-test were limited to macroscopic only and did not envisage concepts that include sub-microscopic particles being difficult. However, the actual lessons observed showed evidence of sub-microscopic particular representations used by the teachers. This might also influenced the choice of concepts in the category *what is difficult to teach* that are sub-microscopic, after engaging in actual teaching. In terms of difficulty, this

finding is in line with that of De Jong and Van Driel (2004), where pre-service teachers were unclear about the difficulties anticipated in teaching when interviewed before teaching. However, after teaching the results of post-lesson interviews revealed that all pre-service teachers were able to report possible teaching difficulties related to the topic in an extensive and detailed manner. The NUGTs also used different forms of representations. This is in line with Shulman (1987)'s view about desirability of multiple forms of representations which help build a bridge between the teacher's comprehension and that desired by the learners. Although *conceptual teaching strategies* have proven to a challenge, there were observable improvements. In line with Mavhunga's (2012) theoretical model, it is expected that the other four categories of Topic Specific PCK need to be blended in order to produce an effective *conceptual teaching strategy*. Not all categories were included and if they were, for example in representations, some NUGTs resorted to using only one kind of representation. To some extent there was a lack of learners' effective interaction through questions, probes, etc. (Shulman, 1987). This finding is similar to Geddis, Onslow, Beynon, and Oesch (1993) who found that novice teachers tend to adopt a transmission model of teaching. The experienced teachers developed a step-wise strategy that took learners gradually towards the concept intended for them to learn (Geddis et al., 1993). One way of improving teachers' performance in my study could be the adoption of a similar step-wise strategy taking into consideration the *curricular saliency*, *what is difficult to teach*, *representations* and *learner prior knowledge* collectively for the conceptual strategy to emerge.

Further evidence of emerging Topic Specific PCK was collected qualitatively from the initial and final CoRes constructed during the workshops. This was meant to deduce the knowledge NUGTs have about the particulate nature of matter. The findings revealed that the task of development of the CoRe forced the NUGTs to begin to think about how they would teach the topic. This was justified by categories *learner prior knowledge*, *what is difficult to teach* and *curricular saliency* that NUGTs found easy in all the three big ideas of the initial CoRe. It implies that through the use of a CoRe, NUGTs were able to envisage misconceptions that learners might have, difficulties associated with teaching the big ideas as well as the pre and post concepts linked to teaching of the particulate nature of matter. These findings point to the evidence that the use of CoRe forces novice teachers to engage with the Topic Specific PCK construct. This was seen in the final CoRe which improved compared to the initial CoRe. However, only a slight improvement in the category *representations* and *conceptual teaching strategies* was observed, indicating that the two remained difficult in both initial and

final CoRe. This could have been affected by not having enough time for CoRe development. A challenge was anticipated in the category *conceptual teaching strategy*, as it was expected to be the most difficult. Considering that these are inexperienced teachers, this lack of teaching experience hinders the teaching strategies from being effective (Geddis et al., 1993). A similar finding was also found by Bertram and Loughran (2012) that pre-service teachers also found difficulty in articulating how the approach to teaching the ideas might be constructed.

All these findings discussed suggest that it is possible for NUGTs to develop Topic Specific PCK through engagement with the PDI and in particular when the PDI includes explicitly teaching the topic under consideration. As indicated by Mavhunga (2012), the finding also indicates progress in illuminating facets of conceptual teaching that are currently rare in South African teachers.

b) The improvement of CK within the particulate nature of matter

The starting point in determining whether there was an improvement in NUGTs' CK was through the use of statistical analysis. The pre vs. post CK test scores were analysed and showed a highly significant difference of 0.001. This implies that the NUGTs gained significantly the understanding of the particulate nature of matter concepts after teaching.

In order to find out more on NUGTs' improvement, a qualitative analysis of both pre- and post-CK tests responses were looked into. The major finding was that most NUGTs demonstrated a better understanding of basic descriptions of types of particles (atoms, molecules, pure substances and mixtures) and interpreting different representations of particles. I assume that this improvement was attributed to the fact that they engaged with the topic and its related concepts. Prior to the actual teaching, most NUGTs were unable to distinguish between mixtures and compounds as illustrated in chapter six. Furthermore, they also found difficulty in identifying particulate representations of compounds and mixtures. On both occasions it was evident that differentiating between macro and sub-micro remained a difficulty before the teaching. It should be mentioned, however, that a few NUGTs still encountered the difficulty even after the teaching of the topic and its pre-requisite concepts in other grades. This finding is related to that of teachers' inability to use different levels of representation which was highlighted in the section of Topic Specific PCK findings above.

It was also found that NUGTs portrayed a reasonable understanding of drawing sub-microscopic representations of oxygen in different phases prior to teaching. However, after teaching some of the case study teachers gave the representation of sub-microscopic particles of oxygen in solid not touching. As highlighted in chapter six most high school textbooks tend to represent the solid in that manner, so I assume that this might have influenced the teachers. It was expecting that this kind of response would be observed in liquids as it is perceived that there is a considerable space between molecules in its representations (Garnett et al., 1995).

Through analysing the response of the question regarding the concept of average atomic mass, it was found that most teachers struggled to give a completely correct justification for their explanation. Prior to the actual teaching most of them showed partial response and resorting to short statements. However, their responses after engaging with the teaching was detailed, and to some extent displayed the manner in which one would teach the concept to the grade 10 learners. Although this response was captured in the CK test, interesting evidence of NUGTs' developing teaching strategies was manifesting which implies emergence of Topic Specific PCK. This finding shows that as novice teachers begin to engage with the actual teaching of a particular concept, there is a possibility of shift from procedural to conceptual understanding.

Finally, it is important to indicate that although the NUGTs showed significant improvement, the post-test mean of 69.13 is considered low for a science graduate, since the test explores school science knowledge only. It was expected that the NUGTs would find the content of the particulate nature of matter the easiest, since teachers should know more than their learners. This finding confirmed those of several researchers (Lutz & Potgieter, 2013; Ramot, 1992) that both chemistry graduates and undergraduates demonstrated poor understanding of knowledge of chemical structure which includes the particulate nature of matter and the understanding of basic descriptions of types of particles.

c) The relation between CK and Topic Specific PCK

As indicated in the previous discussion, that the Consensus model **(**http://pcksummit.bscs.org) shows that teachers draw on professional knowledge bases to produce topic specific professional knowledge which aligns with the construct of topic specific PCK and its five categories (Rollnick & Mavhunga, 2014). It is worth investigating

the relationship that exists between the CK (a category of teacher professional knowledge bases) and Topic Specific PCK in the NUGTs.

Scatter plots indicating the pre- and post-CK and Topic Specific test results with cut-off points were used to investigate the relationship between the two constructs. Both scatter-plots are shown in chapter seven. For the purpose of this discussion the post-scatter plot is shown in figure 8.3 below, reproduced for convenience reading. The major finding emerged was that all the case study teachers (SS, NN, DN and ZD) were found in the top right quadrant, indicating that they had both strong CK and Topic Specific PCK. This indicates that direct teaching experience of the topic may lead to high CK which may in turn yield high Topic Specific PCK. As expected, there were cases of moderately good CK with poor Topic Specific PCK. This can be deduced from some non-case study teachers who portrayed weak Topic Specific PCK despite having moderately good CK. This implies that it is not always the case that a high CK would be associated with high Topic Specific PCK. Finally, there were no cases of weak CK and strong PCK in the top left quadrant. This can be distinguished from other non-case study teachers (MB, WM) who showed both poor CK and Topic Specific PCK This validates the idea that one cannot have PCK without CK (Kind, 2009) and that CK is a pre-requisite to PCK (Rollnick et al., 2008).

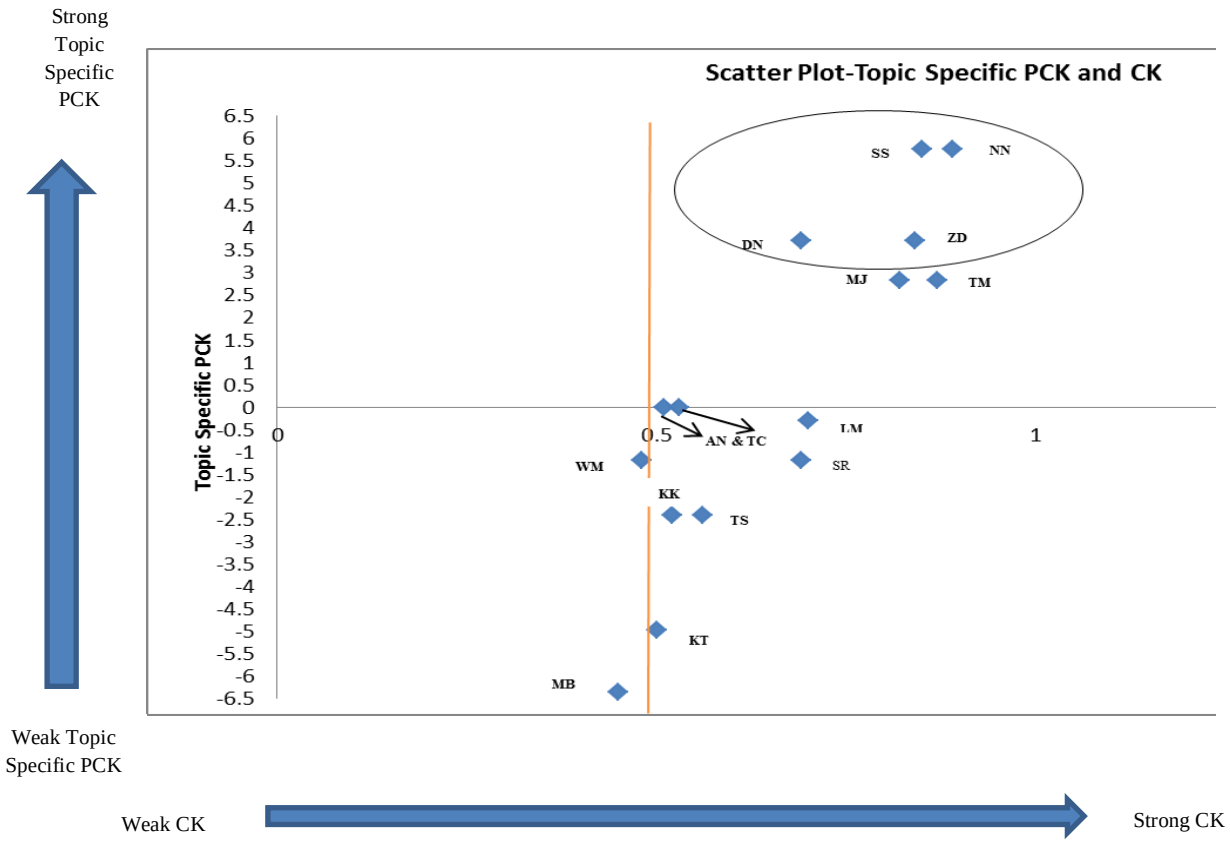


Figure 8.3: Scatterplot for post CK and Topic Specific PCK

8.3 Answering Research Questions

Research Question 1: This research question sought to find out how and whether the Topic Specific PCK construct could be measured. In my study a tool on the particulate nature of matter was developed. The process included piloting of the tool, as well its validation. Similar to Mavhunga (2012), the tool consisted of the five categories of the construct- Topic Specific PCK framed as five items. In the early stages of its development, a reference team was used for reviewing the characteristics of items fitting Topic Specific PCK. This reference team consisted of experts such as doctoral students in science education, high school physical science teachers, senior teacher educators and a physical science mentor assigned for NUGTs by Teach South Africa. As part of refining the tool, fourth year pre-service teachers were requested to complete it. Based on their responses, some items, in particular the category of *learner prior knowledge* was further refined. The piloting process involved a group of practicing science teachers whose authentic responses informed both the vocabulary and contexts. As this research question was about a tool that can measure the quality of Topic Specific PCK, construct validity was not only demonstrated by the process followed but also quantitatively, through Rasch model statistical measurements. The results of the Rasch

measurements indicated that a single construct was being measured and that the combination of the process followed and the use of statistical measurements indicated that the tool intended to measure the Topic Specific PCK is valid.

Research Question 2: This research question intended to find the effect of the PDI on NUGTs' understanding of the CK of the particulate nature of matter. A diagnostic test consisting of content related questions from widely reported literature (the particulate nature of matter) was used. Although the validity of the test was established through the use of commonly known literature, a reference team also gave comments on the test, which improved its content validity. Data with regard to this question was collected in the form of pre- and post-tests that analysed for possible shifts. The NUGTs showed a positive statistical significant gain in the understanding of concepts in the particulate nature of matter after the PDI. The same improvement was also observed qualitatively from the analysed test responses.

Research Question 3: This research question intended to find the extent to which the PDI influenced the development of NUGTs' Topic Specific PCK. Overall there was a statistically significant improvement between two tests in the Topic Specific PCK for the NUGTs in the study with a noticeably larger improvement in the case study teachers who taught the topic, providing further evidence of the validity of the construct of Topic Specific PCK. Qualitatively, the pre- and post-Topic Specific PCK tests responses were also analysed in pairs. Additionally, the initial and final CoRe responses, as well as the lessons of the case study teachers were analysed qualitatively and also played a role in answering the research question. Furthermore, the improvement in Topic Specific PCK was also observed in both analysis of the group initial and final CoRes and the lessons of the case study teachers. Evidence further showed that all case study teachers' Topic Specific PCK improved considerably relative to the non-case study teachers in the post-tests. This could have contributed to the strong relationship yielded by Spearman's Correlation.

Research Question 4: It was established that there is a close link between the CK and Topic Specific PCK (Mavhunga, 2012). Therefore, determining the relationship between these two constructs is recommended, hence the purpose of this research question. Quantitatively, the Spearman's Rank Order Correlation was used for calculating the strength of the relationship between pre-tests and post-tests. A correlation between the pre- and post-tests was found to be significant. However, a moderate relationship between the pre-CK and pre-Topic PCK

was found, while the post-tests indicated a strong relationship. Furthermore, the relationship was looked at qualitatively using the scatterplot graph of the pre-tests and post-tests. The findings showed that (i) teachers with a good CK are likely to present a strong Topic Specific PCK (ii) it does not necessarily mean that a teacher with good CK will display good PCK and (iii) teachers with poor CK portrayed poor PCK.

8.4 Critical Reflections on the Research Process

8.4.1 The Professional Development Intervention (PDI)

Carrying out research that involves an intervention without having full access to the group for the whole duration proved to be a challenge. In the initial stage of the study, I was concerned about how to account for external influences that the NUGTs would be exposed to beyond the two weeks intensive training. It was then that I realised that the 'intervention' in my study needed to be explored further as it was difficult to define the boundaries of the intervention and identify what exactly contributed to any shifts in Topic Specific PCK. It was through the help of a visiting science researcher at Marang who agreed to read my work and suggested the name Professional Development Intervention (PDI) instead of just an intervention. As discussed in detail chapter five, the PDI included the two weeks intensive programme, school experience, teacher training workshops and mentorship experiences, in fact all the experiences that the teachers were exposed to that potentially contributed to the growth of their knowledge. Although agreement on the term 'PDI' was reached, the remaining challenge related to how to account for known and unknown experiences, such as mentorship and workshops NUGTs may have attended. It was through guidance of my supervisor who suggested that a reflective questionnaire be administered at the end of the PDI (Appendix E). Ultimately the discussion in chapter five reflects that the analysis of the reflective questionnaire revealed that mentorship and teacher workshops had little or no influence on the development of NUGTs' Topic Specific PCK. The assigned mentors for case study teachers only visited them in the second school term after they had taught the topic under consideration, while the workshops attended were not content related. Therefore, there was not much to highlight in terms of these two aspects.

Another aspect I would like to reflect on is the decision taken to observe the case study teachers' lessons consecutively over a number of days. This decision did not only allow me to see each teacher's link to what was taught a day before to the new lesson, but also showed me how they approached the same lesson with the next class (with different learners). For

example, in teacher NN's lesson about the atom, learners were ask to explain atomic number. A learner gave the answer 'the number of atoms and electrons', which is correct in a neutral atom but incorrect in a charged atom. The learner insisted that she was taught this way in her previous grade. It took teacher NN a long time to remediate a learner's misconception which delayed his lesson delivery. Teacher NN changed his teaching approach in the next lesson (with different learners). It was through this experience that he decided to first distinguish between atoms and ions and also show the atomic number in both. It was during times like this that I witnessed evidence of developing PCK in teacher NN. Lastly, I observed that in the pre-Topic Specific PCK tests and initial CoRe, NUGTs were reasoning from a CK perspective whilst in the post-tests and final CoRe they were incorporating learners' perspectives. This reasoning shows that after engaging with learners, they started seeing and relating themselves as teachers.

8.4.2 The research methodology used

Firstly, the use of MM approach allowed me to explore the data analysis both quantitatively and qualitatively in my study. The Rasch statistical model used for analysing the Topic Specific PCK test quantitatively highlighted the hierarchy of difficulty of categories. Therefore, knowing the order of difficulty of categories of Topic Specific PCK enabled me to look into the NUGTs' test responses qualitatively to see what exactly was difficult or easy. Furthermore, the use of a case study as a research approach allowed in-depth explorations of interactions to even small-sized research samples. Although the findings could not be generalised, a deeper analysis on case study teachers in my study has provided some insight into NUGTs' understanding and teaching of the particulate nature of matter. Secondly, a methodological constraint was that the CoRes were done in groups, each containing at least one case study teacher. This restricted me from making claims about the NUGTs' knowledge of the particulate nature of matter with regards to both pre- and post-CoRes. It is for this reason that the Topic Specific PCK test was the main indicator of NUGTs' knowledge of the topic. I recommend that teachers construct CoRes collaboratively provided they all taught the topic under consideration.

Lastly, other data collection methods I intended to use such as Facebook chats amongst the NUGTs and mentorship experiences were unsuccessful. I am assuming that since the NUGTs' are inexperienced, they might have found challenges in terms of dealing with the teaching load. This may have left them with limited or no time for Facebook engagement. As

for mentorship, it was highlighted in chapter five that most science mentors visited the case study teachers in the second school term after the topic was taught. It was for this reason that I was unable to deduce any mentoring effect in my study.

8.4.3 The limitations of the study

The sample size utilised in my study was not only determined by the number of science graduates Teach South Africa recruits for the cohort but also the number of those successfully placed in schools. During the intensive training the sample size was 16. But this size was reduced to 15 because teacher DR's placement in school was delayed and she therefore decided to drop out of the programme. The statistical software (Wilcoxon Signed Rank) was used to calculate the significant used paired data, thus teacher DR who did not participate in the post-testing was not included in the analysis process.

It is worth acknowledging that the conclusions of my study cannot be used to generalise to other professional development interventions in Southern Africa or overseas but must be considered in context.

8.5 Conclusions and Recommendations

A study of this kind that involved unqualified graduate science teachers' Topic Specific PCK has never been conducted before in South Africa. Although the findings of the study cannot be generalised, recommendations could be suggested to Teach South Africa that recruits and trains the graduates and the science education community, with implications for overall PDI including the intensive training programme and PCK as a useful construct. The following recommendations with respect to the PDI emanate from my study:

- The organisers of the intensive training should consider incorporating sessions on the transformation of CK in the week of 'into teaching' as shown in table 5.1 of chapter five. The science group focused more on the science content syllabus, lesson planning and assessment in science. The only session on explicit transformation of CK was the one I did on Topic Specific PCK for 2.5 hours. This observation suggests that transformation of CK (PCK) seems not to be much of a priority to the organisers.

- In future, it is recommended that a CoRe template be used as we have seen in the study on findings in chapter five that it reinforced NUGTs to engage with the categories which yield an improved Topic Specific PCK. This would also give the

NUGTs an opportunity to construct a CoRe over number of days (during the intensive programme) unlike in my study where it was done in an hour. I am anticipating that if NUGTs spend more days in developing a CoRe, quality responses in the prompts may be seen in relation to the responses of the initial CoRe in my study.

- In chapter six and seven, the findings about the CK and Topic Specific PCK showed a significant gain in both the understanding and transformation of concepts in the particulate nature of matter. This implies that uncertified novice science teachers do not only possess good CK but are also capable of transforming it better. Therefore it is recommended that more of the science graduates be recruited by Teach South Africa. This move might contribute positively to the dilemma South Africa is facing about the shortage of quality science teachers.

- It is recommended that there should be mentoring for new teachers.

8.6 Future Research

Since my study has revealed that Topic Specific PCK in the particulate nature of matter can be developed in novice unqualified teachers, the tool for measuring PCK may be altered to suit other science topics for investigation. Furthermore, the trends or relationships in aspects of Topic Specific PCK development or improvement according to the subject they majored in can be explored. This may give some indication in terms of the categories in which the physics or chemistry or biology major shows the greatest Topic Specific PCK. While my study showed that the NUGTs' CK of the particulate nature of matter has improved, the pre- and post-CK scores were disappointingly low for university graduates taking into account that the topic in consideration is for high school level. For future research, it would be worth investigating whether the CK tested is not in fact the CK for teaching purposes. This could be done by not only comparing the CK depth of the particulate nature of matter at the high school level and university but observe how it is taught. Ultimately, this may suggest indicators for distinguishing between the raw CK and that of teaching.

8.7 The end-piece

The poor state of science teaching (due to teachers' limited CK and its transformation), the lack of qualified science teachers in high school and poor performance by the grade 12 learners in South Africa were the common concerns that motivated my study. It is assumed that programmes like Teach SA that recruits NUGTs' may mitigate these challenges. Indeed,

the findings of my study suggest that through the PDI, these teachers were able to portray both improved CK and Topic Specific PCK. Considering that this improvement was seen over a period of eight months, an assumption can be made that over the years to come there would be even more improvement and quality in terms of their PCK. However, the study also cautions that while the NUGTs' programme has the potential to produce teachers, care should be exercised in making assumptions about their CK and knowledge for teaching, and training programmes need to pay attention to both CK and Topic Specific PCK.

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APPENDIX A: INTERVIEW QUESTIONS COMBINED WITH OBSERVATION

Before Observation

1. Could you describe today's lesson?
2. What subject matter or concepts do you expect students would have difficulties with today? Why do you think so?
3. What kinds of students' misconceptions associated with this lesson have you noticed? How would you help them correct the misconceptions?
4. What kinds of things do you take into considerations in planning this lesson?
5. How will you be able to know whether your students understand the concepts you try to teach today? What evidence are you looking for that students have been successful in addressing the goals for the lesson?

After Observation

1. How do you feel about the lesson today?
2. What do you consider the most effective teaching moment was in the lesson?
3. Why? How did you achieve it? Why did it work? What signaled you that the students were learning?
4. Were there any students' misconceptions you identified during the class that you have not known? If yes, how did you respond to challenge the misconceptions? Did it work? Why do you think it worked?
5. Did you make any changes in the class that I just observed differently from the other class periods or lesson plan? Why?

APPENDIX B: ADAPTED CoRe

Curricular saliency		
What are the big ideas for the topic?		
What do you intend the learners to know about this idea?		
Why is it important for learners to know this big idea?		
What concepts need to be taught before teaching this big idea?		
What else do you know about this idea (that you do not intend learners to know yet)?		
What do you consider easy or difficult in teaching this big idea?		
Student Misconceptions		
What are the typical student misconceptions on this big idea?		

Teaching Strategies		
What effective teaching strategies would you use to teach this idea?		
What questions would you consider important to ask in your teaching strategies?		
Representations		
What representations would you use in your teaching strategies?		
Assessment		
What ways would you use to assess understanding of learners?		
Reflections		
What aspects of planning and teaching this big idea would you like to reflect on?		

APPENDIX C: FINAL VERSION OF CK TEST

PARTICULATE NATURE OF MATTER TEST

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

SECTION A: BACKGROUND INFORMATION

NAME AND SURNAME: _____ Gender (tick✓):

Female	Male

HOME province and town: _____

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

Qualification and length of course	From (year)	To (year)	Main Subjects

Kindly provide information on any teaching experience you may have, including tutoring and demonstrating.

_____

_____

_____

Code: ……

Code:

CATEGORY A

1. Give one word or term for each of the following description.
   (a) A substance that is made of only one kind of atom.
   (b) A substance made of two or more atoms of different elements chemically bonded.
   (c) A smallest particle of an element that still retains the chemical properties of that element.
   (d) A particle that consists of two or more atoms bonded together.
   (e) A substance that consists of different substances that are not chemically bonded to each other and still retain their original properties.

Answers

(a)_____

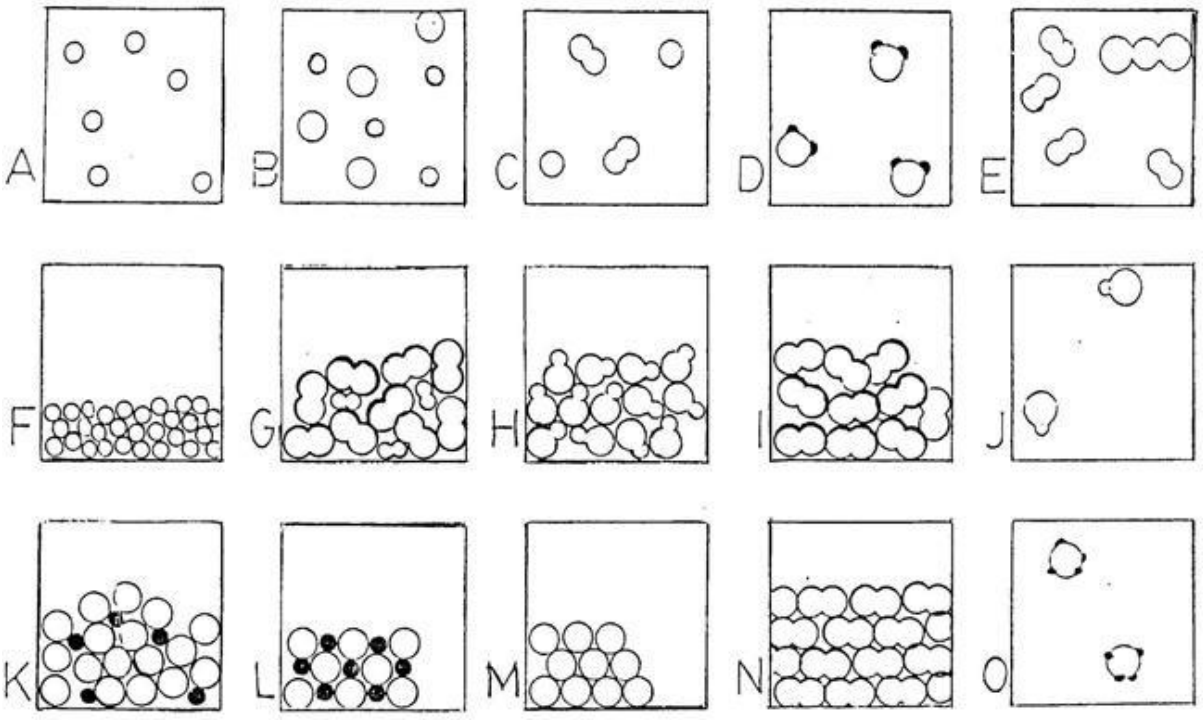
(b)_____

(c)_____

(d)_____

(e)_____

2. In the diagrams below say:



(a) Which diagram(s) consist(s) of only one element?
(b) Which diagram(s) consist(s) of only one compound?
(c) Which diagram(s) represent(s) a mixture?

(d) Which diagram(s) represent(s) a pure solid?
(e) Which diagram(s) represent(s) a pure liquid?
(f) Which diagram(s) represent(s) a gas?
(g) Which diagram(s) represent a pure substance?
(h) Which diagram(s) represent molecules only?

Answers

(a)_____

(b)_____

(c) _____

(d)_____

(e)_____

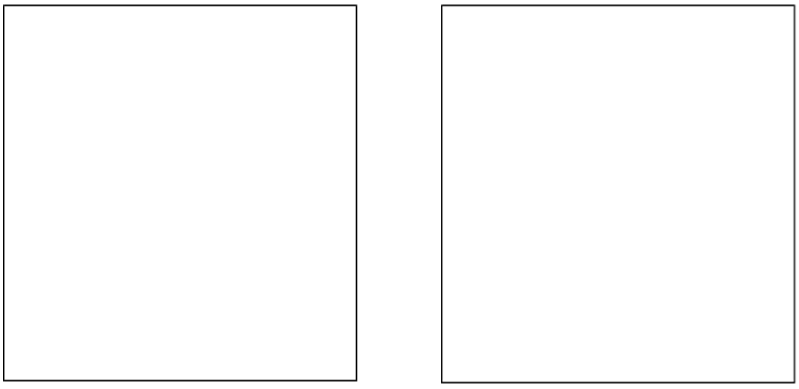
(f)_____

(g)_____

(h)_____

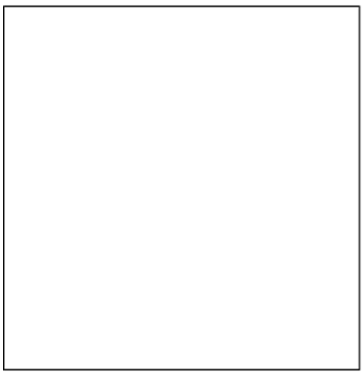
CATEGORY

3. Draw microscopic representations of oxygen as it heated from a solid to a liquid to a gaseous state in the boxes below. Use ●● to represent a single molecule. Draw 9 molecules in each box.



Solid

Liquid



Gas

4. Question 1 to 4: are the following statement true (T) or false (F)?
Circle the correct answer and indicate the degree of confidence i.e. 100% sure, not sure or guessing.

(1) All molecules of a given pure substance are identical. **T/F**

100% sure	*sure*	*guess*

(2) Between molecules of a substance there is "empty space". **T/F**

100% sure	*sure*	*guess*

(3) A molecule of a substance in the solid phase has larger mass than a molecule of the same substance in the gaseous phase. **T/F**

100% sure	*sure*	*guess*

(4) The forces of attraction between molecules of naphthalene in the liquid phase are greater than in the solid phase. **T/F**

100% sure	*sure*	*guess*

CATEGORY C

5.

(a) Name the sub-atomic particles found in the nucleus of an atom?

_____

(b) What type of charge is found on each of the above mentioned sub-atomic particles?

_____

(c) Fill in the blanks on the following table.

Element	Notation	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons	Number of nucleons
				20	18		
Fluoride ion	${}^{19}_{9}F^{-}$						
	${}^{23}_{13}Al^{3+}$						
				17	18		

(d) Which of the following unidentified elements are isotopes of one another?

${}^{12}_{6}X$, ${}^{12}_{7}Y$, ${}^{24}_{12}A$, ${}^{14}_{6}Xy$, ${}^{13}_{6}Mp$ (note X, Y, A, Xy and Mp represent the symbols of unspecified elements).

_____

How did you work out the answer above?

_____

What is the name of an isotopic element represented in (d)?

_____

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

_____
_____
_____
_____
_____

APPENDIX D: FINAL VERSION TOPIC SPECIFIC PCK TEST

PARTICULATE NATURE OF MATTER PCK TEST

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

SECTION A: BACKGROUND INFORMATION

NAME AND SURNAME: _____ Gender (tick✓):

Female	Male

HOME province and town: _____

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

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

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

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

Please provide the following information about your teaching.

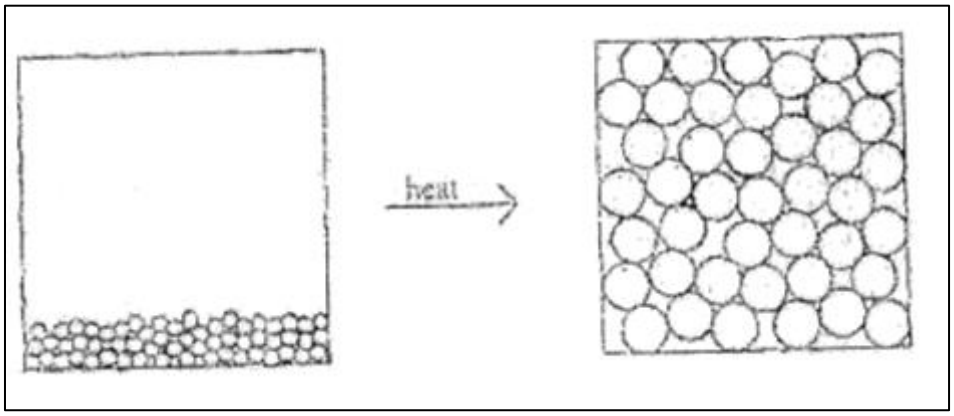
Number of years	School and province	Subjects taught	Classes taught

Code: ……

Code:

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. Learners in a grade 10 class were asked to represent the change that takes place when a substance is heated. The response Teboho has written on the board is shown below.



How would you comment on Teboho's response as part of an explanation to the rest of the class?

Response A: Teboho's response is incorrect. All substances have small particles called atoms that may combine chemically with each other to form molecules. When substances are heated their molecules do not expand in size. The size of the molecules stays the same.

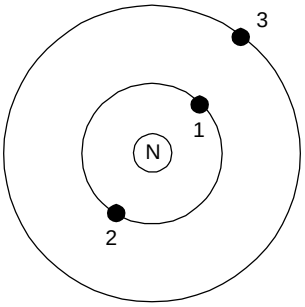
Response B: Teboho's response is incorrect. When a substance is heated, molecules gain kinetic energy. The molecules will start vibrating and the bonds between them weaken to allow re-arrangement and in some cases allowing the molecules to move away from each other. The molecules themselves do not change in size when heated. It is the re-arrangement of molecules that changes.

Response C: Teboho's response is incorrect. When a substance is heated, a phase change occurs. The molecules of a substance become more free from each other as the bonds are weakend in some cases completely broken. Substances that were originally solids may become liquids and liquids may become gases

Response D: None of the above

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

My choice is Response …..



A simple representation of an atom

2. When learners were asked to describe what is happening in the given atomic model above, Lerato gave the following written response:
   An electron further away from the nucleus (electron 3) would experience less attraction to the nucleus.

   What comment(s) would you write on her paper?

Response A: True, electron 3, located further away from the nucleus, will not be attracted in the same way as the electron closer to the nucleus.

Response B: True, the electrons on the energy levels further away from the nucleus experience a smaller force of attraction than those which is in nearer energy levels. However, all electrons are attracted by the same type of force from the nucleus.

Response C: True, electron 3 will experience less attraction towards the nucleus because of the greater distance between the electron and the nucleus.

Response D: None of the above

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

My choice is Response …..

CATEGORY B: CURRICULUM SALIENCY

3. Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10? Choose from the list provided.

Particles are in constant motion	Substance have subatomic particles
Molecules have forces between each other	Compounds are made up of atoms
Elements are made up of atoms	Atom has a specific structure
Matter is made up of small bits that are called particles	There are different type of small bits of substance
Atoms are smallest particle	Matter is found in different phases
Molecules are made from atoms	Other
There are different atomic theories	

1.
2.
3.
4.

3.2 In what sequence would you teach the main ideas you have identified above?

3.3 Make a map or a diagram of these four ideas showing how they link to subordinate ideas.

3.4 What other topics in chemistry do you think require the understanding of particle nature for teaching them?

3.5 Why is it important for learners to learn about particle nature of matter? Identify reasons related to:

i. **Conceptual Progression**
ii. **Application**

iii. Motivation or Interest

CATEGORY C: WHAT MAKES THE TOPIC DIFFICULT TO TEACH?

1. Tick (✓) from the list below, concepts of particle nature of matter you consider difficult to teach? You may also add your own. Explain why you consider the chosen topics difficult to teach.

Concept	✓	What exactly makes it difficult?
There is an empty space between particles of matter		
Particles are in constant motion		
There are different types of small bits of substances.		
Calculating the relative atomic mass of an isotope		

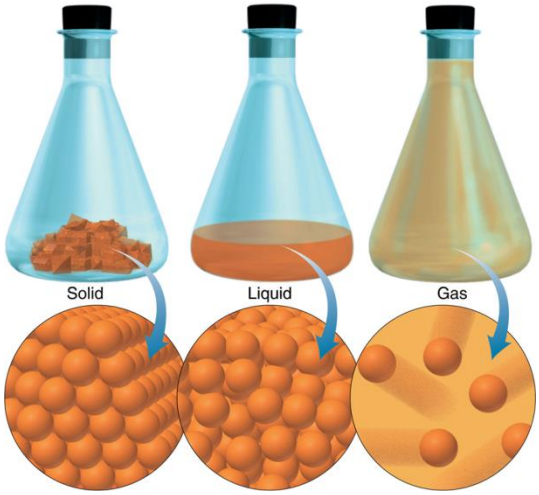
Concept	✓	What exactly makes it difficult?
Finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$		

5. CATEGORY D: REPRESENTATIONS

Phases of Matter

Below are three different representations that can be used for teaching phases of matter. Decide which one(s) you like and complete the table below

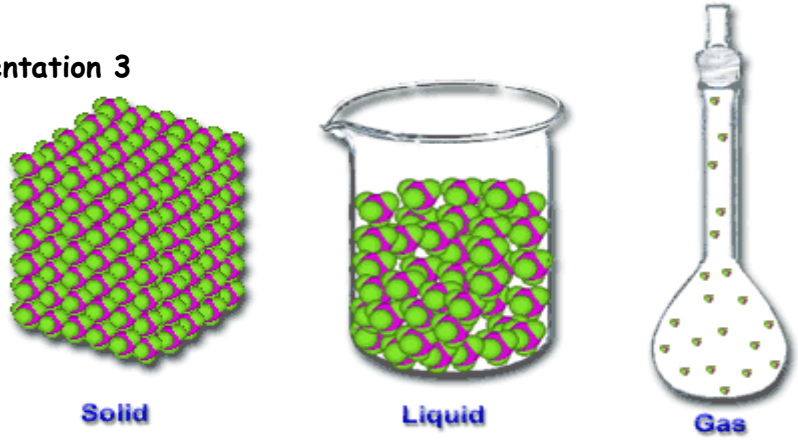
Representation 1



Representation 2



Representation 3



5.1 Complete the table below by providing as many details as possible.

Representation No.	What I Like	What I do not like
1		
2		
3		

5.2 Which representation do you like most?

5.3 How would you use the representation that you like most?

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES

Average relative atomic mass

Shown below is a learners' response to a written test meant to assess learners' prior knowledge on average relative atomic masses.

Question

Calculate the average relative atomic mass of a sample of oxygen gas that contains the following isotopes of oxygen atoms:

Element	Isotopes	Isotopic mass	Percentage abundance
Oxygen	^{16}O	16	99,790
	^{17}O	17	0,037
	^{18}O	18	0,173

A learner's response:

O-16: 16
O-17: 17
O-18: 18

16+17+18=51
51 ÷ 3= 17amu

Following the learner's response, how will you teach a lesson on calculating the average relative atomic mass?

APPENDIX E: REFLECTIVE QUESTIONNAIRE

1. How did you manage your first year of science teaching? Was it what you expected?

   _____

   _____

   _____

   _____

   _____

2. (i) Did you teach the particulate nature of matter in grade 10? **YES / NO**

   (ii) If **YES,** how did you find the teaching of the particulate nature of matter?

   _____

   _____

   _____

   _____

   _____

   _____

   (iii) If **NO** which grade did you teach? _____

   (iv) What topics if any did you teach that were related to the particulate nature of matter? (These could be about molecules, particles, atoms etc. below grade 10 or other topics above grade 10).

   _____

   (iv) How did you find the teaching of the topics you mentioned above?

   _____

   _____

   _____

   _____

   _____

3. (i) Did the assigned mentor from Teach SA visit you during your teaching? **YES / NO**

   (ii) If **YES**, how often did the mentor visit you? _____

   (iii) How was the mentorship useful to the teaching of science and in particular to the particulate nature of matter topic or its related concepts?

   _____

   _____

   _____

_____

_____

4. (i) Did you receive any mentoring from your school? **YES / NO**
   (ii) If **YES,** who was your mentor? _____
   (iii) How was the mentorship useful to the teaching of science and in particular to the particulate nature of matter topic or its related concepts?

   _____

   _____

   _____

   _____

   _____

5. (i) Did you attend any science workshops or in-service training? **YES / NO**
   (ii) If **YES**, how did the workshop or in-service training help you understand the teaching and learning of the particulate nature of matter or its related concept better?

   _____

   _____

   _____

   _____

   (iii) If not, what was the topic of the workshop?

   _____

   _____

6. How useful was the two weeks training academy attended in December 2011? Please highlight the information learned from the academy that assisted you in your teaching of science.

   _____

   _____

   _____

7. From you teaching experience, would you consider enrolling for the post graduate studies such as PGCE? **YES / NO.**
   Explain your choice

_____

_____

APPENDIX F: EXPERT CoRe (Loughran)

This Core is designed for students in Lower Secondary School, i.e., Years 7 – 9.	IMPORTANT SCIENCE		
	A: Matter is made up of small bits that are called particles.	**B: There is empty space between particles.**	**C: Particles are in constant motion.**
What you intend the students to learn about this idea.	If we break up substances, the smallest bit of substance we can get is a particle.	The relative distances between particles differs in solids, liquids and gases.	Particles of matter are always moving. The speed of particles can be changed (by heating/cooling, pressure change). The way particles are arranged can change when their speed changes.
Why it is important for students to know this.	Because it helps to explain the behaviour of everyday things **e.g.**, diffusion.	Because it explains the ability to compress things and helps to explain events such as expansion and dissolving.	Because it explains what happens in phase changes, e.g., the need to contain gases is evidence the particles are moving.
What else you know about this idea (that you do not intend students to know yet).	At this stage 'particles' is used in a general sense without discriminating between atoms and molecules. Subatomic structure. Chemical reactions. Ions. More complex properties of materials. More complicated models of matter. Links to diffusion and thermal properties of matter.		
Difficulties/ limitations connected with teaching this idea.	Particles are too small to see. The use of particular science models is not necessary to comprehend science in everyday life. It is difficult to decide when to introduce the labels (i.e., atoms, molecules) for different kinds of particles. Substances seem to disappear when dissolved. What holds particles together? Why don't substances automatically become a gas?	There is a big difference between macro (seen) and micro (unseen) levels, e.g., wood seems solid so it is hard to picture empty space between the 'wood' particles. Students don't tend to think of gases as matter and therefore have difficulty thinking about empty spaces between gas particles.	That macro properties are a result of micro arrangements is hard to understand. The commonly used term 'states of matter' implies that all things can be discretely classified as solid, liquid or gas. It is difficult to imagine particles in a solid moving. There are problems with some textbook representations of liquid, e.g., particles are often shown as being much further apart than they are in solids. 'Melt' and 'dissolve' are often used interchangeably in everyday life.

This Core is designed for students in Lower Secondary School, i.e., Years 7 – 9.	IMPORTANT SCIENCE		
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What you intend the students to learn about this idea.	If we break up substances, the smallest bit of substance we can get is a particle.	The relative distances between particles differs in solids, liquids and gases.	Particles of matter are always moving. The speed of particles can be changed (by heating/cooling, pressure change). The way particles are arranged can change when their speed changes.
Why it is important for students to know this.	Because it helps to explain the behaviour of everyday things e.g., diffusion.	Because it explains the ability to compress things and helps to explain events such as expansion and dissolving.	Because it explains what happens in phase changes, e.g., the need to contain gases is evidence the particles are moving.
What else you know about this idea (that you do not intend students to know yet).	At this stage 'particles' is used in a general sense without discriminating between atoms and molecules. Subatomic structure. Chemical reactions. Ions. More complex properties of materials. More complicated models of matter. Links to diffusion and thermal properties of matter.		
Difficulties/ limitations connected with teaching this idea.	Particles are too small to see. The use of particular science models is not necessary to comprehend science in everyday life. It is difficult to decide when to introduce the labels (i.e., atoms, molecules) for different kinds of particles. Substances seem to disappear when dissolved. What holds particles together? Why don't substances automatically become a gas?	There is a big difference between macro (seen) and micro (unseen) levels, e.g., wood seems solid so it is hard to picture empty space between the 'wood' particles. Students don't tend to think of gases as matter and therefore have difficulty thinking about empty spaces between gas particles.	That macro properties are a result of micro arrangements is hard to understand. The commonly used term 'states of matter' implies that all things can be discretely classified as solid, liquid or gas. It is difficult to imagine particles in a solid moving. There are problems with some textbook representations of liquid, e.g., particles are often shown as being much further apart than they are in solids. 'Melt' and 'dissolve' are often used interchangeably in everyday life.

IDEAS/CONCEPTS			
D: Particles of different substances are different.	**E: There are different types of small bits of substances.**	**F: Atom particles don't disappear or get created, but their arrangements may be changed.**	**G: Models are used in science to help explain phenomena. All models have limitations.**
The characteristics of substances are related to the types of particles they contain.	There are two types of small bits of substance: • Atoms • Molecules. Molecules form when atoms combine.	Atoms don't change but molecules can. New atoms can't be made and atoms can't be destroyed (Conservation of matter).	Particle theory is an idea constructed by scientists to help us understand some aspects of the behaviour of matter. There are limitations to what particle theory can explain. Constructions are modified over time. Breaking up all substances into categories of solids, liquids and gases can be problematic.
Because it explains the observable behaviours of different substances.	Because it explains why there are a limited number of elements, but many different kinds of compounds. Organise ideas that are later developed when studying 'chemical reactions'.	Because in any reaction involving matter, all of that matter must be able to accounted for.	Because it helps students understand why the particle model is not perfect and because it gives some insights into how science works.
(As per Big Ideas A, B & C.)	Details about ionic and molecular structures. Fission and fusion reactions.		
	Students can come to think that molecules 'disassociate' in boiling water (because of the confusion between atoms and molecules).	Atoms don't change. It is difficult to understand that different substances with the same types of atoms have different properties. Generally students have never had any cause to consider the notion of conservation of matter on a microscopic scale.	

	A: Matter is made up of small bits that are called particles.	B: There is empty space between particles.	C: Particles are in constant motion.
Knowledge about students' thinking which influences your teaching of this idea.	Many students will use a continuous model (despite former teaching).	The notion of 'space' is very difficult to think about – most students propose there is other 'stuff' between the particles. Students think that particles get bigger during expansion.	Students have commonly encountered 'states of matter' but do not understand the ideas in terms of particle movement. Students can be confused by the notion of melting and think a particular particle melts.
Other factors that influence your teaching of this idea.	Maturity – stage of psychological development, readiness to grapple with abstract ideas. Dealing with many different student conceptions at once. Knowledge of context (students' and teacher's). Using the term 'phase' suggests the idea of a continuum and may help to address the difficulties associated with the term 'state'.		
Teaching procedures (and particular reasons for using these to engage with this idea).	**Probes of student understanding:** e.g., students draw a flask containing air, then re-draw the same flask with some of the air removed. Probes promote student thinking and uncover individual's views of situations. **Analogies:** Use of analogies to draw parallel between new ideas and specific/similar situations. For example, although something may appear to be made up of one thing – like a pipe is made up of one piece of metal – it is really the combination of lots of small things. This can be analogous to a jar of sand. From a distance it looks like one thing, but up close you can see the individual grains of sand.	**POE (Predict-Observe-Explain):** e.g., squashing syringe of air (ask students to predict the outcome based on different models of matter – e.g., continuous vs. particle). **Mixing activities:** e.g., noting that the combined volume of methylated spirits and water or salt and water is less than the sum of individual volumes. (The outcome can be explained by empty space between the bits.) **Comparing models:** (e.g., continuous and particle.)	**Translation activities:** e.g., role-play, modelling, drawing. For example, my life as a Carbon Atom; or, write about what you would see if you were inside a particle of water. **Imaginative writing:** Compare pieces with & without misconceptions, i.e., share students' work around the class and encourage students' comments on aspects of understanding in them. **Using models & demonstrations:** e.g., a jar of marbles as model: packed tight to illustrate a solid; remove one & shake to demonstrate movement in a liquid. **Observation:** dry ice sublimating- what's happening?

	A: Matter is made up of small bits that are called particles.	B: There is empty space between particles.	C: Particles are in constant motion.
Knowledge about students' thinking which influences your teaching of this idea.	Many students will use a continuous model (despite former teaching).	The notion of 'space' is very difficult to think about – most students propose there is other 'stuff' between the particles. Students think that particles get bigger during expansion.	Students have commonly encountered 'states of matter' but do not understand the ideas in terms of particle movement. Students can be confused by the notion of melting and think a particular particle melts.
Other factors that influence your teaching of this idea.	Maturity – stage of psychological development, readiness to grapple with abstract ideas. Dealing with many different student conceptions at once. Knowledge of context (students' and teacher's). Using the term 'phase' suggests the idea of a continuum and may help to address the difficulties associated with the term 'state'.		
Teaching procedures (and particular reasons for using these to engage with this idea).	**Probes of student understanding:** e.g., students draw a flask containing air, then re-draw the same flask with some of the air removed. Probes promote student thinking and uncover individual's views of situations. **Analogies:** Use of analogies to draw parallel between new ideas and specific/similar situations. For example, although something may appear to be made up of one thing – like a pipe is made up of one piece of metal – it is really the combination of lots of small things. This can be analogous to a jar of sand. From a distance it looks like one thing, but up close you can see the individual grains of sand.	**POE (Predict-Observe-Explain):** e.g., squashing syringe of air (ask students to predict the outcome based on different models of matter – e.g., continuous vs. particle). **Mixing activities:** e.g., noting that the combined volume of methylated spirits and water or salt and water is less than the sum of individual volumes. (The outcome can be explained by empty space between the bits.) **Comparing models:** (e.g., continuous and particle.)	**Translation activities:** e.g., role-play, modelling, drawing. For example, my life as a Carbon Atom; or, write about what you would see if you were inside a particle of water. **Imaginative writing:** Compare pieces with & without misconceptions, i.e., share students' work around the class and encourage students' comments on aspects of understanding in them. **Using models & demonstrations:** e.g., a jar of marbles as model: packed tight to illustrate a solid; remove one & shake to demonstrate movement in a liquid. **Observation:** dry ice sublimating- what's happening?

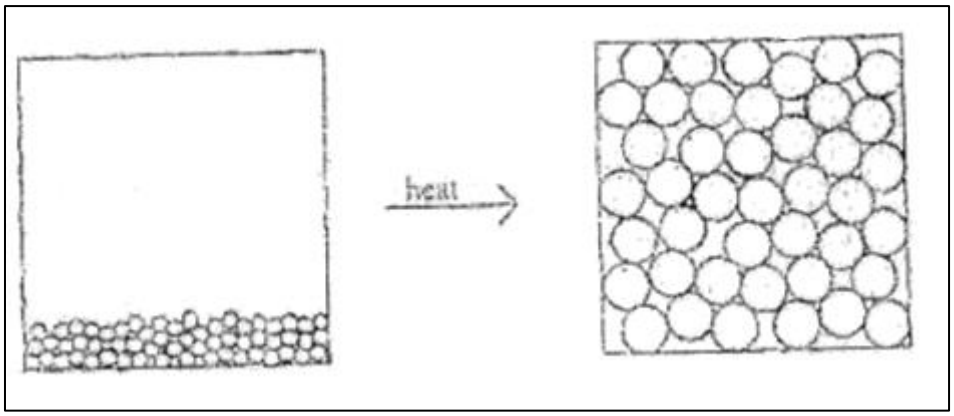
D: Particles of different substances are different.	E: There are different types of small bits of substances.	F: Atom particles don't disappear or get created, but their arrangements may be changed.	G: Models are used in science to help explain phenomena. All models have limitations.
Students tend to internalise a model from textbooks that shows circles all of the same size, so they think all particles are the same.	Students use the terms 'molecule' and 'atom' without understanding the difference between these concepts. They simply adopt the language.	Students believe that new stuff can appear and that stuff can disappear (e.g., when water evaporates).	It's hard for students to shift from thinking of science as 'discovered' to 'constructed'.
(As per Big Ideas A, B & C.)			This is not traditionally addressed in science curricula.
Mixing activities: It can be helpful to model the mixing of different substances by, for example, using different sized balls for the mixing of water and methylated spirits.	**POE (Predict-Observe-Explain):** e.g., What is the vapour above boiling water? Students predict what happens to hydrogen and oxygen molecules when water is boiled. Many students predict that H and O will separate. Teacher establishes test for each gas, and class explains outcome of POE using gas tests as required. (This can create a need for different kinds of smallest bits.) **Modelling with specific materials**: e.g., explore the possible combinations of atoms and molecules in new things (e.g., using different sized blocks of plasticine). [continued over]		**Historical research:** Students investigate history of ideas about atoms and atomic structure and how scientists observing nature came to different interpretations of it. Students can sequence a set of historical events including Dalton, Faraday, & Thompson's inferences and observations (i.e., progressively building on models of matter and atoms.) **Classification and Interpretive Discussion:** Ask students to classify some substances as solid, liquid, gas. Include some problematic examples (e.g., 'Oobleck', honey, sand, foam, jelly, toothpaste.) Discuss aspects that are problematic in definitions.

APPENDIX G: PILOT VERSION OF TOPIC SPECIFIC PCK

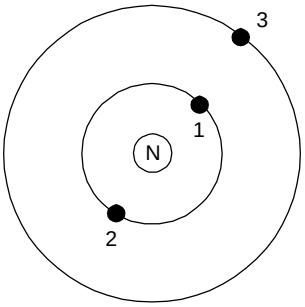
Code:

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. Learners in grade 10 class were asked to represent the change that takes place when a substance is heated. Shown below is the response Teboho has written on the board.



How would you comment on Teboho's response as part of explain to the rest of the class?



A simple representation of an atom

2. When learners were asked to describe what is happening in the given atomic model above, Lerato gave the following response:

   (i) An electron further away from the nucleus (electron 3) would be attracted by a stronger force as it is further away and therefore it will need a stronger force to draw the electron towards the centre.
   (ii) The type of attracting electron towards the nucleus is a pull force.
   (iii) There is no force acting on the nucleus exerted by the electron.
   (iv) The electrons are on the shells and have a fixed distance away from each other and therefore there will be no force between them.

How would you respond to Lerato's description?

CATEGORY B: CURRICULUM AWARENESS

3. Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the three main ideas (main concepts) to be taught about particle nature & atomic theory at Grade 10? Choose from the list provided.

Kinetic Energy	Different atoms possesses different number of subatomic particles
Particles are in constant motion	Isotopes
Intermolecular forces	Calculation of relative atomic mass
There is an empty space between particles	Nuclide notation
Matter is made up of small bits that are called particles	Number of protons in an atom never changes
Boiling point	Calculating categories of atoms (mass number, atomic number & number neutrons)
Temperature	Other

5.	2.
6.	3.
7.	4.

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

3.3 What topics must have been covered in chemistry before you can teach particle nature & atomic theory?

List of Topics to be taught before particle nature & atomic theory	**Place them in a sequence** (the one to be taught first , place it as No. 1)	**Provide reasons for the proposed sequence**
	1.	
	2.	
	3.	
	4.	

3.4 Why is it important for learners to learn about particle nature & atomic theory? Identify reasons related to:

i. Conceptual Progression
ii. Application

iv. Motivation or Interest

CATEGORY C: WHAT MAKES THE TOPIC DIFFICULT TO UNDERSTAND?

4 Tick (✓) from the list below, concepts of particle nature & atomic theory you consider difficult to teach? You may also add your own. Explain why you consider the chosen topics difficult to teach.

Concept	✓	Why considered difficult?
There is an empty space between particles		
Electrostatic force between electrons and nucleus in an atom.		
Particles are in constant motion		
Calculating the relative atomic mass of an isotope		

Concept	✓	Why considered difficult?
Intermolecular forces		
Matter is made up of small bits that are called particles		
Finding number of electrons in an ion for example ${}^{24}_{12}Mg^{2+}$		
Identifying the isotopic elements.		

5 CATEGORY D: REPRESENTATIONS/ MODELS

Phases of Matter

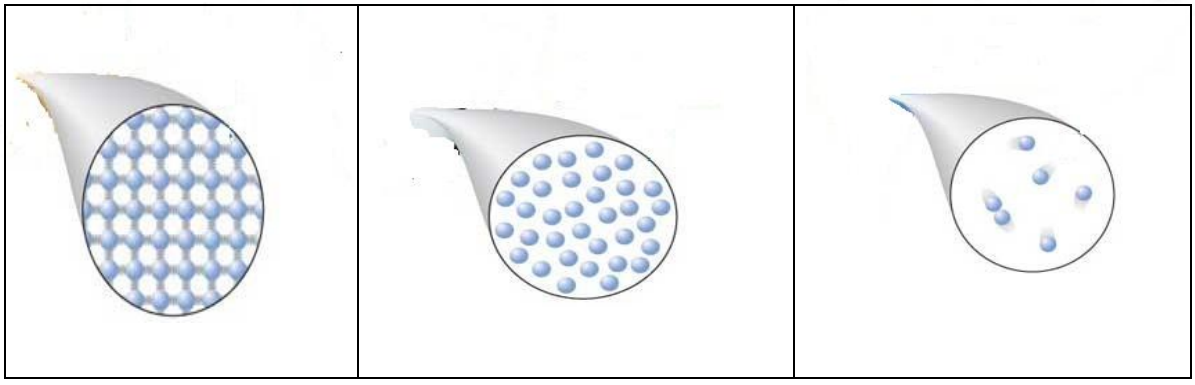
Representation 1

Solid	Liquid	Gas

Representation 2



Representation 3



5.1 Complete the table below by providing as many details as possible.

Representation No.	What I Like	What I do not like
1		
2		
3		

5.2 Which representation do you like most?

5.3 How would you use the representation that you like most?

CATEGORY E: TEACHING STRATEGIES

Average relative atomic mass

6 Shown below is a learners' respond to a written test meant to assess learners' prior knowledge on average relative atomic masses.

Question

Calculate the average relative atomic mass of the following isotopes of oxygen atom:

Element	Isotopes	Isotopic mass	Percentage abundance
Oxygen	^{16}O	16	99,79
	^{17}O	17	0,037
	^{18}O	18	0,204

A learner's response:

O-16: 16
O-17: 17
O-18: 18

16+17+18=51
51 ÷ 3= 17amu

Following the learner's response, how will you teach a lesson on calculating the average relative atomic mass?

APPENDIX H: RUBRIC

Topic Specific PCK Categories	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Repeats standard definition with no expansion or with incorrect explanation	• Identifies misconception or prior knowledge • Provide standardized knowledge as definition • Expands and re-phrase explanation correctly	• Identifies misconception or prior knowledge • Provide standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding
Curricular Saliency	• Identified concepts are a mix of Big Ideas and subordinate ideas • Identified subordinate ideas are a mix with those of other topics or no subordinates provided • Identified post-concepts are a mix with those to be taught in current topic • Sequencing no value due to mixed concepts • Reasons given for importance of topic limited to generic benefit of education	• Identifies at least 3 Big Ideas • Not all 3 Big ideas have subordinate concepts identified however those identified are correct • Sequencing has one or two illogical placing of main concepts (Big Ideas) • Identified post-concepts are far from the current topic, they refer to concepts basic to the subject. • Reasons given for importance of topic exclude conceptual considerations such as scaffolding or sequential development for other topics in the subject.	• Identifies at least 3 Big Ideas • Identifies correct subordinate ideas and shows links to Big ideas with no additional explanations • Provides logical sequence of concepts of all three Big Ideas. • Identified post-concepts includes those needed for the current topic • Reasons given for importance of topic include reference to conceptual scaffolding/sequential development of understanding of other topics in the subject however without specifying the topics	• Identifies at least 3 Big Ideas • Identifies correct subordinate ideas and explains links to Big Ideas • Provides logical sequence of all three Big Ideas • Identified post-concepts include those needed in discussing the introductory definitions and those sequentially needed in the next Big Ideas of the current topic. • Reasons given for importance of topic include conceptual scaffolding/sequential development of understanding for specified subsequent topics in the subject.
What makes topic difficult	• Identifies broad topics without specifying the actual sub-concepts that are problematic • Reasons not given	• Identifies specific concepts but provides broad generic reasons such as 'abstract'	• Identifies specific concepts with reasons related to specified prior knowledge of students or common misconceptions	• Identifies specific concepts with reasons related to prior knowledge of specified students or common misconceptions • Provides reasons linking to specific gate keeping concepts that when not fully understood adds to the difficulty of a

Topic Specific PCK Categories	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
				concept regarded as difficult
Representations	• Limited to use of only macroscopic analogies, demos, etc.) representation with no explanation of specific links to the concepts represented	• Identification of macroscopic representation (analogies, demos, etc.) • Use of sub-microscopic representation for different aspects of a concept not enforcing a specific aspect	• Identification of macroscopic representation (analogies, demos, etc.) • Use of sub-microscopic representation for different aspects of a concept not enforcing one specific aspect of a concept	• Use of macroscopic representation (analogies, demos, etc.) • Use of sub-microscopic representation for different aspects of a concept not enforcing at least two specific aspects of a concept
Conceptual Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions • Lacks aspects of curriculum saliency • Use of representations limited to macroscopic or symbolic scientific representation with no linking explanatory notes • Suggested activities are largely teacher centred	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy • Lacks aspects of curriculum saliency • Use of macroscopic and symbolic representations for With no linking explanatory notes • Limited involvement of learners	• Overall, strategy workable • Considers confirmation/confrontation of student prior knowledge and/or misconceptions • Considers at least one aspect related to curriculum saliency: sequencing or what not to discuss yet or emphasis of important concepts • Uses at least two different levels of representations to enforce an aspect of a concept with explanations • There is evidence of encouraged learner involvement	• Overall , excellent strategy to teach required concept • Considers confirmation/confrontation of student prior knowledge and/or common misconceptions • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce a singular aspect of a concept. • Highly learner centred lesson

Appendices

APPENDIX I: KAPPA STATISTICS RESULTS

PILOT

Inter-rater agreement (kappa)

Observer A	WD
Observer B	PP

Observer B	Observer A											
	7	8	9	10	11	12	13	14	15	16	17	
7	0	0	0	0	0	0	0	0	0	0	0	0 (0.0%)
8	0	0	0	1	0	0	0	0	0	0	0	1 (9.1%)
9	1	0	1	0	0	0	0	0	0	0	0	2 (18.2%)
10	0	0	0	0	1	0	0	0	0	0	0	1 (9.1%)
11	0	0	0	1	0	0	0	0	0	0	0	1 (9.1%)
12	0	0	0	1	0	0	0	0	0	0	0	1 (9.1%)
13	0	0	0	0	0	1	0	0	0	0	0	1 (9.1%)
14	0	0	0	1	0	0	0	0	0	0	0	1 (9.1%)
15	0	0	0	0	0	0	0	1	0	0	0	1 (9.1%)
16	0	0	0	0	0	0	0	1	0	0	0	1 (9.1%)
17	0	0	0	0	0	0	0	0	1	0	0	1 (9.1%)
	1 (9.1%)	0 (0.0%)	1 (9.1%)	4 (36.4%)	1 (9.1%)	1 (9.1%)	0 (0.0%)	2 (18.2%)	1 (9.1%)	0 (0.0%)	0 (0.0%)	11

Weighted Kappa[a]	0.479
Standard error	0.101
95% CI	0.282 to 0.676

[a] Linear weights

PRE-CK

Inter-rater agreement (kappa)

Observer A	PP
Observer B	WD

	Observer A																
Observer B	26	33	35	36	37	46	50	51	52	56	60	65	66	70	71	73	
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
35	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
36	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
37	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	
50	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
51	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
60	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	
65	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
73	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	1 (6.7%)	1 (6.7%)	0 (0.0%)	2 (13.3%)	0 (0.0%)	2 (13.3%)	0 (0.0%)	1 (6.7%)	1 (6.7%)	1 (6.7%)	2 (13.3%)	0 (0.0%)	1 (6.7%)	1 (6.7%)	1 (6.7%)	0 (0.0%)	(

Weighted Kappa[a]	0.757
Standard error	0.105
95% CI	0.552 to 0.963

[a] Linear weights

POST-CK

Inter-rater agreement (kappa)

Observer A	PP
Observer B	WD

	Observer A															
Observer B	46	47	50	51	52	54	55	56	59	70	72	73	86	87	88	89
46	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0 (0.0%)	1 (6.7%)	1 (6.7%)	0 (0.0%)	1 (6.7%)	1 (6.7%)	1 (6.7%)	1 (6.7%)	1 (6.7%)	0 (0.0%)	2 (13.3%)	1 (6.7%)	1 (6.7%)	0 (0.0%)	1 (6.7%)	1 (6.7%)

Weighted Kappa[a]	0.877
Standard error	0.034
95% CI	0.811 to 0.944

[a] Linear weights

PRE-TOPIC SPECIFIC PCK

Inter-rater agreement (kappa)

Observer A	PP
Observer B	WD

	Observer A								
Observer B	7	8	9	10	11	12	13	16	
7	0	1	0	0	0	1	0	0	2 (13.3%)
8	1	0	0	0	0	0	0	0	1 (6.7%)
9	2	0	1	1	0	0	0	0	4 (26.7%)
10	0	2	0	0	0	0	0	0	2 (13.3%)
11	0	0	1	0	0	0	0	0	1 (6.7%)
12	0	0	0	0	1	0	0	0	1 (6.7%)
13	0	0	0	0	2	1	0	0	3 (20.0%)
16	0	0	0	0	0	0	1	0	1 (6.7%)
	3 (20.0%)	3 (20.0%)	2 (13.3%)	1 (6.7%)	3 (20.0%)	2 (13.3%)	1 (6.7%)	0 (0.0%)	15

Weighted Kappa[a]	0.324
Standard error	0.128
95% CI	0.0727 to 0.576

[a] Linear weights

PRE-TOPIC SPECIFIC PCK

Inter-rater agreement (kappa)

Observer A	PP
Observer B	WD

	Observer A												
Observer B	7	8	9	10	11	12	13	14	15	16	17	19	
7	0	0	2	0	0	0	0	0	0	0	0	0	2 (13.3%)
8	0	0	1	0	0	0	0	0	0	0	0	0	1 (6.7%)
9	0	0	0	1	1	0	0	0	0	0	0	0	2 (13.3%)
10	0	0	0	0	1	1	2	0	0	0	0	0	4 (26.7%)
11	0	0	0	1	0	0	0	0	0	0	0	0	1 (6.7%)
12	0	0	0	0	0	0	0	1	0	0	0	0	1 (6.7%)
13	0	0	0	0	0	0	0	0	0	0	0	0	0 (0.0%)
14	0	0	0	0	0	0	0	0	0	0	0	0	0 (0.0%)
15	0	0	0	0	0	0	0	1	0	0	0	0	1 (6.7%)
16	0	0	0	0	0	0	1	0	0	0	0	0	1 (6.7%)
17	0	0	0	0	0	0	0	0	0	0	0	1	1 (6.7%)
19	0	0	0	0	0	0	0	0	0	0	1	0	1 (6.7%)
	0 (0.0%)	0 (0.0%)	3 (20.0%)	2 (13.3%)	2 (13.3%)	1 (6.7%)	3 (20.0%)	2 (13.3%)	0 (0.0%)	0 (0.0%)	1 (6.7%)	1 (6.7%)	15

Weighted Kappa[a]	0.521
Standard error	0.096
95% CI	0.332 to 0.709

[a] Linear weights

APPENDIX J: SAMPLES OF COMPLETED QUESTIONS EXTRACTED FORM CoRes, TESTS, REFLECTIVE QUESTIONNAIRE AND CK MEMO

FINAL CoRe

Curriculum Saliency	
What are the big ideas for the topic?	There is an empty space between the particles
What do you intend the learners to know about this idea?	- The spaces between the particles determines the phases of matter - know what physical change is - know what melting, boiling & freezing point are - define melting, evaporation, freezing, sublimation & condensation in terms of changes in state.
Why is it important for learners to know this big idea?	- It helps the learners explain how the different phases changes occur - To be able to understand the kinetic theory of gases - Understanding of intermolecular forces
What concepts need to be taught before teaching this big idea?	- All matter is made up of small bits called particles - what matter is - phases of matter
What else do you know about this idea (that you do not intend learners to know yet)?	- chemical change & how it differ from physical change - Intermolecular forces - Bond lengths

FINAL CoRe

What is difficult to teach	
What do you consider easy or difficult in teaching this big idea?	- Since the empty spaces can not be seen with naked eye it is hard to grasp the concept - It is difficult to teach that air is also made up of particles
Student Misconceptions	
What are the typical student misconceptions on this big idea?	- Particles in a solid are arranged in a way that has no spaces between the particles. - Thinking that space means air, they may think the spaces are filled with air
Teaching Strategies	
What effective teaching strategies would you use to teach this idea?	- Have a demonstration using water and let the learners see how the different phases change - Have flow diagrams that illustrate how the particles behave in the different states
What questions would you consider important to ask in your teaching strategies?	- How the particles of the different states are arranged? - Explain what happens to the particles when phases change - Ask what is in the spaces so as to see if they understood that there is an empty space

FINAL CoRe

Representations	
What representations would you use in your teaching strategies?	- Demonstration model - Flow diagrams
Assessment	
What ways would you use to assess understanding of learners?	- Give the learners activities to do with different phase changes & let them identify & explain them - Have an activity where they link the different phases to boiling, melting & freezing
Reflections	
What aspects of planning and teaching this big idea would you like to reflect on?	- The teaching strategies : You have to evaluate if the learners understood what you were trying to teach them. Reflect if the demonstrations made sense and how the learners performed in the assessment you gave them. Does their performance show that they understood, if not what are you going to change so you convey the message better.

INITIAL CoRe

Curriculum Saliency	
What are the big ideas for the topic?	There is an empty space between the particles
What do you intend the learners to know about this idea?	- The spaces between the particles determines the phases of matter - know what physical change is - know what melting, boiling & freezing point are - define melting, evaporation, freezing, sublimation & condensation in terms of changes in state.
Why is it important for learners to know this big idea?	- It helps the learners explain how the different phases changes occur - To be able to understand the kinetic theory of gases - Understanding of intermolecular forces
What concepts need to be taught before teaching this big idea?	- All matter is made up of small bits called particles - what matter is - phases of matter
What else do you know about this idea (that you do not intend learners to know yet)?	- Chemical change & how it differ from physical change - Intermolecular forces - Bond lengths

INITIAL CoRe

What is difficult to teach	
What do you consider easy or difficult in teaching this big idea?	They cannot see the spaces between the particles
Student Misconceptions	
What are the typical student misconceptions on this big idea?	- Empty space is made of air - There are no spaces between solid particles
Teaching Strategies	
What effective teaching strategies would you use to teach this idea?	- Simulation - Videos - Models - Drawings
What questions would you consider important to ask in your teaching strategies?	- What is a vacuum? - Why is it wrong to say air is empty space? - Why is it wrong to say there are no spaces between particles in a solid phase?

INITIAL CoRe

Representations	
What representations would you use in your teaching strategies?	- Diagrams (flow diagrams) - Demonstration models - Simulations
Assessment	
What ways would you use to assess understanding of learners?	- Quizing
Reflections	
What aspects of planning and teaching this big idea would you like to reflect on?	- Linking the concept that matter is made of particles to the spaces found between the particles.

PRE-CK TEST- (TEACHER ZD)

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

Qualification and length of course	From (year)	To (year)	Main Subjects
Bsc Physical Sciences	2007	2011	Chemistry and Mathematics.

Kindly provide information on any teaching experience you may have, including tutoring and demonstrating.

Tutored for a week at a high school with the Umfundo programme. Tutored maths in grade 6.

CATEGORY A

1. Give one word or term for each of the following description.
   (a) A substance that is made of only one kind of atom.
   (b) A substance made of two or more atoms of different elements chemically bonded.
   (c) A smallest particle of an element that still retains the chemical properties of that element.
   (d) A particle that consists of two or more atoms bonded together.
   (e) A substance that consists of different substances that are not chemically bonded to each other and still retain their original properties.

Answers

(a) Molecule

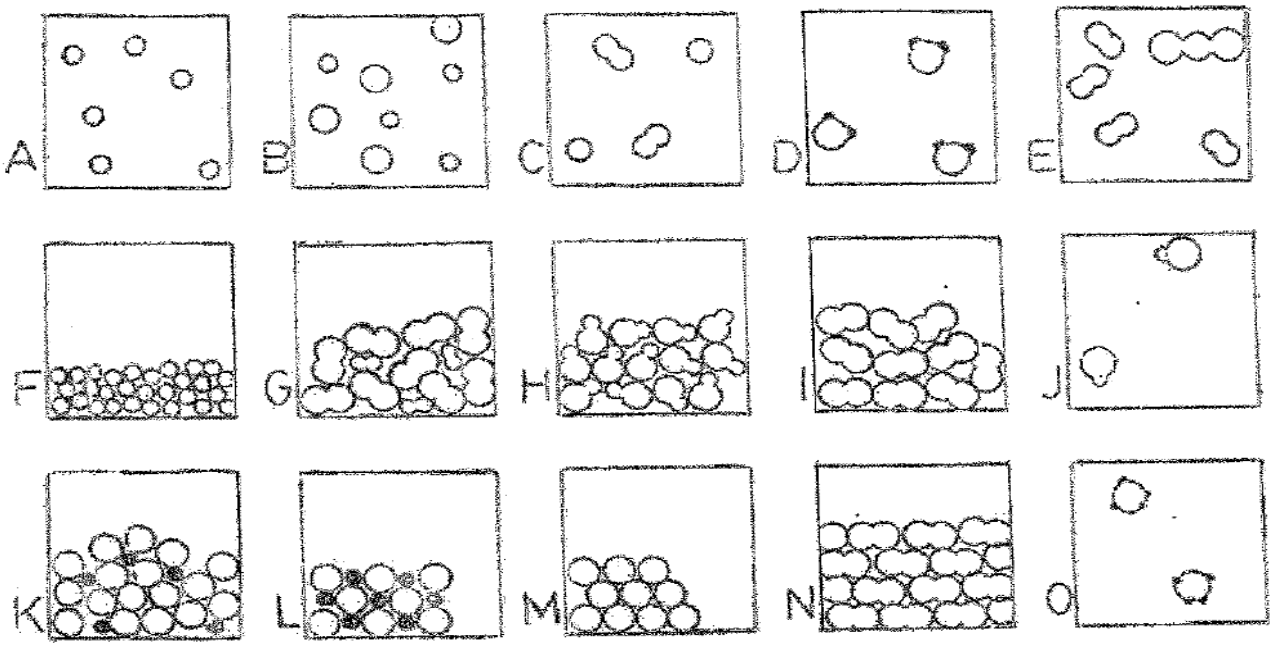
(b) molecule, compound.

(c) nucleus

(d) Orbital.

(e) Mixture

2. In the diagrams below say:



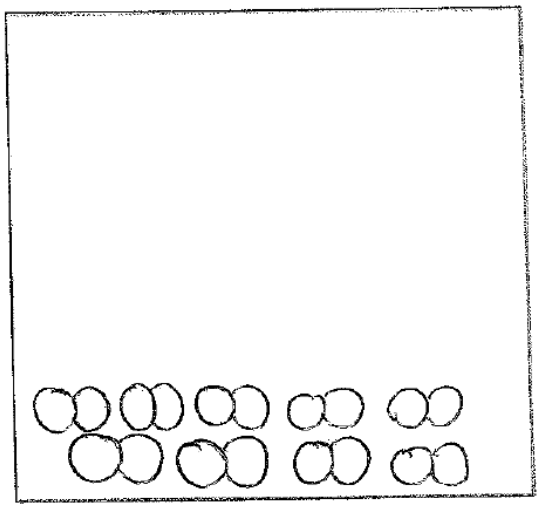
(a) Which diagram(s) consist(s) of only one element?
(b) Which diagram(s) consist(s) of only one compound?
(c) Which diagram(s) represent(s) a mixture?
(d) Which diagram(s) represent(s) a pure solid?
(e) Which diagram(s) represent(s) a pure liquid?
(f) Which diagram(s) represent(s) a gas?
(g) Which diagram(s) represent a pure substance?
(h) Which diagram(s) represent molecules only?

Answers

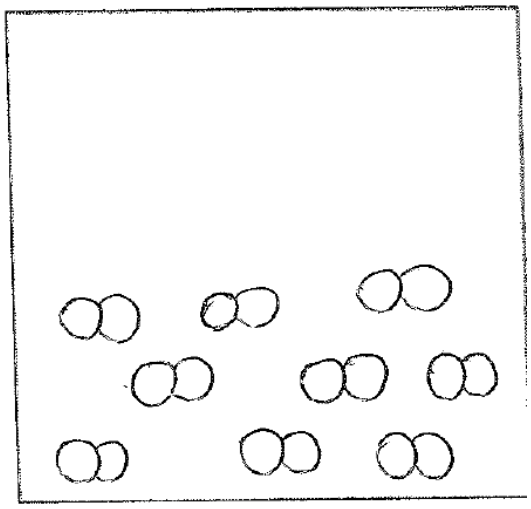
(a) A, F, M
(b) D, J, N, H, I
(c) B, C, E, G, K, L
(d) F, M, N, L
(e) G, H, I, K
(f) A, B, C, D, E, J, O
(g) M
(h) D, J, O

CATEGORY

3. Draw microscopic representations of oxygen as it heated from a solid to a liquid to a gaseous state in the boxes below. Use ⬤⬤ to represent a single molecule. Draw 9 molecules in each box.

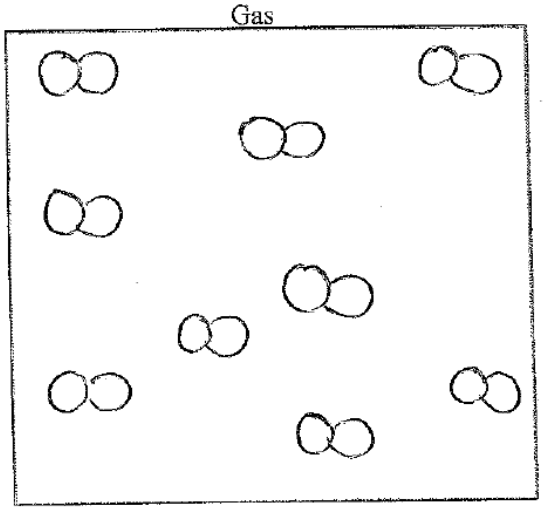


Solid



Liquid

Gas



4. Question 1 to 4: are the following statement true (T) or false (F)?
Circle the correct answer and indicate the degree of confidence i.e. 100% sure, not sure or guessing.

(1) All molecules of a given pure substance are identical (T)/F

100% sure	(*sure*)	*guess*

(2) Between molecules of a substance there is "empty space". (T)/F

100% sure	*sure*	(*guess*)

(3) A molecule of a substance in the solid phase has larger mass than a molecule of the same substance in the gaseous phase. T(F)

100% sure	(*sure*)	*guess*

(4) The forces of attraction between molecules of naphthalene in the liquid phase are greater than in the solid phase. T(F)

100% sure	*sure*	(*guess*)

CATEGORY C

5.

(a) Name the sub-atomic particles found in the nucleus of an atom?

protons and neutrons

(b) What type of charge is found on each of the above mentioned sub-atomic particles?

Positive and neutral

(c) Fill in the blanks on the following table.

Element	Notation	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons	Number of nucleons
Barium ion	$^{20}_{10}Ba^{2+}$	20	10	20	18	9 36	21
Fluoride ion	$^{19}_{9}F^{-}$	19	9	13	14	26	21
Aluminium ion	$^{23}_{13}Al^{3+}$	23	13	18	15	24 ~~20~~	51
Chloride ion	$^{35}_{25}Cl^{-}$	35	25	17	18	34	51

(d) Which of the following unidentified elements are isotopes of one another?

$^{12}_{6}X$, $^{12}_{7}Y$, $^{24}_{12}A$, $^{14}_{6}Xy$, $^{13}_{6}Mp$ (note X, Y, A, Xy and Mp represent the symbols of unspecified elements).

$^{14}_{6}Xy$ and $^{13}_{6}Mp$ are isotopes of one another

How did you work out the answer above?

They have the same

What is the name of an isotopic element represented in (d)?

Carbon - which exists as carbon 13 and carbon 14

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
(B)	66	33
C	33	66
(D)	100	1

~~^{35}Cl occurs more naturally than ^{37}Cl because it is more stable the in the first form than it is in the second form.~~ ^{35}Cl is mostly found naturally than ^{37}Cl which only exists in small quantities.

POST-CK TEST- (TEACHER ZD)

CATEGORY A

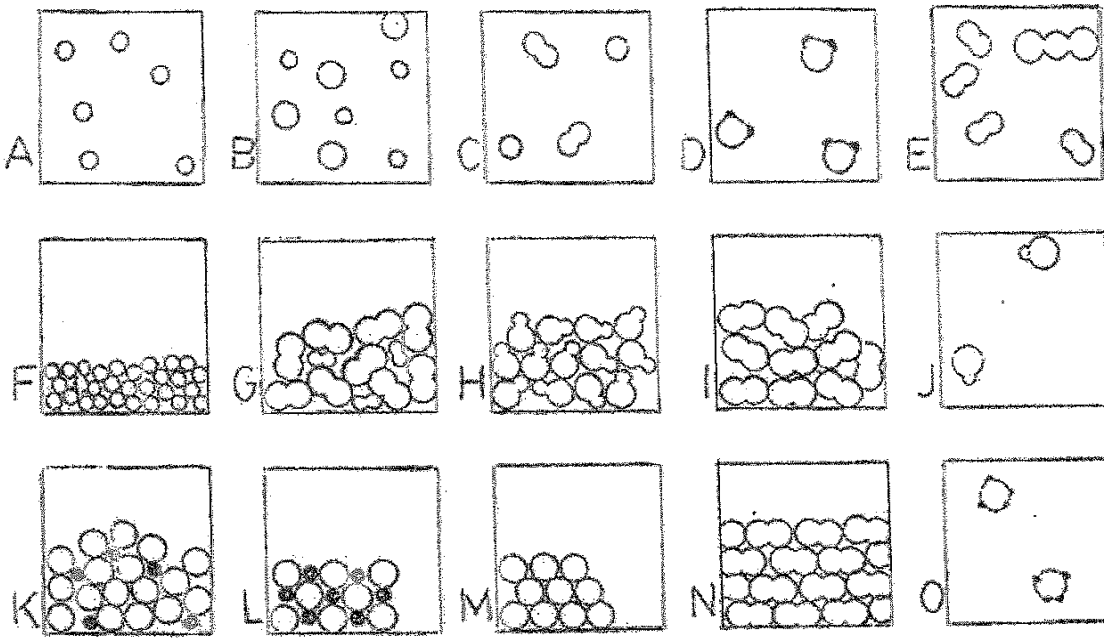
1. Give one word or term for each of the following description.
   (a) A substance that is made of only one kind of atom.
   (b) A substance made of two or more atoms of different elements chemically bonded.
   (c) A smallest particle of an element that still retains the chemical properties of that element.
   (d) A particle that consists of two or more atoms bonded together.
   (e) A substance that consists of different substances that are not chemically bonded to each other and still retain their original properties.

Answers

(a) Element ✓
(b) Compound ✓
(c) Atom ✓
(d) Molecule ✓
(e) Mixture ✓

5

2. In the diagrams below say:



(a) Which diagram(s) consist(s) of only one element?
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(d) Which diagram(s) represent(s) a pure solid?
(e) Which diagram(s) represent(s) a pure liquid?
(f) Which diagram(s) represent(s) a gas?
(g) Which diagram(s) represent a pure substance?
(h) Which diagram(s) represent molecules only?

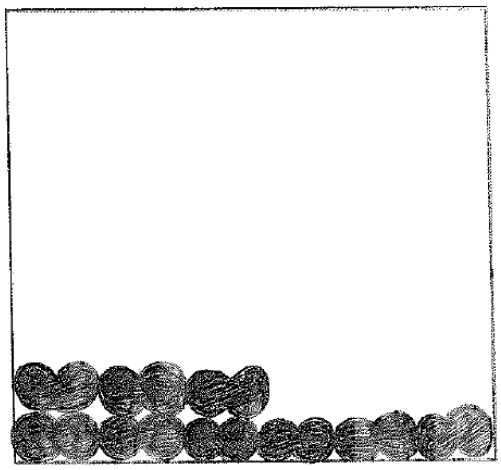
Answers

Question 5 -Pre Topic Specific PCK-test (Teacher NN)

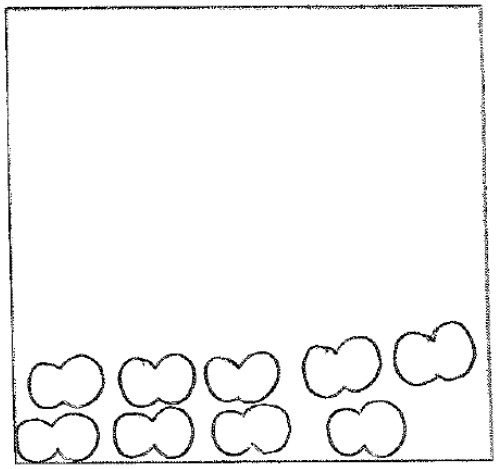
(a) A, F, M (4)
(b) D, H, I, J, N, O (5)
(c) B, C, E, G, K, L (3)
(d) F, L, M, N (2)
(e) H, I, (7)
(f) A, B, C, D, E, J & O (9)
(g) A, D, F, H, I, J, M, N & O (6)
(h) O, N, J, I, H, D

CATEGORY

3. Draw microscopic representations of oxygen as it heated from a solid to a liquid to a gaseous state in the boxes below. Use ● to represent a single molecule. Draw 9 molecules in each box.

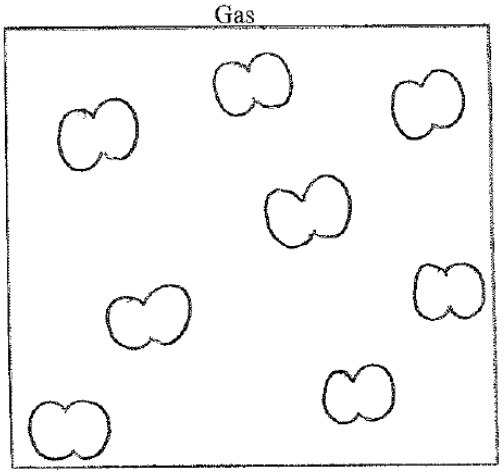


Solid



Liquid

Gas



4. Question 1 to 4: are the following statement true (T) or false (F)?
Circle the correct answer and indicate the degree of confidence i.e. 100% sure, not sure or guessing.

(1) All molecules of a given pure substance are identical. (T)/F

100% sure	X *sure*	*guess*

(2) Between molecules of a substance there is "empty space" (T)/F

100% sure X	*sure*	*guess*

(3) A molecule of a substance in the solid phase has larger mass than a molecule of the same substance in the gaseous phase. T(F)

100% sure	*sure* X	*guess*

(4) The forces of attraction between molecules of naphthalene in the liquid phase are greater than in the solid phase. T(F)

100% sure X	*sure*	*guess*

CATEGORY C

5.

(a) Name the sub-atomic particles found in the nucleus of an atom?

Protons and neutrons

(b) What type of charge is found on each of the above mentioned sub-atomic particles?

Protons - Positive neutrons - no charge

(c) Fill in the blanks on the following table.

Element	Notation	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons	Number of nucleons
Calcium ion	Ca^{2+}	20	38	20	18	18	38
Fluoride ion	$^{19}_{9}F^{-}$	9	19	9	10	10	19
Aluminium ion	$^{23}_{13}Al^{3+}$	13	23	13	10	10	13
Chloride ion	Cl^{-}	17	35	17	18	18	35

(d) Which of the following unidentified elements are isotopes of one another?

$^{12}_{6}X$, $^{12}_{7}Y$, $^{24}_{12}A$, $^{14}_{6}Xy$, $^{13}_{6}Mp$ (note X, Y, A, Xy and Mp represent the symbols of unspecified elements).

$^{12}_{6}X$, $^{14}_{6}Xy$ & $^{13}_{6}Mp$

How did you work out the answer above?

Isotopes have the same atomic number but different masses

What is the name of an isotopic element represented in (d)?

Carbon

(e) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

C is most likely. The amu of an isotope is calculated by the sum of the percentages of the the different occuring isotopes.

(B) 66% ^{35}Cl & 33% ^{37}Cl

23,1 + 12,21 = 35,31

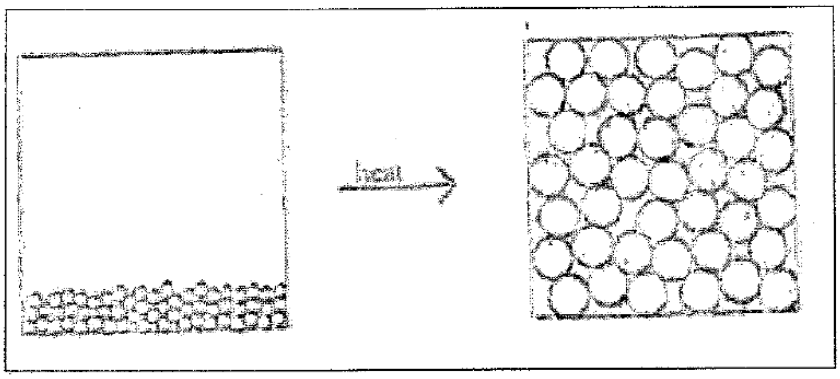
(C) 33% ^{35}Cl , 66% ^{37}Cl

11,55 + 24,42 => 35,97. => the closest to the answer

PRE-TOPIC SPECIFIC CK TEST- (TEACHER NN)

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. Learners in grade 10 class were asked to represent the change that takes place when a substance is heated. The response Teboho's has written on the board is shown below.



How would you comment on Teboho's response as part of an explanation to the rest of the class?

Response A: Teboho's response is incorrect. All substances have small particles called atoms that may combine chemically with each other to form molecules. When substances are heated their molecules do not expand in size. The size of the molecules stays the same.

Response B: Teboho's response is incorrect. When a substance is heated, molecules gain kinetic energy. The molecules will start vibrating and the bonds between them weaken to allow re-arrangement and in some cases allowing the molecules to move away from each other. The molecules themselves do not change in size when heated. It is the re-arrangement of molecules that changes.

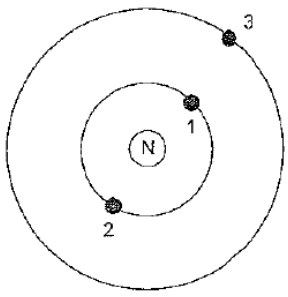
Response C: Teboho's response is incorrect. When a substance is heated, a phase change occurs. The molecules of a substance become more free from each other as the bonds are weakend in some cases completely broken. Substances that were originally solids may become liquids and liquids may become gases

Response D: None of the above

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

My choice is Response B

When a substance is heated, the gain in kinetic energy will cause the particles to vibrate and the bonds weaken. A good example of this is seen in the heating of metals. A heated metal will expand in size as the bonds weaken and particles move away from each other. However, if the temperature is increased to the melting point of that metal, it will melt.



A simple representation of an atom

2. When learners were asked to describe what is happening in the given atomic model above, Lerato gave the following written response:

   An electron further away from the nucleus (electron 3) would experience less attraction to the nucleus.

   What comment(s) would you write on her paper?

Response A: True, electron 3, located away from the nucleus will not be attracted in the same way as the electron closer to the nucleus.

Response B: True, the electrons on the energy levels further away from the nucleus experience a smaller force of attraction compared those which are on nearer energy levels. However, all electrons are attracted by the same type of force from the nucleus.

Response C: True, electron 3 will experience less attraction towards the nucleus because of the greater distance between the electron and the nucleus.

Response D: None of the above

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

My choice is Response B.

Electrons further away from the nucleus are easily lost from the atom. This means that they experience a small attraction force than those that are closer to the nucleus. It would be correct to suggest that the attraction force between a nucleus and an electron is inversely proportional to the distance between them.

CATEGORY B: CURRICULUM AWARENESS

3. Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10? Choose from the list provided.

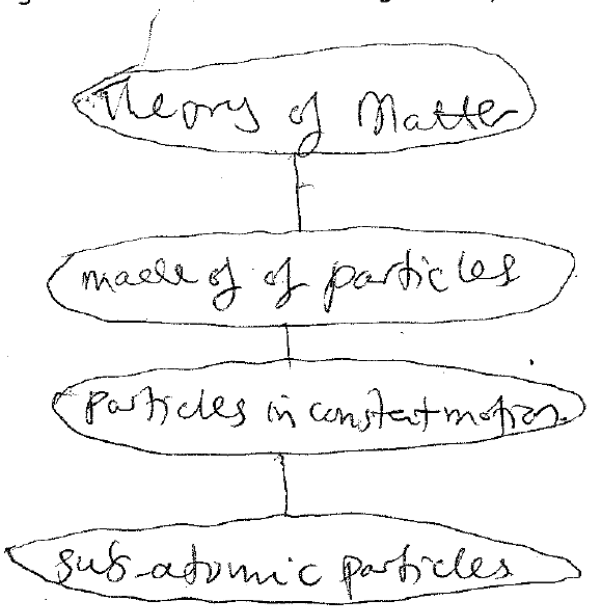
Particles are in constant motion	Substance have subatomic particles
Molecules have forces between each other	Compounds are made up of atoms
Elements are made up of atoms	Atom has a specific structure
Matter is made up of small bits that are called particles	There are different type of small bits of substance
Atoms are smallest particle	Matter is found in different phases
Molecules are made from atoms	Other
There are different atomic theories	

1. Matter is made up of small bits called particles
2. Particles are in constant motion
3. There are diffrent types of small bits of substance
4. Substance have subatomic particles

3.2 In what sequence would you teach the main ideas you have identified above?

I will start by teaching them that matter is made up of particles. And then I would go one and explain that these particles are in constant motion. I would conclude by teaching them that the particles are diffrent in a given matter. And that there are subatomic particles

3.3 Make a map or a diagram of these four ideas showing how they link to subordinate ideas.



3.4 What other topics in chemistry do you think require the understanding of particle nature for teaching them?

Chemical reactions and mixtures

3.5 Why is it important for learners to learn about particle nature of matter? Identify reasons related to:

i. Conceptual Progression
It is important because it is the bases on which they will get to understand other related topics because all matter has particles.
ii. Application
In everyday life, the learners need to be able to observe and explain certain things when they encounter them. For example, why metals or water expand when heated
iii. Motivation or Interest
Knowing how things occur in a chemical sense is good and should be the bases of ~~their~~ interest.

CATEGORY C: WHAT MAKES THE TOPIC DIFFICULT TO UNDERSTAND?

1. Tick (✓) from the list below, concepts of particle nature of matter you consider difficult to teach? You may also add your own. Explain why you consider the chosen topics difficult to teach.

Concept	✓	What exactly makes it difficult?
There is an empty space between particles of matter	✓	If they is an empty space between them, why can't we see it. Why don't the substances fall apart.
Particles are in constant motion	✓	In solids such as rocks and metals, how can you prove that because the motion is microscopic
There are different types of small bits of substances.	✓	How do we identify the different small bits of a substance?
Calculating the relative atomic mass of an isotope		

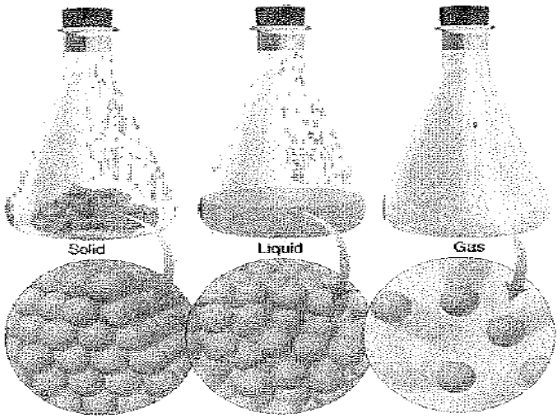
Concept	✓	What exactly makes it difficult?
Finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$		

5. CATEGORY D: REPRESENTATIONS/ MODELS

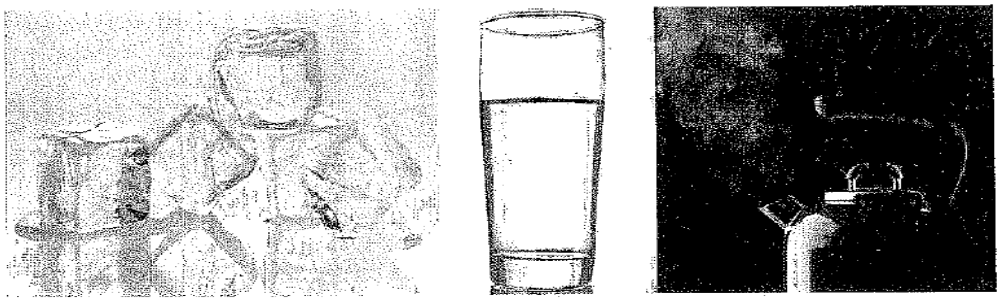
Phases of Matter

Below are three different representations that can be used for teaching phase of matter. Decide which one(s) you like and complete the table below

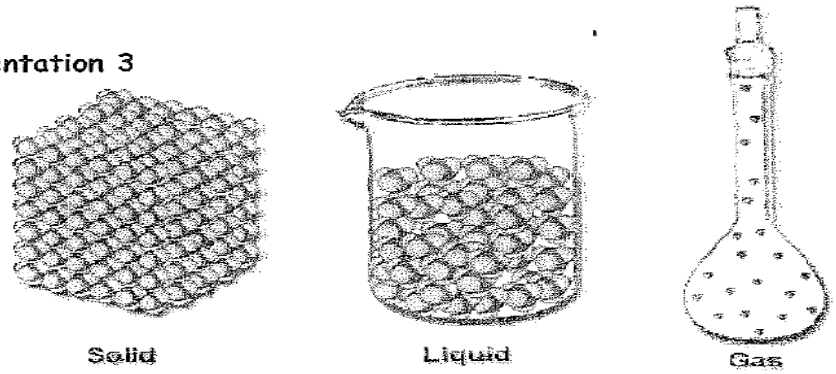
Representation 1



Representation 2



Representation 3



5.1 Complete the table below by providing as many details as possible.

Representation No.	What I Like	What I do not like
1	none	It is difficult to see the gas in the jar.
2	It is water in diffrent states.. learners can clearly tell the differences because they can touch and associate with	(none) The arrangement of particles need to be explained though.
3.	The arrangements of particles is clearly shown in the 3 states.	Learners will not be able to relate what they see to what they know.

5.2 Which representation do you like most?

2

5.3 How would you use the representation that you like most?

I would ask the learners to try and separate the water in the diffrent states and see how much effort they need to put to break the water. They then use that information to explain how they think the particles are arranged and how strong the bonds are.

CATEGORY E: TEACHING STRATEGIES

Average relative atomic mass

Shown below is a learners' respond to a written test meant to assess learners' prior knowledge on average relative atomic masses.

Question

Calculate the average relative atomic mass of a sample of oxygen gas that contains the following isotopes of oxygen atoms:

Element	Isotopes	Isotopic mass	Percentage abundance
Oxygen	^{16}O	16	99,79
	^{17}O	17	0,037
	^{18}O	18	0,204

A learner's response:

O-16: 16
O-17: 17
O-18: 18

16+17+18=51
51 ÷ 3= 17amu

Following the learner's response, how will you teach a lesson on calculating the average relative atomic mass?

I would tell the learner to express the percentage abundance in decimal form by dividing it by 100 to get 0,9979, 0,0037 and 0,00204. With these decimal numbers, s/he should multiply them with the corresponding isotopic mass and add the three of them as shown below:
(0,9979 x 16) + (0,0037 x 17) + (0,00204 x 18)
The answer s/he will get will be the average relative atomic mass.

$^{16}O \Rightarrow (99,79/100 \times 16) = x$

$^{17}O \Rightarrow (0,037/100 \times 17) = y$

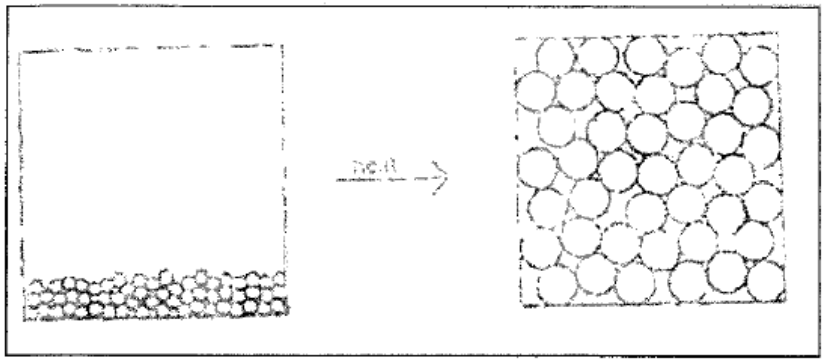
$^{18}O \Rightarrow (0,204/100 \times 18) = z$

$\therefore$ Ami $= x + y + z$.

POST-CK TEST- (TEACHER NN)

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. Learners in a grade 10 class were asked to represent the change that takes place when a substance is heated. The response Teboho has written on the board is shown below.



How would you comment on Teboho's response as part of an explanation to the rest of the class?

Response A: Teboho's response is incorrect. All substances have small particles called atoms that may combine chemically with each other to form molecules. When substances are heated their molecules do not expand in size. The size of the molecules stays the same.

Response B: Teboho's response is incorrect. When a substance is heated, molecules gain kinetic energy. The molecules will start vibrating and the bonds between them weaken to allow re-arrangement and in some cases allowing the molecules to move away from each other. The molecules themselves do not change in size when heated. It is the re-arrangement of molecules that changes.

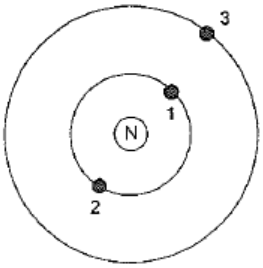
Response C: Teboho's response is incorrect. When a substance is heated, a phase change occurs. The molecules of a substance become more free from each other as the bonds are weakend in some cases completely broken. Substances that were originally solids may become liquids and liquids may become gases

Response D: None of the above

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

My choice is Response B

Matter is made up of particles and there is an empty space between the particles. When the particles are heated, they gain kinetic energy and starting moving away from each other as the overcome the forces of attraction between them. This therefore means that the spaces between the particles increases. The size of the particles, however, does not change.



A simple representation of an atom

2. When learners were asked to describe what is happening in the given atomic model above, Lerato gave the following written response:

   An electron further away from the nucleus (electron 3) would experience less attraction to the nucleus.

   What comment(s) would you write on her paper?

Response A: True, electron 3, located further away from the nucleus, will not be attracted in the same way as the electron closer to the nucleus.

Response B: True, the electrons on the energy levels further away from the nucleus experience a smaller force of attraction than those which is in nearer energy levels. However, all electrons are attracted by the same type of force from the nucleus.

Response C: True, electron 3 will experience less attraction towards the nucleus because of the greater distance between the electron and the nucleus.

Response D: None of the above

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

My choice is Response B.

Electrons in a common energy level will experient the same amount of attraction from the nucleus. However, these electrons experience less force of attraction from the nucleus that the electrons in an energy shell below them and more force of attraction than electrons in an energy level above theirs. All the energy levels (all electrons in those energy levels) experience a force of attraction from the nucleus; the only difference is the size of the attraction that electrons in each energy level experience.

CATEGORY B: CURRICULUM AWARENESS

3. Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10? Choose from the list provided.

Particles are in constant motion —	Substance have subatomic particles
Molecules have forces between each other	Compounds are made up of atoms
Elements are made up of atoms	Atom has a specific structure
Matter is made up of small bits that are called particles ①	There are different type of small bits of substance
Atoms are smallest particle	Matter is found in different phases
Molecules are made from atoms	Other
There are different atomic theories	

1.	Matter is made up of small bits that are called particles
2.	Particles are in constant motion.
3.	Molecules have forces between them.
4.	Matter is found in diffent phases

3.2 In what sequence would you teach the main ideas you have identified above?

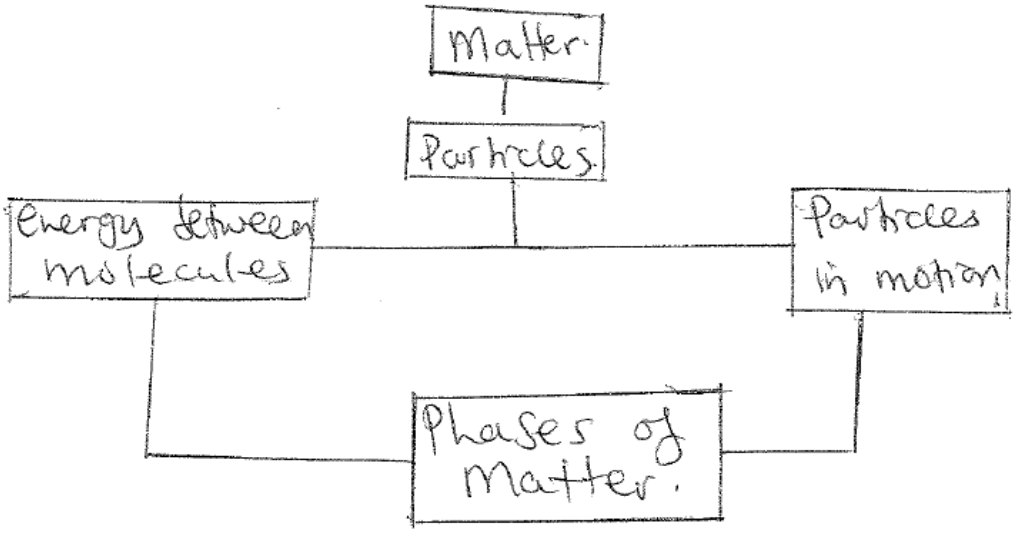
1

2

3

4

3.3 Make a map or a diagram of these four ideas showing how they link to subordinate ideas.



3.4 What other topics in chemistry do you think require the understanding of particle nature for teaching them?

- Chemical Bonding
- Chemical Reactions

3.5 Why is it important for learners to learn about particle nature of matter?
Identify reasons related to:

i. Conceptual Progression
- It is important that they know and understand that all matter is made of particles.
- It is also important for them to know that there are spaces between particles and they are forces
ii. Application
- Phase changes is a direct result of or consequence of the fact that matter is made of particles with empty spaces between them and some attraction and repulsive forces.
iii. Motivation or Interest
- How does a gain or loss of energy affect matter?
- What would happen if ~~particle~~ matter was not made up of particles? Will life be as we know it today?

As the learners go about trying to answer these questions, they learn and ~~appri~~ appreciate what they have learnt.

CATEGORY C: WHAT MAKES THE TOPIC DIFFICULT TO UNDERSTAND?

1. Tick (✓) from the list below, concepts of particle nature of matter you consider difficult to teach? You may also add your own. Explain why you consider the chosen topics difficult to teach.

Concept	✓	What exactly makes it difficult?
There is an empty space between particles of matter	✓	It does not make sense that a solid like this paper I am writing on has empty space within why does it not fall apart then?
Particles are in constant motion	✓	Can we see them move? A student would ask. It is difficult to demonstrate this is solid
There are different types of small bits of substances.	X	
Calculating the relative atomic mass of an isotope	✓	Many learners struggle with Maths. This is one section that requires them to have sound mathematical skills.

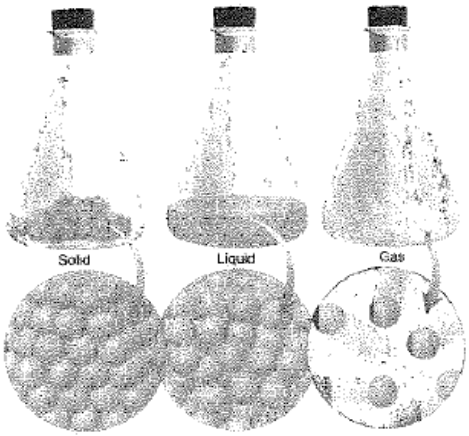
Concept	✓	What exactly makes it difficult?
Finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$	✓	In everyday life + means there has been an addition, but here it means there has been a subtraction of electrons. Difficult for most kids to understand at first.
Isotopes.	✓	It is difficult for learners to understand that one element can have ~~diffent~~ different forms

5. CATEGORY D: REPRESENTATIONS/ MODELS

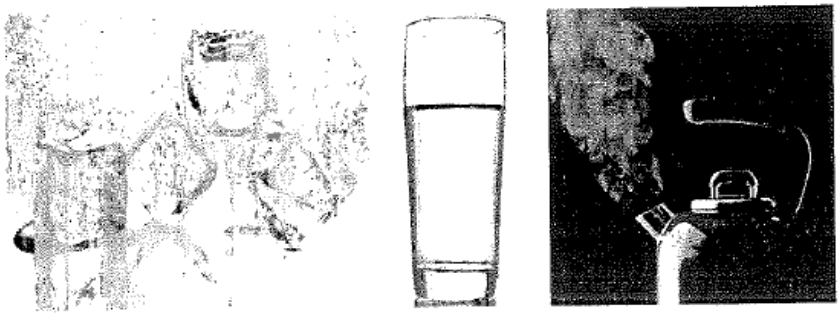
Phases of Matter

Below are three different representations that can be used for teaching phases of matter. Decide which one(s) you like and complete the table below

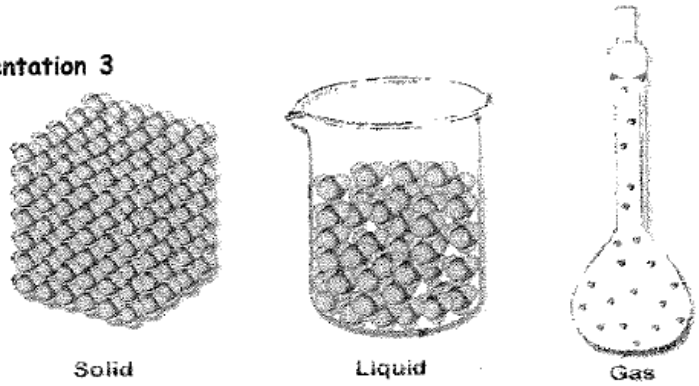
Representation 1



Representation 2



Representation 3



5.1 Complete the table below by providing as many details as possible.

Representation No.	What I Like	What I do not like
1	- The arrangement of particles is shown in each phase. - everyday substances that learners know are used.	- the substances are enclosed, so learners can not touch and feel them.
2	- water, a very common substances is used in its 3 states. - the learners can touch and feel the different states.	
3	- the arrangement of particles is clearly demonstrated in each phase.	- It seems different substances have been used so to learners, the type of substances used might be the reason for the particle arrangement, not the phase of substance.

5.2 Which representation do you like most?

Presentation 2.

5.3 How would you use the representation that you like most?

- I would provide learners with water in its different states. I would use a beaker for the set
- Would then ask the learners to identify the differences between solids to liquids and to gases and vice-versa.
- Would ask the learners to demonstrate which phase has the strongest attraction forces by trying to take the phases apart.

- By trying to break the water in each phase, they would realise that it is more difficult to take ice apart; and then the liquid. The gases will disperse when the presence of a small amount of air.
- Will also ask the learners to heat the ice (solid water) and observe what happens.

CATEGORY E: TEACHING STRATEGIES

Average relative atomic mass

Shown below is a learners' response to a written test meant to assess learners' prior knowledge on average relative atomic masses.

Question

Calculate the average relative atomic mass of a sample of oxygen gas that contains the following isotopes of oxygen atoms:

Element	Isotopes	Isotopic mass	Percentage abundance
Oxygen	^{16}O	16	99,790
	^{17}O	17	0,037
	^{18}O	18	0,173

A learner's response:

O-16: 16
O-17: 17
O-18: 18

16+17+18=51
51 ÷ 3= 17amu

Following the learner's response, how will you teach a lesson on calculating the average relative atomic mass?

Step 1: Find the contribution of each isotope to Average Atomic Mass by multiplying its percentage abundance by its isotopic mass. Remember: percentage means its out of 100

For ^{16}O its contribution will be given by

99,790/100 X 16. = 15.966amu.

For ^{17}O, its contribution will be given by

0.037/100 X 17 = 0,006amu.

For ^{18}O, its contributions will be given by

$0,173/100 \times 18 = 0,031$ amu.

Step 2: Add up the isotopic contributions to get the Average Atomic Mass.

Average Atomic Mass = 15.996amu + 0,0 6amu + 0.03 5

= 16.057 amu.

Alternatively, you can do this in one step as follows:

Average Atomic mass $= \left[\frac{99,790}{100} \times 16\right] + \left[\frac{0,037}{100} \times 17\right] + \left[\frac{0,173}{100} \times 18\right]$

[use your calculate]

$\therefore$ = 16,057 amu [same as above]

COMPLETED-REFLECTIVE QUESTIONNAIRE (SS)

1. How did you manage your first year of science teaching? Was it what you expected?

It was reasonably ok, I managed pretty well in the first term. It became a bit more challenging in the second term when I ~~had~~started teaching Grade 12 life Science because the workload increased, having to balance between extra classes for the Physical and life Science learners, and classes the went clashing

2. (i) Did you teach the particulate nature of matter in grade 10? YES / NO

(ii) If YES, how did you find the teaching of the particulate nature of matter?

It was relative good. I layed a solid ~~the~~ foundation by utilising different textbooks, presentations and videos to get the concepts through to the learners. It was also challenging because the learners have misconceptions and so on, pre-conceived ideas as well.

(iii) If NO which grade did you teach? 8.

(iv) What topics if any did you teach that were related to the particulate nature of matter? (These could be about molecules, particles, atoms etc below grade 10 or other topics above grade 10).

Atoms, molecules, Elements and Compounds

(iv) How did you find the teaching of the topics you mentioned above?

It was very challenging because at Grade 8 level, the learners become easily confused and they cannot use the imaginary brain as well to picture atoms. I had to be very slow, and they confused atoms and molecules in terms of similarities and differences

3. (i) Did the assigned mentor from Teach SA visit you during your teaching? YES / NO

(ii) If YES, how often did the mentor visit you? _____

(iii) How was the mentorship useful to the teaching of science and in particular to the particulate nature of matter topic or its related concepts?

COMPLETED-REFLECTIVE QUESTIONNAIRE (SS)

4. (i) Did you receive any mentoring from your school? YES / NO ✓
   (ii) If YES, who was your mentor? _____
   (iii) How was the mentorship useful to the teaching of science and in particular to the particulate nature of matter topic or its related concepts?

5. (i) Did you attend any science workshops or in-service training? YES / NO ✓
   (ii) If YES, how did the workshop or in-service training help you understand the teaching and learning of the particulate nature of matter or its related concept better?
   These were CAPS training workshops for Grade 11 2013, to know what is new in the curriculum and what has been removed. Also attended content workshops where Vertical projectile motion and Work, energy and power were discussed.
   (iii) If not, what was the topic of the workshop?
   CAPS training, content workshop - Vertical projectile motion and the Work, energy and power.
   Hey science workshop.

6. How useful was the two weeks training academy attended in December 2011? Please highlight the information learned from the academy that assisted you in your teaching of science.
   Very useful. Mentors prepared us for the environment we were going to face, the kinds of children we may come across. We were taught about different ways of teaching improvising where resources are lacking, how to be a constructive teacher.

7. From you teaching experience, would you consider enrolling for the post graduate studies such as PGCE? YES / NO.
   Explain your choice
   I have developed some passion for teaching, although it has its down moments, it is about the kids that really deserve quality education.
   Some resources were provided to ease our work should the resources be lacking at our school

CK TEST-MEMO

CATEGORY A

6. Give one word or term for each of the following description.
   (f) A substance that is made of only one kind of atom.
   (g) A substance made of two or more atoms of different elements chemically bonded.
   (h) A smallest particle of an element that still retains the chemical properties of that element.
   (i) A particle that consists of two or more atoms bonded together.
   (j) A substance that consists of different substances that are not chemically bonded to each other and still retain their original properties.

Answers

(**a) Elements/**

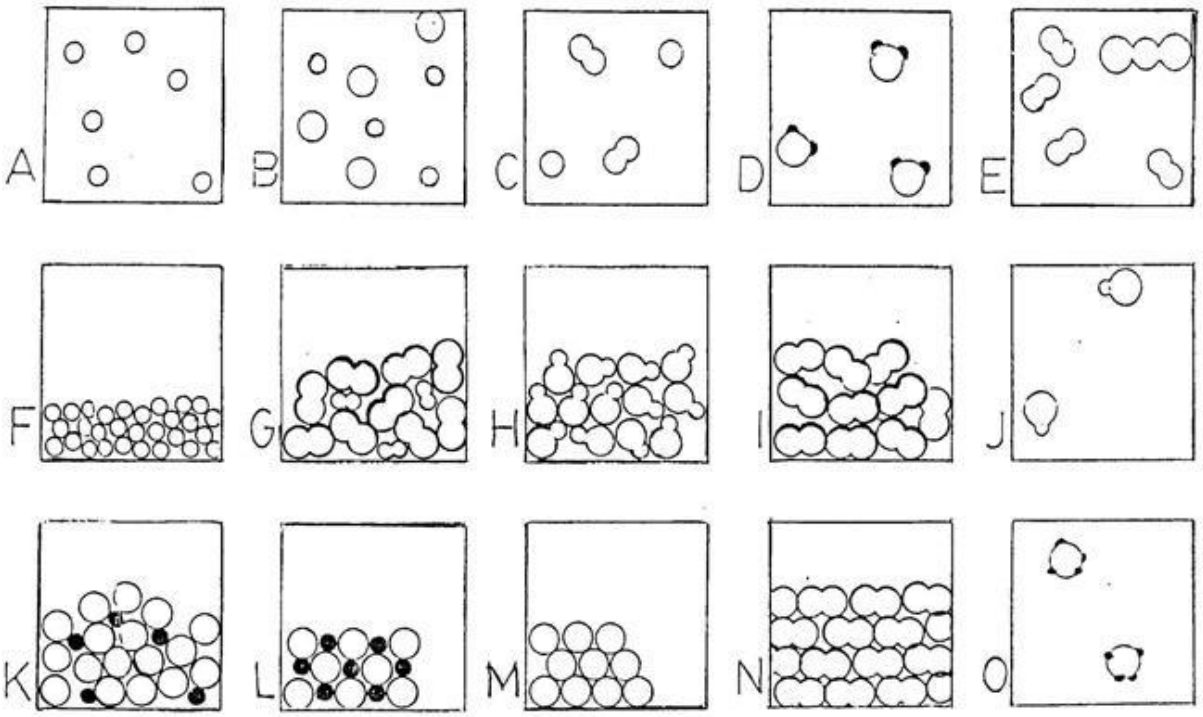
(b) Compounds

(c) Atom

(d)Molecule

(e) Mixture (heterogeneous/homogenous) **(5)**

7. In the diagrams below say:



(i) Which diagram(s) consist(s) of only one element?
(j) Which diagram(s) consist(s) of only one compound?
(k) Which diagram(s) represent(s) a mixture?
(l) Which diagram(s) represent(s) a pure solid?
(m) Which diagram(s) represent(s) a pure liquid?
(n) Which diagram(s) represent(s) a gas?
(o) Which diagram(s) represent a pure substance?
(p) Which diagram(s) represent molecules only?

Answers

(a) A, F,I,M,N

(b) D,H,J,L,O

(c) B,C,E,G,K

(d) L,M,N

(e) F,G,H,I,K

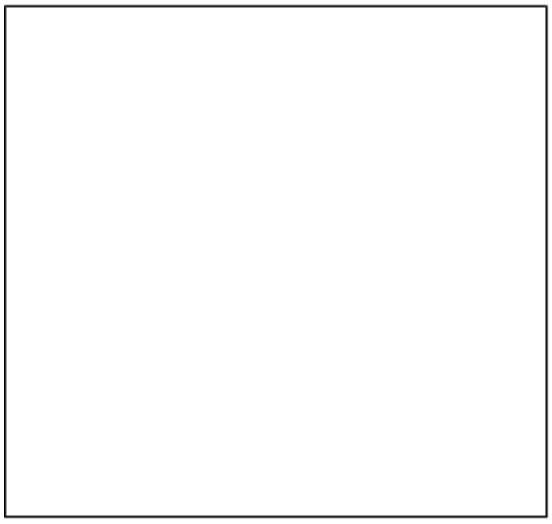
(f) A,B,C,D,E,J O

(g) A,D,F, H,I,J,L,M,N,O

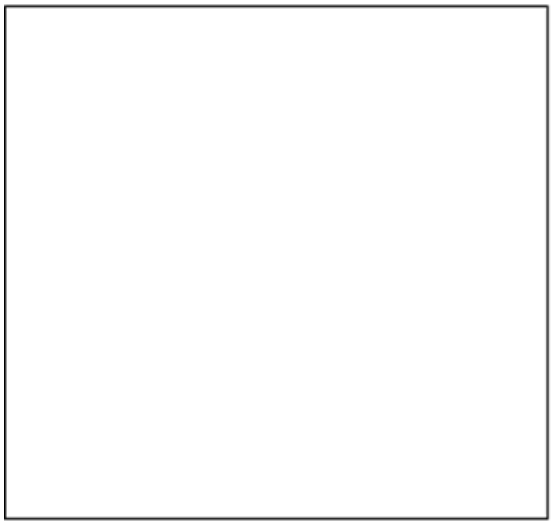
(h)D, E, G, H, I, J, N, O **(48)**

CATEGORY

8. Draw microscopic representations of oxygen as it heated from a solid to a liquid to a gaseous state in the boxes below. Use ●● to represent a single molecule. Draw 9 molecules in each box.

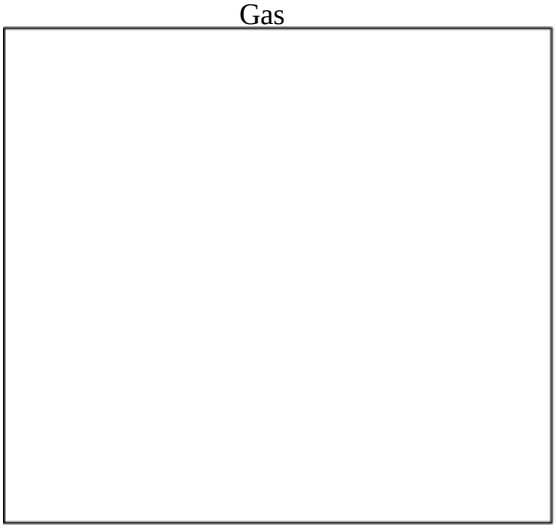


Solid



Liquid

Gas



2 marks each for a correct representation (6)

9. Question 1 to 4: are the following statement true (T) or false (F)?
Circle the correct answer and indicate the degree of confidence i.e. 100% sure, not sure or guessing.

(5) All molecules of a given pure substance are identical. **T**/F

100% sure	*sure*	*guess*

(6) Between molecules of a substance there is "empty space". **T**/F

100% sure	*sure*	*guess*

(7) A molecule of a substance in the solid phase has larger mass than a molecule of the same substance in the gaseous phase. T/**F**

100% sure	*sure*	*guess*

(8) The forces of attraction between molecules of naphthalene in the liquid phase are greater than in the solid phase. T/**F**

100% sure	*sure*	*guess*

2 Marks each-(8)

CATEGORY C

10.

(f) Name the sub-atomic particles found in the nucleus of an atom?

Neutrons and Protons (2)

(g) What type of charge is found on each of the above mentioned sub-atomic particles?

P^+, n^o (2)

(h) Fill in the blanks on the following table.

Element	Notation	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons	Number of nucleons
Calcium ion	$^{40}_{20}Ca^{+}$	**20**	**40**	20	18	**20**	**40**
Fluoride ion	$^{19}_{9}F^{-}$	**9**	**19**	**9**	**10**	**10**	**19**
Aluminum ion	$^{23}_{13}Al^{3+}$	**13**	**23**	**13**	**10**	**10**	**23**
Chloride ion	$^{35}_{17}cl^{-}$	**17**	**35**	17	18	**18**	**35**

(25)

(i) Which of the following unidentified elements are isotopes of one another?

$^{12}_{6}X$, $^{12}_{7}Y$, $^{24}_{12}A$, $^{14}_{6}Xy$, $^{13}_{6}Mp$ (note X, Y, A, Xy and Mp represent the symbols of unspecified elements). $^{12}_{6}X$, $^{14}_{6}Xy$, $^{13}_{6}Mp$ (3)

How did you work out the answer above?

Z stays out the same but A changes (2)

What is the name of an isotopic element represented in (d)?

Carbon (1)

(j) Chlorine consists of two isotopes ^{37}Cl and ^{35}Cl. The average atomic mass of naturally occurring chlorine is 35,5amu. Which of the following percentages of the two isotopes is most likely in naturally occurring chlorine? **Justify your choice**

	% ^{35}Cl	% ^{37}Cl
A	50	50
B	66	33
C	33	66
D	100	1

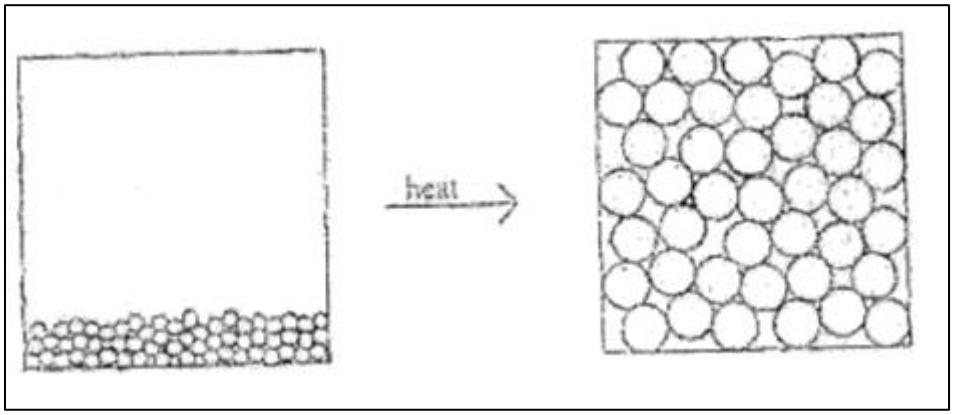
B, the average atomic mass (35.5amu) is closer to that of ^{35}Cl-meaning ^{35}Cl more that ^{37}Cl and most abundant. Hence, B 66% ^{35}Cl and 33% ^{37}Cl

(3)

PCK CK TEST-MEMO

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. Learners in a grade 10 class were asked to represent the change that takes place when a substance is heated. The response Teboho has written on the board is shown below.



How would you comment on Teboho's response as part of an explanation to the rest of the class?

Response A: Teboho's response is incorrect. All substances have small particles called atoms that may combine chemically with each other to form molecules. When substances are heated their molecules do not expand in size. The size of the molecules stays the same.

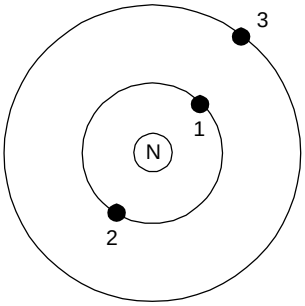
Response B: Teboho's response is incorrect. When a substance is heated, molecules gain kinetic energy. The molecules will start vibrating and the bonds between them weaken to allow re-arrangement and in some cases allowing the molecules to move away from each other. The molecules themselves do not change in size when heated. It is the re-arrangement of molecules that changes.

Response C: Teboho's response is incorrect. When a substance is heated, a phase change occurs. The molecules of a substance become more free from each other as the bonds are weakend in some cases completely broken. Substances that were originally solids may become liquids and liquids may become gases

Response D: None of the above

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

My choice is Response **B**



A simple representation of an atom

3. When learners were asked to describe what is happening in the given atomic model above, Lerato gave the following written response:
   An electron further away from the nucleus (electron 3) would experience less attraction to the nucleus.

   What comment(s) would you write on her paper?

Response A: True, electron 3, located further away from the nucleus, will not be attracted in the same way as the electron closer to the nucleus.

Response B: True, the electrons on the energy levels further away from the nucleus experience a smaller force of attraction than those which is in nearer energy levels. However, all electrons are attracted by the same type of force from the nucleus.

Response C: True, electron 3 will experience less attraction towards the nucleus because of the greater distance between the electron and the nucleus.

Response D: None of the above

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

My choice is Response ***C***

CATEGORY B: CURRICULUM AWARENESS

3. Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the four main ideas (main concepts) to be taught about particle nature of matter at Grade 10? Choose from the list provided.

Particles are in constant motion	Substance have subatomic particles
Molecules have forces between each other	Compounds are made up of atoms
Elements are made up of atoms	Atom has a specific structure
Matter is made up of small bits that are called particles	There are different type of small bits of substance
Atoms are smallest particle	Matter is found in different phases
Molecules are made from atoms	Other
There are different atomic theories	

8. Matter is made up of small bits that are called particles
9. Molecules have forces between each other
10. Particles are in constant motion
11. Matter is found in different phases

3.6 In what sequence would you teach the main ideas you have identified above?

Any 3 big ideas and justified sequence

3.7 Make a map or a diagram of these four ideas showing how they link to subordinate ideas.

<u>Big idea used as the starting point in the construction of a map</u>

3.8 What other topics in chemistry do you think require the understanding of particle nature for teaching them?

- **Chemical Bonding**
- **Chemical change**

- **Quantitative aspects of chemical change (any relevant topics)**

3.9 Why is it important for learners to learn about particle nature of matter? Identify reasons related to:

Reasons to include conceptual considerations, everyday application / intrinsic interest

CATEGORY C: WHAT MAKES THE TOPIC DIFFICULT TO UNDERSTAND?

5. Tick (✓) from the list below, concepts of particle nature of matter you consider difficult to teach? You may also add your own. Explain why you consider the chosen topics difficult to teach.

Choose a concept and justified correctly

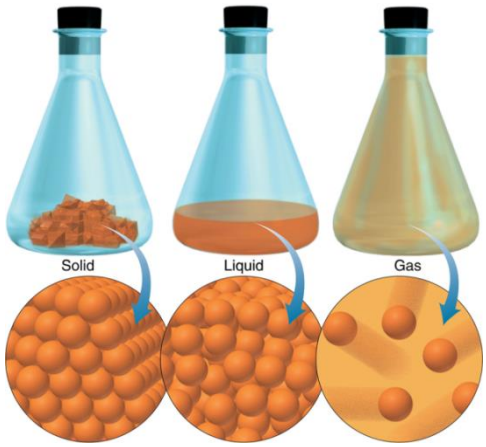
Concept	✓	What exactly makes it difficult?
There is an empty space between particles of matter		
Particles are in constant motion		
There are different types of small bits of substances.		
Calculating the relative atomic mass of an isotope		
Finding number of electrons in an ion for example $^{24}_{12}Mg^{2+}$		

CATEGORY D: REPRESENTATIONS/ MODELS

Phases of Matter

Below are three different representations that can be used for teaching phases of matter. Decide which one(s) you like and complete the table below

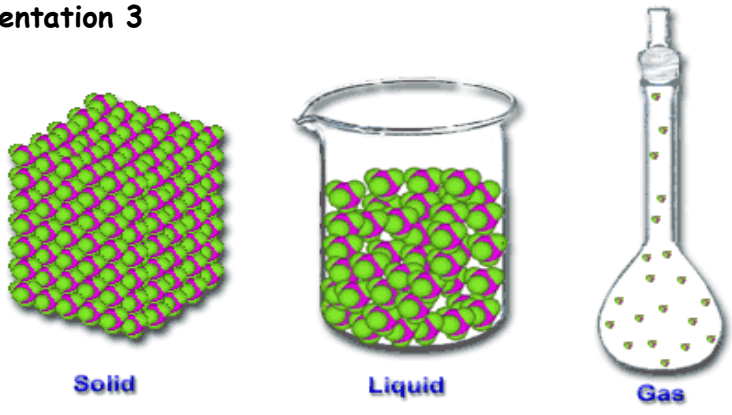
Representation 1



Representation 2



Representation 3



5.1 Complete the table below by providing as many details as possible.

Representation No.	What I Like	What I do not like
1		
2		
3		

5.2 Which representation do you like most?

Any choice of representation

5.3 How would you use the representation that you like most?

Logical explanation /Well explained choice

CATEGORY E: TEACHING STRATEGIES

Average relative atomic mass

Shown below is a learners' response to a written test meant to assess learners' prior knowledge on average relative atomic masses.

Question

Calculate the average relative atomic mass of a sample of oxygen gas that contains the following isotopes of oxygen atoms:

Element	Isotopes	Isotopic mass	Percentage abundance
Oxygen	^{16}O	16	99,790
	^{17}O	17	0,037
	^{18}O	18	0,173

A learner's response:

O-16: 16

O-17: 17

O-18: 18

16+17+18=51

51 ÷ 3= 17amu

Following the learner's response, how will you teach a lesson on calculating the average relative atomic mass?

Any acceptable strategy-taking into consideration learners' prior knowledge, difficulties, representations and curricular saliency.

APPENDIX K: SAMPLE OF A TRANSCRIBED LESSON AND AN INTERVIEW

Lesson 1

ZD: what I expect you guys to be able to know *(neh)* ok- you must be able to define an atom. If I asked you what an atom is, you must be able to define it. You must be able to define and give a category that make up an atom. Where do you find the protons, where do we find the electrons, where do we find the neutrons? If I give you an atomic number and atomic number and atomic mass of an element, you should be able to work out how many protons it has, how many electrons it has and how many neutrons it has. That is what you should be able to do at the end of it. And then identify isotopes as well if I give you an isotope. How many neutrons does one have?

Learner: what is an isotope?

ZD: you will learn that as we go ok .I won't give the definition as yet so as to not confuse you. And you will also learn how to do electronic configuration. If I give you a periodic table on how to work that out. In the question I will give you an element and say for example oxygen to give me the electronic configuration of oxygen then you will be able to do that using the orbitals and all of that. Remember when I talked about the orbitals and you guys said no we don't know. So those things you will be able to know with your orbitals and how to fit in an electron and things like that. So today we will be going to do the atoms. What is an atom?

Learner: an atom is a tiny particle that makes up matter

Learner: an atom is a tiny particle that we can't see with our naked eye

Learner: an atom is a tiny that cannot be broken down into smaller particle

Learner: everything on earth is made up of an atom

ZD: yes, but I asked you what is an atom?

Learner: is a small particle that makes up everything

Learners chorusing: (ZD intervenes asking learners not to sing)

ZD: anyone who still wants to say what an atom is? Ok-it's the smallest particle that retains the chemical properties of an element. To retain means to keep, so the properties that an element has it is the atom that keeps those properties. For example, let's say an atom behaves a certain way, you know when we talking about the properties we talk about how the elements behave. So it is the atom that keeps those properties

Learner: requesting ZD to repeat the definition of an atom and also to write it on the board

Learner: Miss? What do you mean when you say they retain the chemical properties?

ZD: they keep

Learner: why are atoms so special?

ZD: we are going to get to that. We going to get to what is it that makes the atoms so special. But each element, remember guys you have got your metals, your non-metals and semi-metals. They all behave differently don't they?

Learner: yes Miss

ZD: So the atom is the one that keep the different property that that particular element has. Am I making sense now?

Learner (chorusing): yes

ZD: who is saying I am making sense? (Pointing at a learner). Can you explain to her (learner who still don't understand? Ok who gets what I am saying. Please try and explain it in your words, don't repeat what I have said.

Learner: elements that are metals, non-metals, metalloids so atoms make sure that metalloids keeps its own property as well as the metals

ZD: did you hear?

Learner: no Miss I didn't understand

ZD: so it retains the chemical properties of the element. What is an element?

Learner: carbon

ZD: Don't give an example. You see when you say carbon that is an example. What is an element?

Learner: the most basic substance

Learner: the pure substance

ZD: the most basic substance from which all materials are made out of. That is an element (capturing it on the board). So the atoms keep the properties of an element. Where do we find our elements?

Learner (chorusing): In the periodic table

ZD: what is the atom look like?

Learner: It's got a round shape, but can't see it. But we can't see an atom with a naked eye

Learner: it's small like as a dot

Learner: miss I think is not round

Learner: is it true Miss that is not round?

ZD: we shall soon find out

Learner: I think atom does not have a shape

ZD: what is an atom made out of?

Learners: electrons, protons, neutrons

ZD: (pasting a rectangular paper written answers learners gave). Where do we find these things in the atom? Can I have (pointing at the learners to come show where to find electrons, protons and neutron and assigning learners as electrons, protons and neutrons). Come and paste them on the model of the atom

ZD: so we were still at the stage where had come to the board to come put up where they think the different categories of the atom are. So where did they put the neutrons

Learner (chorusing): inside the nucleus

ZD: (ZD pasting neutron) and protons?

Learner (chorusing): in the nucleus

ZD: (ZD pasting protons) and electrons?

Learner (chorusing): on the orbitals

ZD: what do we say we find in between?

Learners (chorusing): empty space

Learner: what is holding the orbital and the nucleus together? Is it one thing all together or is the orbital on its own or are they all joined together?

ZD: they all make up one thing. Is like you have your classroom here Your classroom will be your orbitals and then you have the desks inside which will be your nucleus. Is the picture clear or am I still confusing you? The room and the desk *(into ye one)* is it one thing*?* Are they one thing?

Learner: No

ZD: what do you have in the middle?

Learner: desks

ZD: What do you have outside?

Learner: walls, windows

ZD: is there something holding the one in place? Is the desk holding on to the wall or is the wall holding on to the desk?

Learner: No

ZD: so look at this now as if you looking at the atom. What is inside?

Learner: the nucleus

ZD: and what is around the nucleus

Learner: the orbitals

ZD: the orbitals so what is in between them in the middle?

Learner: empty spaces

ZD: so there is nothing. So is your question answered? Did you guys get his questions?

Learner (chorusing): some yes and some no

ZD: pretend, look at this room say a wall around you that is your orbital. And the desk in the middle that is the nucleus. And what is holding the desk to the wall? Are they holding on to each other?

Learners (chorusing): No

ZD: so but look at Lwazi (a learner's name) pretend he is an atom. So what will Lwazi be?

Learner: Nucleus

ZD: and what will the wall be?

Learner (chorusing): orbitals

ZD: what is in between Lwazi and the wall?

Learner (chorusing): empty spaces

ZD: so there is nothing that is holding onto each other. They make up one thing but separate parts

Learner: so can the nucleus move around or it stands on one position? So if there is empty space it means a nucleus can start from there and bounce around. Is there a liquid inside it Miss?

ZD: what is liquid?

Learner: is there. What is called (struggling to answer)

ZD: Particles are something. They are not nothing. There is nothing absolutely nothing. That is why I said there is no air. Because some people think when we say there is nothing in that room there is air. But what is air made out of?

Learner: there is nothing like nothing?

ZD: nothing, nothing, nothing

Learner: if someone can enter in that empty space will die because there is no air

ZD: there is no air so you will die. So the nucleus does not bounce around and move there and there and there. (Pointing on the representations)

Learner: why? But there must be something that holds it into one place

ZD: there forces that hold the nucleus together that holds it in place inside the nucleus. It is very small, it holds it in place. It does not move around

Learner: you mean those forces is nothing?

ZD: No the forces, you see now. You were not listening. You see this part we talking about (ZD pointing at the diagram on the nucleus). We are talking about this part. The forces are in the nucleus, holding the nucleus together inside the nucleus. But out here (pointing at the space) there is nothing. You we have to throw you in there you will die.

ZD: where are your periodic tables? What is the atomic number?

Learner: number of protons

ZD: (capturing it on the board-linked to) so on the periodic table that you have, there are two numbers. Look at the top block with copper. What is the symbol for copper?

Learner (chorusing): Cu

ZD: can everybody see Cu? (Checking if learners know what is a periodic table). So you see the arrow pointing saying atomic number. What number is it pointing at?

Learner (chorusing): 29

ZD: yes, it is 29, so what does that mean?

Learner: number of protons in Cu are 29

ZD: Yes, thank you

Learner: so Miss only that? It only shows protons? What about the electrons?

ZD: I am getting to that. So Cu has 29 protons in a neutral atom listen to me carefully. What does neutral mean?

Learner (chorusing): no charge

ZD: when we say no charge what does that mean?

Learner: neutral

ZD: no something else?

Learner: it means there are balanced

ZD: what is balanced?

Learner: the positive and negative charges

ZD: yes, positive and negative charges must balance (capturing it on the board). So what is positively charged on your atom?

Learner: protons

ZD: so the number of protons must equal the number of the negatively charged. So what is the negatively charged?

Learner (chorusing): electrons

ZD: so the number of protons equals the number of electrons in a neutral element. So how many electrons does Cu have?

Learner (chorusing): 29

ZD: so what is the atomic number of mg?

Learners (chorusing): 12

ZD: how many protons does mg have?

Learner: 12

ZD: when is neutral how many electrons?

Learner: 12

ZD: is it is not neutral, how is it?

Learners (chorusing): it is charged

ZD: how can it be charged?

Learner: positive and negative are not balanced Miss

ZD: if is not neutral it is charged. It is an ion. That is the name given to it. If the atom is not neutral, if the number of electrons and protons are not equal then it must have some charge. So the charge can either be cat ion and an ion. (ZD captures the response on the board).

Learner: you say number of protons is equal to the number of electrons if the charge is neutral. So Miss if the charge is not neutral, what will be the number of electrons?

ZD: so if it has a charge, I will give you an example

Learner: so Miss how do we see the charged ones on the periodic table?

ZD: All the elements on the periodic table, everything on your periodic table is neutral. Everything recorded there is neutral. All the elements on your periodic table are neutral. There is no charged element here.

ZD: let's look at H. What is the atomic number for hydrogen?

Learner: one

ZD: one ok the atomic number. Guys look at the things-when I say look at it look at it. So how many protons does hydrogen have?

Learners (chorusing): one

ZD: how many electrons?

Learners (chorusing): one

ZD: what is the charge here?

Learners (chorusing): neutral

ZD: so hydrogen uses an electron. It decided to give away its electron to another element

Learner: why?

ZD: because it can. It only has one. We will get to the why when we do bonding, valences when we get to the electron configuration you will understand how you place the electrons. And why it is easier for some elements to give away and some to take. We will still get there ok. For the sake of avoiding confusion, just take my word as is for now. We are getting there guys as to why hydrogen gives away its electron instead of taking something else. Just keep it at the back of your head we will get there.

We will get there remember when we do the orbitals; remember I was talking about the orbitals the other day when I was trying to teach how to make the compounds and you guts said you don't know how to. That will explain because you need to have a certain number of electrons in an orbital to satisfy the octate rule. So we will talk about that when we do the electron configuration. So for now unfortunately you are going to have to take my word until we get to that point.

So hydrogen loses an electron. So hydrogen has gone from having one electron to having zero electrons. If it loses an electron if it gives away; if I have one apple and give it away how many apples do I have?

Learner: Zero

ZD: so hydrogen has one it gives away its electron how many electrons does it have

Learner: Zero

ZD: so what is the charge now?

Learners (chorusing): some negative and other positive

ZD: so the charge is positive (capturing + on the board). So if you lose an electron you are left with a positive charge. If you gain an electron, you are left with a negative charge. For you to be charged as either you gain an electron or lose an electron. If you gain it, now you have more electrons than protons. If we were to add an electron to say Cu, which has 29 electrons and 29 protons if you add one electron, how many electrons will be there?

Learners (chorusing): 30

ZD: you have 30 now. Is less or more than 29?

Learners (chorusing): more

ZD: so what will the charge be?

Learner: negative

ZD: so if you gain an electron, your charge becomes negative. It you lose, you become negative

Learner: is there a periodic table that shows the charges?

ZD: No, you know the periodic table; what they did is the way in which they ordered the elements. So they found or discovered these elements and they have different masses and they behave differently. So it was a system of putting them together and grouping them according to how they behave in reactions. There is not like a person who first initially arranged them according to their mass. And after a while they noticed that they behave a certain way and that they actually follow some pattern and that how they ended up on this. We are going to do that later on, how we got to the periodic table

ZD: so what is the atomic number of carbon?

Learner: Some say 6 and others 12

ZD: 6 at the bottom (moving atomic number closer to 6) you know at the periodic table, they put the atomic number at the bottom and other put them at the top. So they swap them around. So let's do the atomic mass so that you can be able to know the difference. What is the atomic mass?

Learner: Miss, I think the atomic number is always smaller than the mass number like the 12 and 6 in carbon

ZD: yes, she is actually picked up the difference that the atomic number is smaller than the atomic mass

Learner: Can I ask you about the elements at the bottom of the periodic table?

ZD: guys don't worry so much about these elements at the bottom. Don't concern yourselves so much about these elements for now. You are still at beginners' level.

ZD: So what is the atomic mass?

Learner: mass of the element

ZD: what else?

Learner: weight

ZD: the atomic mass tells you how heavy an atom is. It is the number of protons and neutrons. There is a difference between mass and weight. Mass is actually how heavy something is. Weight has to do

with how much gravity is pulling you towards the centre of the earth. So if you say is the weight, it is not the weight

PRE AND POST OBSERVATION INTERVIEW

Before Observation

1. **Could you describe today's lesson?**

   ZD: Today they will be learning about atoms, its structure about the atomic mass and atomic mass and how to find it in the periodic table.

2. **What subject matter or concepts do you expect students would have difficulties with today?**

   ZD: I think their terminology. Some might confuse the atomic number with the atomic mass. And as well as that there is an empty space between the nucleus and the orbitals. Some might think that there is actually air in there so I think that might be a bit of a challenge

3. **Why do you think so?**

   ZD: because it is hard to imagine that there is nothing. Like in a room you can't see the air but it's there. I think that's why is gonna be hard to get that answered.

4. **What kinds of students' misconceptions associated with this lesson have you noticed?**

   ZD: nothing as yet because I have not taught the lesson
   How would you help them correct the misconceptions?
   ZD:

5. **What kinds of things do you take into considerations in planning this lesson?**
   ZD: visual, a lot of diagrams because they have to imagine how it looks like; what the atom actually looks like.

6. **How will you be able to know whether your students understand the concepts you try to teach today?**
   ZD: in the questions they ask and in how they answer their questions. I will ask them, their responses will be an indication if they understand or not

7. **What evidence are you looking for that students have been successful in addressing the goals for the lesson?**

ZD: They should be able to find what an atom is. Tell me where they to find electrons and protons and neutrons. Being able to explain the terminology associated with the atom

After Observation

1. **How do you feel about the lesson today?**

   ZD: I will say it went well. I feel good

2. **What do you consider the most effective teaching moment was in the lesson?**

   ZD: learners explaining what they think like directing questions when they asking a question and you direct them to the answer and getting them to answer their own questions. So I think that was the most effective

   Why?

   ZD:

3. **How did you achieve it?**

   ZD: By breaking down their questions like if they ask me I ask them what they think first so I find out where they are directing them to the answer by asking them questions that push them towards the answer

   Why did it work?

   ZD: because the learners already have idea about the atoms. It is not like they completely blank so they have a bit of information to draw on.

4. **What signaled you that the students were learning?**

   ZD: the questions they were asking. Even like what the other learner noticed that the atomic mass is actually bigger than the atomic number without having been told that form working through their periodic table

5. **Were there any students' misconceptions you identified during the class that you have not known?**

   ZD: that the nucleus and orbitals (like the atom is one). It is like all together and there is like forces pulling the orbitals and nucleus together

6. **If yes, how did you respond to challenge the misconceptions?**

   ZD: I just gave an example about having a room as the orbital and the furniture inside as nucleus and that there are no forces pulling the room and the furniture. So that's the same with an atom

Did it work?

Yes, it did

Why do you think it worked?

It worked because they could physically see the room and the furniture. So they could picture the atom in that way. Kind of link the two together

7. **Did you make any changes in the class that I just observed differently from the other class periods or lesson plan?**

   Yes

   Why?

   Addressing the misconceptions that I saw here first to eliminate time spent dealing with that. I think I will do that

APPENDIX L: ETHICS CLEARANCE LETTER

Wits School of Education

27 St Andrews Road, Parktown, Johannesburg, 2193 Private Bag 3, Wits 2050, South Africa
Tel: +27 11 717-3064 Fax: +27 11 717-3100 E-mail: enquiries@educ.wits.ac.za Website: www.wits.ac.za

Student Number:

Protocol Number:
2012ECE64

Date: 01-Aug-2012

Dear Ramatsobane Pitjeng

Application for Ethics Clearance: Doctor of Philosophy

Thank you very much for your ethics application. The Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate has considered your application for ethics clearance for your proposal entitled:

INVESTIGATING THE EFFECT OF AN INTERVENTION ON NOVICE SCIENCE TEACHERS TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE

The committee recently met and I am pleased to inform you that clearance was granted. The committee was delighted about the ways in which you have taken care of and given consideration to the ethical dimensions of your research project. Congratulations to you and your supervisor!

Please use the above protocol number in all correspondence to the relevant research parties (schools, parents, learners etc.) and include it in your research report or project on the title page.

The Protocol Number above should be submitted to the Graduate Studies in Education Committee upon submission of your final research report.

All the best with your research project.

Yours sincerely

MMabeta

Matsie Mabeta
Wits School of Education

011 717 3416

APPENDIX M: CONSENT FORMS

Wits School of Education

27 St Andrews Road

Parktown

Date

Dear science teacher

I am currently doing research towards my PhD in Education degree, specialising in science teacher development. I am researching the development of Pedagogical Content Knowledge (PCK) in novice teachers. PCK is the kind of knowledge that enables the teacher to transform her comprehension about subject matter in a manner that students understand, and subsequently record good performance. I am specifically interested in beginning science teachers, who are specializing in Physical Science, FET Phase, who are now in their first year of teaching. I believe that your input and experience would be a very valuable source of information for me, and I would like to invite you to join the study.

My study happens the first teaching term which is part of the knowledge area of matter & materials. There will be an information session where all the details of the study are explained. You will be asked to participate in tests conducted prior to any teaching in the programme that aim at eliciting your thoughts about the process of teaching and your beliefs about teaching and learning. These tests are pencil and paper type and last about 60 minutes. At all times, your name will be kept confidential you will be identified by a pseudonym only. The people you may mention will also be kept confidential. You may be quoted in the dissertation, but it will be done in such a way that your identity is not revealed.

The purpose of this investigation is to identify those knowledge types and processes that will help novice/beginning science teachers to conduct their early lessons with confidence and expertise that leads to improved understanding by learners. The dissertation will be published, and the research generated may lead to staff seminars. It is hoped that any input you share may help the university to institute novice teacher induction programmes such that graduate teachers can start their career with confidence and expertise. Furthermore, as a novice teacher, exposure to the treatment will give you advantage in possibly improving your PCK in teaching Particulate Nature of Matter. You will also have access to the research findings once published.

Yours sincerely

Ms RJ Pitjeng (Researcher)

Informed Consent form

Research Dissertation: PhD: Investigating the effect on an Intervention on Novice Science Teachers' Topic Pedagogical Content Knowledge.

I,_____ consent to participate in my study conducted by Phihlo Pitjeng (0419042J) for a research dissertation investigating the development of PCK in novice science teachers.

• I realize that no harm will come to me, and that the research is being conducted for educational purposes.

• I participate voluntarily and that I may withdraw from the study at any time.

• I also have the right to review the transcripts made of our conversation before these are used for analysis, if I so choose.

• I can delete, amend or retract any of my remarks.

• Everything I say will be kept confidential by the interviewer. I will only be identified by a pseudonym in the dissertation. In addition, any persons I refer to in an interview will be kept confidential.

• Quotes from me may be used in the dissertation, but they will be reported in such a way that my identity is anonymous. Any specific individuals I refer to will be given a pseudonym. I understand that the dissertation will be published, but my identity will remain anonymous.

Name: _____

Signature: _____

Date: _____

Dear learners

I am interested in studying how the physical science teacher transforms his or her particulate nature of matter (science) content into teachable forms. Please note that this will not interfere with your studies as the topic is part of the grade 10 work.

I am asking your permission to carry out video for my research. Videotaping will involve placing one digital camera at the back of the classroom, which will run throughout the discussion period on each day of taping. The videotapes and audio recordings collected in these sessions will only be used for the purpose of teaching and research purposes.

Some video clips may be shown and shared with fellow researchers at seminars and conferences. Please note that the clips used during seminars and conferences will show only the researcher, not the learners. Also note that you have the right to review the video and the transcripts made of our conversations before these are used for analysis if you so choose. You can delete or amend any material or retract or revise any of my remarks. Everything you say will be kept confidential by the researcher. You will only be identified by a pseudonym in the transcript. In addition, any persons I refer to in the video will be kept confidential.

As part of research, please note that there will be a written class activity to be done by you which will be used only for research purposes and therefore will not be part of the assessment. The participation is voluntarily and I understand that you may withdraw from the study at any time.

Please read the attached consent form carefully and decide if you will be willing to allow video and audio taping in your classroom. Your consent would be greatly appreciated.

Thank you for considering this request.
Yours Sincerely,
Pitjeng RJ
(PhD student at the University of the Witwatersrand)

Consent Form

I,

Printed Name & Surname ----------

Institution ----------

Consent to participate in my study conducted by Pitjeng Phihlo of the University of Witwatersrand I realise that no harm will come to me as a result of participation in my study, and that the study is being conducted for purposes of improving the learning and teaching of science. I give permission for the material to be used for research or teaching only.
I further consent to being video and audio recorded as part of the study as outlined in the information sheet above.

I have no objection to being recognized/I wish my face to be obscured (Please delete the option not applicable).

Verbatim quotes from me may be used in the research report, but they will be reported so that my identity is anonymous.

Signature----------

Date----------

APPENDIX N: APPROVAL BY THE ORGANISATIONS

December 2011

TO WHOM IT MAY CONCERN

APPROVAL TO CONDUCT RESEARCH IN TEACH SA SCHOOLS THROUGHOUT THE CPOUNTRY LOOKING AT THEIR TEACHING ACTIVITIES RESEACHER: PHIHLO PITJENG

TEACH SOUTH AFRICA has the pleasure to give PITJENG RJ student no 0419042J permission to conduct her PhD research in all the schools that have TEACH SA ambassadors.

The bearer of this letter is fully authorised to work with the TEACH SA ambassadors in all the activities for her PhD research including interviews of the ambassadors, the bearer is also authorised to attend the TEACH SA workshops for training if she needs to do so in gaining more understanding of the work we do.

Yours Sincerely



Mr Richard K. Masemola
Executive Director
Cell: 0828118182
Office: 011209-8067
Email:Richard@teachsouthafrica.org

Directors: M Diaho, RK Masemola
Postnet Suite 597, Private Bag X9, Benmore 2010
Teach South Africa is a Section 21 company. Reg No: 2008/010176/08

www.teachsouthafrica.org

education
Department of Education
FREE STATE PROVINCE

Enquiries: Alexander LV
Reference: 16/4/1/10 - 2012

Tel: 051 404 9283
Fax: 086 6678 678
E-mail: research@edu.fs.gov.za

2012 – 03 –26

MS P. R. J PITJENG REQUESTS PERMISSION TO CONDUCT RESEARCH IN THE DEPARTMENT OF EDUCATION, FREESTATE PROVINCE.

1. PURPOSE

To request permission to conduct a research project with Schools, Educators and Learners in the secondary schools sampled in the five (5) Education Districts - Free State Province.

2. BACKGROUND

- Ms Pitjeng is a full time student studying for Doctor of Philosophy (PhD) degree in Education with the University of Witwatersrand – Johannesburg Campus.
- The title of the research project is: **Investigating the effect of an Intervention on Novice Science Teachers' Topic Specific Pedagogical Content Knowledge.**
- The research will provide valuable information to the Education Department regarding improvement of Science teachers' performance when delivering specific topic and ultimately impact on the Grade 12 performance in the province.

3. SELECTION OF A TARGET

- 7 X Schools
- Science Educators in the sampled schools
- Learners (Only Science classes in each school)
- Grade = 10
- Age = 15 & 16 years old
- Gender = Both male & female
- Language = Sesotho, English, Xhosa & Afrikaans

4. DISCUSSION

- Since all the documentation is in order, there is no apparent reason to withhold permission to conduct research.
- The request should be granted under the conditions as stipulated under recommendations.

5. FINANCIAL IMPLICATIONS

None.

6. PERSONNEL IMPLICATIONS

None.

7. LEGAL IMPLICATIONS

None.

8. PARTIES CONSULTED

None.

9. RECOMMENDATION

It is recommended that:

9.1 Permission be granted to **Ms Pitjeng** to conduct a research in Free State Province under the following conditions:

9.1.1 A report on this study is donated to the Free State Department of Education after completion of the project.

9.1.2 The researcher donates a copy of the summary of the report on a computer disc when the hard copy is given to the Department.

9.1.3 The researcher addresses a letter to the Superintendent General: Education accepting the conditions as laid down.

9.2 The enclosed letter to the applicant is signed.

Recommended / ~~Recommended as amended~~ / ~~Not Recommended~~

Comments:

.....

.....

.....

DATE: 28/03/2012.

KK MOTSHUMI
DEPUTY DIRECTOR: STRATEGIC PLANNING, POLICY & RESEARCH

Approved / ~~Approved as amended / Not approved~~

Comments:

.....

.....

DATE: 30/03/2012

MJ MOTHEBE
DIRECTOR: STRATEGIC PLANNING, POLICY & RESEARCH

Directorate: Strategic Planning, Policy & Research, Private Bag X20565, Bloemfontein, 9300 – Old CNA Building, Maitland Street,
Tel: 051 404 9283/9275 - Fax: 086 667 8678 E-mail: research@edu.fs.gov.za

education
Department of Education
FREE STATE PROVINCE

Enquiries: LV Alexander
Reference: 16/4/1/10 - 2012

Tel: 051 404 9283
Fax: 086 6678 678
E-mail: research@edu.fs.gov.za

2012 – 03 – 26

Ms P. R. J Pitjeng
27 Alpine Street
Malvern East
GERMISTON
1401

Dear Ms Pitjeng

REGISTRATION OF RESEARCH PROJECT

1. This letter is in reply to your application for the registration of your research project.

2. Research topic: : **Investigating the effect of an Intervention on Novice Science Teachers' Topic Specific Pedagogical Content Knowledge.**

3 Your research project has been registered with the Free State Education Department.

4. Approval is granted under the following conditions:-

4.1 The name of participants involved remains confidential.

4.2 The questionnaires are completed and the **interviews are conducted outside normal tuition time**.

4.3 This letter is shown to all participating persons.

4.4 A bound copy of the report and a summary on a computer disc on this study is donated to the Free State Department of Education.

4.5 Findings and recommendations are presented to relevant officials in the Department.

5. The costs relating to all the conditions mentioned above are your own responsibility.

6. **You are requested to confirm acceptance of the above conditions in writing to:**

DIRECTOR: STRATEGIC PLANNING, POLICY AND RESEARCH,
Old CNA Building, Maitland Street OR Private Bag X20565, BLOEMFONTEIN, 9301

We wish you every success with your research.

Yours sincerely

MJ MOTHEBE
DIRECTOR: STRATEGIC PLANNING, POLICY AND RESEARCH

education

Department of
Education
FREE STATE PROVINCE

Enquiries: LV Alexander
Reference no. : 16/4/1/10-2012

Tel: 051 404 9275
Fax: 086 6678 678
Email:research@edu.fs.gov.za

2012 - 03 - 26

TO: DISTRICT DIRECTORS

The Director: Lejweleputswa Education District
The Director: Motheo Education District
The Director: Xhariep Education District
The Director: Fezile Dabi Education District
The Director: Thabo Mofutsanyana Education District

Dear Director

NOTIFICATION OF A RESEARCH PROJECT IN YOUR DISTRICT

Please find attached copy of the letter giving **Ms P. R. J Pitjeng** permission to conduct research in sampled schools in the Province.

Ms Pitjeng is a full time student studying for Doctor of Philosophy (PhD) degree in Education with the University of Witwatersrand – Johannesburg Campus.

Yours sincerely

M. J. MOTHEBE
DIRECTOR: STRATEGIC PLANNING, POLICY AND RESEARCH