DECONSTRUCTING TEACHER CONTENT AND PEDAGOGICAL KNOWLEDGE IN MATHEMATICS AND SCIENCE CURRICULA IN TEACHER EDUCATION IN SOUTH AFRICA

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DECLARATION OF INDEPENDENT WORK

DECLARATION WITH REGARD TO

INDEPENDENT WORK

I, RATOKELO WILLIE THABANE do hereby declare that apart from the assistance acknowledged, this research project titled:

DECONSTRUCTING TEACHER CONTENT AND PEDAGOGICAL KNOWLEDGE IN MATHEMATICS AND SCIENCE CURRICULUM IN TEACHER EDUCATION IN SOUTH AFRICA

submitted to the Central University of Technology, for the degree of Doctor of Philosophy in Education: Faculty of Humanities, Bloemfontein is my own independent work. It has not been submitted before for any degree or examination in any other university.

October 2015

SIGNATURE OF STUDENT **DATE**

ABSTRACT

Teacher education at university is an initial, professional preparation of a teacher where the programmes offered should prepare student teachers to be professionally ready and able to cope with the daily demands of working in schools. This means that after qualifying at university, teachers should possess knowledge that will enable them to teach the subjects in which they major during their studies. Universities therefore, have the role of providing student teachers with the types of 'knowledges' required to teach these subjects. Mathematics and science teachers can be trained at universities of technology or traditional/conventional universities.

The purpose of this study is to examine current teacher knowledge of mathematics and science, with reference to how theoretical and propositional knowledge in these subjects is navigated to practice by teachers in South African education. Instruments such as interviews, document analysis, and a review of the literature were used to collect data.

The study yielded the following in relation to the research questions:

It was found that teachers generally lack an adequate understanding of the different types of teacher knowledges, which are critical to producing teachers who can teach mathematics and science. Furthermore, curriculum reform and transformation have impacted negatively on both lecturers and teachers of mathematics and science. It was also found that the theoretical knowledge in the curriculum of BEd (FET) provided in schools of teacher education does not adequately prepare students to teach mathematics and science effectively. In addition, it was found that there was no difference in the way mathematics and science teachers are trained in traditional universities and universities of technology. This study will hopefully contribute to knowledge relating to knowledge bases for mathematics and science education.

Keywords: theoretical knowledge; content knowledge; pedagogical knowledge; pedagogical content knowledge; knowledge structures; curriculum; teacher preparation; inquiry learning; social realism; practical rationalism.

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DEDICATION

In loving memory of my late parents, Ntate Ashton and Me Makatiso Thabane, and my late father-in-law, Ntate Buang Tau for their passion and love for education that was a driving force behind my seeing this project to its finality.

LIST OF ACRONYMS

BA	Bachelor of Arts
BEd	Bachelor of Education
BSc	Bachelor of Science
CAPS	Curriculum and Assessment Policy Statements
CHE	Council on Higher Education
FET	Further Education and Training
GET	General Education and Training
HEI	Higher Education Institution
ICT	Information and Communication Technology
MRTEQ	Minimum Requirements for Teacher Education Qualifications
NDHET	National Department of Higher Education and Training
NDoE	National Department of Education
OBE	Outcomes based Education
TATE	Teaching and Teacher Education

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CHAPTER 1

INTRODUCTION AND AN OVERVIEW OF THE RESEARCH

1.1 INTRODUCTION

This chapter provides an overview of the research project. The aspects of the research covered in this chapter are: background to the study; statement of the problem; theoretical framework and focus of the study; literature review; purpose of the study; research design; and the outline of the study.

1.2 BACKGROUND

The system of teacher education in South Africa prior to 1994 was shaped by the political logic of the apartheid system, which sought to provide separate forms of education for different racial, ethnic and regional groupings. During this period there were 19 departments of education (Jansen & Taylor, 2003), which led to a duplication and fragmentation of teacher education institutions. There were over 281 institutions providing various forms of teacher training (Schafer & Wilmot, 2012). These included more than 100 colleges of education, where 18 were for Whites, 16 for Coloureds, 2 for Indians and 13 for Blacks. A further 77 colleges were for Blacks residing in the nine homelands or Bantustans created by the apartheid government (Council on Higher Education, CHE, 2010). Alongside the various colleges of education, 36 universities also offered teacher training. This consequent duplication and fragmentation of teacher education institutions led to a lack of overall coherence in the system and a multiplicity of curricula and qualifications (Robinson, 2003).

The post-1994 government set about addressing the challenge of restructuring and transforming the teacher education system into an equitable, non-sexist, non-racial, democratic system (Zimmerman, Howie & Long, 2009; Schafer & Wilmot, 2012). In line with international trends, colleges of education were incorporated as faculties or schools into existing universities and what were then technikons. Colleges were first rationalised to 50 institutions and then incorporated into higher education institutions in 2001. From 2004, the rationalisation of teacher education was overshadowed by yet another significant development; this development related to the configuration of the higher education landscape. This configuration saw the abolition of the binary between universities and technikons, institution mergers and the reduction of the number of institutions offering teacher education. The number of higher education institutions (HEIs) – university education faculties, schools and departments – decreased from 36 to 23 (CHE, 2010).

Three significant developments with a direct bearing on the discourses of teacher knowledge in South Africa warranted further discussion. The first was the recognition of education as an autonomous discipline with its own rules governing admissions, curriculum, pedagogy and assessment. This saw the creation of degrees and qualifications in education, such as the Bachelor of Education (BEd) as an undergraduate teacher qualification.

The second was reforms in school policy including a shift from content knowledge to a new discourse that included the notions of skills, re-skilling, outcomes, competence, accountability, quality assurance, lifelong learning and the adoption of an outcomes-based education (OBE) orientation to education and training (Schafer & Wilmot, 2012). Together with learner-centred education and integration, OBE was a key design feature of the first post-apartheid national curriculum and it shaped the design of teacher education policy. Third, were policy changes that dominated the discourses of the reconfiguration of the higher education landscape, particularly the recommended shifts from qualifications based on disciplines towards programmatic planning (Human Sciences Research Council, 1996; South Africa, 1997; CHE, 2004). The programmatic planning that is currently shaping the discourses of teacher knowledge is contained in the policy for teacher education and training (Department of Education, 2000: CHE, 2010; RSA, 2011).

1.3 PROBLEM STATEMENT

In South Africa, mathematics and science (physical sciences and life sciences) are considered gateway subjects. However, the country is continuing to experience the problem of not producing teachers qualified to teach mathematics and science. The curriculum of teacher education does not seem to provide courses and programmes for teachers that strengthen their knowledge of these subjects in ways that are useful for teaching.

This is in agreement with Makgato and Mji (2006) and Kriek and Grayson (2009) who posit that HEIs do not seem to provide adequate knowledge that teachers need to teach mathematics and natural science, which comprise biology, chemistry and physics.

Apart from the curriculum as the source of the problems, there are three main categories of teaching problems for mathematics and science that face the education department. The first category comprises those who are under-qualified or unqualified to teach mathematics and science and who use outdated teaching practices. Under the apartheid rule, the majority of teachers were trained in colleges of education and attained two- or three-year diplomas as teaching qualifications (Schafer & Wilmot, 2012) and as a result of seeming mathematics and science teacher shortages, these teachers teach mathematics and science in secondary schools. The second category is teachers who may have the requisite content knowledge of mathematics and science but lack pedagogical knowledge. These teachers lack an understanding of what students find confusing or difficult and do not have alternative explanations, models and analogies to represent core concepts and processes (Wilson, Shulman & Richert, 1987). The third category is those who might have the necessary content knowledge but have unprofessional attitudes, such as being frequently absent from class or coming late to classes and leaving early.

Central to teacher knowledge are the competing epistemological positions on theory and practice in teacher education, but more specifically, how theoretical knowledge acquired at universities and colleges is navigated to practice. According to Adler and Davis (2006), there are significant challenges in the current preparation and development of mathematics teachers, one critical element of which is how mathematics for teaching is embraced in these programmes.

The CHE (2010) states that the Bachelor of Education (BEd) has been approved and is implemented in some higher education institutions (HEIs). This four-year degree programme, aims at preparing teachers to teach in the formal schooling situation and the regulatory framework for the BEd are the norms and standards for educators. A secondary mathematics and science specialisation is possible within this degree. There is seemingly a problem in the conceptualisation and teaching of mathematics and science in this undergraduate programme. In the norms and standards for educators, it is stipulated that the qualification is intended for candidates seeking a focused teaching degree with strong subject and educational theory competence. This signifies a shift from a knowledge base to competences. Compared to entry into mathematics and science in a BSc or BA degree, there are also lower entrance criteria for BEd students, including those who intend to specialise in mathematics and science (Adler & Davis, 2006). Owing to these lower entrance criteria, a large number of students admitted to a BEd degree could possibly have had a lower mathematics and science mark in high school than the students are who have been admitted to a BSc or BA degree.

Another core problem for teacher education seems to be the gap between theory and practice, which Vreugdenhil (2005: 1) describes as follows:

> This problem is made up of three sub problems. The theory does not always facilitate an adequate performance in the school practicum. Student teachers are not always able to restructure the theory received into meaningful knowledge for their practical activities in the classroom. The everyday practice in schools is not always the right field of action for an elaborated theory, as instructed in teacher education.

A connection between theory and practice is expected to ensure a healthy balance between academic imperatives and work-based learning (the school-based teaching experience).

1.4 LITERATURE REVIEW

Teacher education at university is an initial professional preparation of a teacher where the programmes offered should prepare student teachers to be professionally ready and able to cope with the daily demands of working in schools. This means that after qualifying at university, teachers are expected to possess knowledge that will enable them to teach the subjects, in which they major during their studies. Universities therefore, have an obligation to provide mathematics and science student teachers with the types of knowledge required in teaching mathematics and natural sciences in school.

Kennedy (2002) distinguishes three separate sources of knowledge that are relevant to teaching. First, there is craft knowledge, which is acquired largely through experience and tends to be a-theoretical and idiosyncratic. Secondly, systematic knowledge, which is acquired mainly through colleges and universities, research articles, journals and professional associations and tends to be more theoretical, codified and abstract. Finally, there is prescriptive knowledge, which is acquired generally through institutional policies and tends to consist of 'should' and 'ought' statements.

Procedural knowledge is a form of practical knowledge that is not easily codified but nonetheless, plays a key role in school-based practices and activities. This knowledge is often context specific and is referred to variously as cultural knowledge or horizontal knowledge. This form of knowledge is difficult to make explicit or to represent in a textual form because it is largely acquired informally through participation in social activities. Moreover, it is often so 'taken for granted' that people are unaware of its influence on their behaviour (Bernstein, 2000).

Ball, Thames and Phelps (2008), when referring to the teaching of mathematics, argue that the focus must be on the work of teaching – what teachers need to do in teaching mathematics. They propose mathematical knowledge for teaching; the mathematical knowledge needed to carry out the work of teaching mathematics. They further assert that since teaching involves showing students how to solve problems, answering students' questions and checking students' work demands an understanding of the content of the school curriculum. Mathematical knowledge for teaching is divided into four domains, namely:

- Common knowledge content (mathematical knowledge and skill used in settings other than teaching);
- Specialised knowledge content (mathematical knowledge and skill unique to teaching);
- Knowledge of content and students (knowledge that combines knowing about students and knowing about mathematics); and
- Knowledge of content and teaching (combines knowing about teaching and knowing about mathematics).

The National Curriculum Statement grade R-12 (with special reference to the Curriculum and Assessment Policy Statements for mathematics, physical sciences and life sciences); the Norms and Standards for Educators (NDoE, 2000) and the Minimum Requirements for Teacher Education Qualifications (NDHET, 2011) documents were analysed for this study. These policy documents form the framework of teacher education qualifications in South Africa. The Norms and Standards for Educators policy (NDoE, 2000) signalled the state's intention to adopt a new non-technical approach to teacher education (Schafer & Wilmot, 2012). The policy adopts a competency-based approach and sets out knowledge, skills and values that teachers must acquire and the roles they must perform. It emphasises practical and foundational competencies, as well as the development of reflexive competencies. Teachers are expected to perform seven roles, including mediator and assessor of learning, and developer of curriculum and learning support materials. This policy, updated in 2006, was used as a guiding framework for initial and pre-service teacher education programmes offered by university education faculties (Schafer & Wilmot, 2012).

The Minimum Requirements for Teacher Education Qualifications (NDHET, 2011) is a current policy document that guides teacher education. It sets out the new framework for teacher education and specifies a set of requirements for teacher education qualifications to ensure that the higher education system produces the kinds of teachers that South Africa needs. This document signals a shift from applied competence and the roles of teachers to a framework that encapsulates notions of applied and integrated knowledge (NDHET, 2011) by proposing various types of knowledge that underpin teachers' practice.

The types of learning associated with the acquisition, integration and application of knowledge for teaching purposes as envisaged by this policy document are the following: disciplinary learning (which refers to disciplinary or subject matter content and can be presented in two components, namely the study of education and its foundations and the study of specific specialised subject matter); pedagogical learning (which incorporates general pedagogical learning and specialised pedagogical content knowledge); practical learning (which involves learning in and from practice); fundamental learning (which refers to learning to converse competently in a second official language and the ability to use information and communication technologies (ICTs) competently and the acquisition of academic literacies); and situational learning (which refers to knowledge of the various learning situations, contexts and environments of education, as well as to prevailing policy, political and organisational contexts) (NDHET, 2011).

1.5 THEORETICAL FRAMEWORK AND FOCUS OF STUDY

The following contesting theoretical strands may contribute to the knowledge that teachers need for teaching: social realism, practical rationalism and social constructivism.

1.5.1 Social realist framework

Bernstein's social realism focuses on the structure of knowledge. His analysis of the structuring of knowledge and pedagogic practice, according to Wheelahan (2005; 2010), is encapsulated in his concept of the pedagogic device. The pedagogic device consists of the pedagogic code and the rules that mediate its enactment. The pedagogic code refers to the way in which knowledge is classified and framed (Wheelahan, 2010).

Classification of knowledge refers to the way in which knowledge is defined in different fields and how these fields are distinguished and insulated from one another and how the specialisation of different fields of knowledge is maintained by the strength or weakness of the boundaries and the degree of insulation between them (Bernstein, 2000).

Framing is concerned with the 'how' of knowledge and refers to the locus of control over the selection, pacing, sequencing and evaluation of knowledge and it can also be strongly or weakly framed. Strongly framed knowledge is knowledge where students have little or no control over the selection of knowledge in the curriculum, its pacing, sequencing and evaluation; while in weakly framed knowledge, students have much greater control over their own learning process (Wheelahan, 2005; 2010).

The *classification* and *framing* of knowledge is mediated through distributive rules (which define and distribute access to different knowledges); recontextualisation rules (which are the rules that determine what knowledge and skill is to be selected from the field in which it was produced and then translated into pedagogic knowledge and practice); and evaluation rules (where acquirers (students) demonstrate that they can produce the required text called for by the implementation of the pedagogic code). In other words, students implicitly understand the assessment process and how to produce the right outcome (Wheelahan, 2005; 2010). Bernstein (2000) further distinguishes between singular forms of knowledge and regions of knowledge. The former describes the academic disciplines, while the latter defines education that is oriented to a field of practice, rather than a singular body of knowledge.

1.5.2 Practical rationalist framework

Shulman (1986) describes the knowledge base for teachers as comprising content knowledge (the knowledge of the subject content that needs to be taught); context knowledge (knowledge about the background of learners, knowing the organisational culture of the school); general pedagogic knowledge (knowledge of different teaching strategies, classroom management strategies, assessment strategies) and pedagogic content knowledge which entails, among other things: knowledge of how to structure and represent academic content for direct teaching to students; knowledge of the common conceptions, misconceptions and difficulties that students encounter when learning particular content; and knowledge of the specific teaching strategies that can be used to address students' learning needs in particular classroom circumstances.

The curriculum-orientated work of Shulman (1986) attempts to answer the question: How does the successful college student transform his or her expertise into the subject matter form that high school students can comprehend? Shulman's conceptual work is based on the distinction between subject content knowledge, curricular knowledge and the category of pedagogic content (Banks & Moon, 2005). Shulman (1986) challenges the widespread tacit assumption that the knowledge base for teaching involves two kinds: the knowledge of the disciplinary content and the knowledge of the pedagogical methods. He proposes rather, that the requisite knowledge base for teaching involves the integration of the two into pedagogical content knowledge, which involves knowing the substantive disciplinary area, but knowing it in terms of the pedagogical activities that would best enable learners to cope with likely hurdles and block points. Pedagogic content knowledge as defined by Shulman (1986) requires the subject specialist to know "the most useful forms of analogies, illustrations, examples, explanations and demonstrations – in a word the ways of representing and formulating the subject in order to make it comprehensible to others" (Banks & Moon, 2005: 340). This is dependent on the type of knowledge student teachers gain from their programmes.

1.5.3 Social constructivist framework

Social constructivists, according to Creswell (2009), assume that individuals seek an understanding of the world in which they live and work; that individuals develop subjective meanings of their experiences-meanings directed toward certain objects or things. Thus, the goal of research is to rely as much as possible on the participants' views of the situation being studied; in the case of this study, teacher knowledge of mathematics and science.

Drawing from social constructivism, Van Dijk (2009) posits that knowledge has the inherent cultural and social dimensions of particular contexts where knowledge and experiences of what constitute it, is shared by for example, a community of practice.

1.6 PURPOSE OF THE STUDY

The purpose of this study is to examine current teacher knowledge of mathematics and science, with reference to how theoretical and propositional knowledge in these subjects is navigated to practice by teachers in South African education.

1.7 RESEARCH DESIGN

1.7.1 Paradigm

This study is foregrounded on an interpretive paradigm. This paradigm supports the belief that reality is constructed by subjective perception and predictions cannot be made. It was considered suitable for this study since it emphasises the world of experience as it is lived, felt and undergone by social actors (Patton, 1990; Schwandt, 1994; Creswell, 2007; Denzin & Lincoln, 2005).

1.7.2 Methods and approaches

In line with the chosen paradigm for this study the methods, type and approaches appropriate to collect qualitative types of data are used. Instruments used are interviews, observations and document reviews (Mertens, 2009).

The main research question for this study is:

What is the teacher knowledge of mathematics and science in BEd programmes; how is this knowledge integrated into the curriculum and how is theoretical knowledge acquired at universities navigated to practice to enhance effective teaching and learning?

The following are the subsidiary questions:

- What are the different kinds of teacher knowledges; how do they relate and how are they acquired and developed?
- How do employers' prescriptions shape the curriculum content of mathematics and science and their pedagogy?
- To what extent does theoretical knowledge in the curriculum of the BEd provided in schools of teacher education, adequately prepare students to teach mathematics and science effectively?
- How does the training of teachers to teach mathematics and science in universities of technology differ from a similar training in conventional universities?

1.7.3 Propositions

The following propositions guided this study:

- An adequate understanding of teacher knowledges is critical in producing teachers who can teach mathematics and science.
- The notion of framing (locus of control over selection, pacing, sequencing and evaluation of knowledge) might assist in closing the gap between theory and the practice of mathematics and science.

- The current curriculum of BEd programmes provided in schools of teacher education has not sufficiently integrated theoretical knowledge that teachers need to teach mathematics and science.
- Universities of technology are better placed to train teachers to teach mathematics and science.

1.7.4 Sampling

Purposive sampling was used for the selection of participants for this study (Patton, 2002; Denzin & Lincoln, 2005; Creswell, 2007). Faculties or schools of education, which offer BEd (FET) programmes for the preparation of teachers to teach mathematics and sciences, were sampled. Five faculties or schools of education from five universities nationally were selected to participate in the research study. Of these five, one faculty or school of education was chosen from formerly English-speaking universities; one from formerly Afrikaans-speaking universities; and three from former technikons, now transformed into universities of technology.

Two categories of participants were developed. The first category comprised seven lecturers: Out of each university, faculty or school of teacher education the intention was initially to interview two lecturers, one offering instruction in mathematics and the other in science. In most cases, one lecturer was accessed and interviewed, even though in other cases two were available. These lecturers provided views about individual experiences in the preparation of mathematics and science teachers.

The second category comprised six experienced mathematics and/or science teachers in schools, who graduated with a BEd (FET) degree. The main criterion for inclusion was that these teachers would have gone through the process of teacher training to teach mathematics and science and as a result, are assumed to be in a better position to give informed comments on how they have been taught and how they have acquired the requisite knowledge to be mathematics and science teachers.

1.7.5 Instrumentation

Instruments used to collect data for this study were interviews, document analysis and a literature review. In accordance with the chosen paradigm, semi-structured interviews with individual informants were conducted (Denzin & Lincoln, 1994; Miles & Huberman, 1994; Patton, 2002). Interview schedules were used. The interviews were recorded and later transcribed. The processes, such as data reduction, data display and conclusion drawing/verification was used to analyse data. Policy documents on teacher education, such as the Norms and Standards for Educators (NDoE, 2000) and the Minimum Requirements for Teacher Education Qualifications (NDHET, 2011) were analysed for this study. Reviewing the literature assisted in establishing the background and context of teacher knowledge in mathematics and science in South Africa.

1.7.6 Data reduction and analysis

In line with the chosen paradigm, the process of reducing and analysing data was carried out within the analytical framework proposed by Miles and Huberman (1994). Once actual field notes and interviews were available, the following analytic moves were undertaken: identifying of themes, issues, emerging patterns; affixing codes to a set of field notes drawn from interviews; noting reflections or other remarks in the margins; sorting and sifting through these materials to identify similar phrases, relationships between variables, patterns, themes, distinct differences between sub-groups and common sequences; and isolating these patterns and processes, commonalities and differences (Miles & Huberman, 1994).

1.7.7 Procedures for credibility and trustworthiness

The procedures for credibility and trustworthiness were meant to enhance the quality of this study by showing that the findings are "worth paying attention to" (Lincoln & Guba, 1985). Lincoln and Guba (1985) propose four criteria for evaluating interpretive research work that need attention, namely: credibility, transferability, dependability and confirmability. These criteria are explained in detail in Chapter 3.

1.7.8 Ethical clearance

The Faculty Research Committee of the Central University of Technology, Bloemfontein, granted the ethical clearance for this study. The task of this committee is to ensure that research participants are protected from harm. A consent form for interviewees (Appendix D) was provided to all participants. This form included a pledge by the researcher to ensure voluntary participation, informed consent, confidentiality and anonymity of participants.

1.8 CONCLUSION

Chapter 1 provided an overview of this study. In this chapter the background that led to this study was discussed. Problems regarding teacher knowledge were identified. It also highlighted the statement of the problem and the theoretical frameworks that may contribute to knowledge that teachers require. The literature relating to teacher knowledge was discussed. The research design of this study was also outlined and an outline of the study chapters was developed.

1.9 DISCUSSION OF REMAINING CHAPTERS

The thesis comprises five chapters.

Chapter One provided an overview of this research project. The aspects of the research covered in this chapter were the background to the study; statement of the problem; the theoretical framework and focus of study; the literature review; purpose of the study; research design; and the outline of the study.

Chapter Two focuses on the literature review. It first introduces the knowledge bases of mathematics and science teaching. Secondly, it identifies the theoretical frameworks underpinning the study. Lastly, it explores the literature on teacher knowledge of mathematics, science and teacher education policy in South Africa.

Chapter Three provides the research design. It includes analysis of the selected paradigm, perspectives, methods and approaches used in this study. It also discusses the research questions, propositions, sampling strategies and procedures for dealing with the data.

Chapter Four reports the results of the study. The report is organised in terms of the four research questions underlying the study.

Chapter Five presents discussions and the conclusion of the study. It integrates arguments, issues and challenges that emerged from all the chapters. In particular, the chapter projects the researcher's own views and opinions on the different research questions that underpin the study. This chapter also draws a conclusion to the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is a review of the literature on teacher knowledge of mathematics and science. The chapter first introduces the knowledge bases of mathematics and science teaching. Secondly, it identifies the theoretical frameworks underpinning the study. Lastly, it explores the literature on teacher knowledge of mathematics, science and teacher education policy in South Africa.

2.2 KNOWLEDGE BASES OF TEACHING

2.2.1 Types of knowledge

Human knowledge, according to Polanyi (1966), can be classified into tacit and explicit knowledge. Tacit knowledge is highly personal and hard to formalise, making it difficult to communicate or share with others. Subjective insights, intuitions and hunches fall into this category of knowledge. Explicit knowledge is codified knowledge that can be transmitted in formal systematic language. It can be expressed in words and numbers and shared in the form of data, scientific formulae, specifications and manuals. This knowledge can be transmitted readily among individuals formally and systematically.

On the other hand, Jong and Ferguson-Hessler (1996) distinguish four types of knowledge: situational knowledge, conceptual knowledge, procedural knowledge and strategic knowledge. Situational knowledge refers to knowledge about situations as they typically appear in a particular domain, and knowledge of problem situations enables the solver to sift relevant features of the problem statement (selective perception) and, if necessary, to supplement information in the statement. Conceptual knowledge refers to static knowledge about fact, concepts and principles that apply within a certain domain. Procedural knowledge contains actions or manipulations that are valid within a domain. Procedural knowledge helps the problem-solver make transitions from one problem state to another. Strategic knowledge helps students organise their problem-solving process by directing which stages they should go through to reach a solution. A strategy can be seen as a general plan of action in which the sequence of solution activities is laid down.

2.2.2 Sources of knowledge

Kennedy (2002) proposes three separate sources of knowledge that are relevant to teaching. First, there is craft knowledge, which is acquired largely through experience and which tends to be a-theoretical and idiosyncratic. Secondly, there is systematic knowledge, which is acquired mainly through colleges and universities, research articles, journals and professional associations and which tends to be more theoretical, codified and abstract. Finally, there is prescriptive knowledge, which is acquired generally through institutional policies and which tends to consist of 'should' and 'ought' statements.

2.2.3 Teacher knowledge

Ure (2010) identifies a set of student teachers' knowledge bases as (a) for teaching and learning (building the discipline knowledge base for teaching and learning); and (b) about teaching and learning (the academic study of the principles of the teaching and learning processes and how students develop).

Shallcross, Spink, Stephenson and Warwick, (2002) argue that good teaching requires the integration and application of four knowledge bases: general pedagogic knowledge; classroom management; substantive (knowing that); and syntactical (knowing how) knowledge. They further aver that a set of knowledge criteria stresses the need for integrating these knowledge areas in order for science teachers to feel empowered in their teaching.

Wilson and Demetriou (2007) maintain that teacher knowledge can be classified into two categories; that is, codified academic knowledge that is based on the idea that learning is primarily a cognitive 'of the mind' activity, or an accumulation of propositional knowledge that can be transferred to practice through a variety of contextual situations. This knowledge is embedded in texts, databases, cultural practices of teaching, studentship, scholarship and research. In each school, textual material takes the form of organisation-specific information, such as records, correspondence and manuals. Codified knowledge is referred to otherwise as declarative or propositional knowledge and vertical knowledge; that is, knowledge that is related to intellectual development and progresses through a hierarchy leading to greater levels of abstraction and a deeper understanding of teaching.

A focus of interest on the knowledge of teachers to both policymakers and educators (Shulman, 1986) still exists today. Grossman and Richert (1988) define teacher knowledge as a body of professional knowledge that encompasses both knowledge of general pedagogical principles and skills and knowledge of the subject matter to be taught. Verloop, van Driel and Meijer (2001) refer to teacher knowledge as the whole of the knowledge and insights that underlie teachers' actions in practice.

Teacher knowledge may have a variety of origins including both practical experiences, such as day-to-day practice and formal schooling in the past; that is, initial teacher education or continued professional training (Calderhead, 1996). It is the total knowledge that a teacher has at his/her disposal at a particular moment that, by definition, underlies his/her actions (Carter, 1990).

Various scholars espouse different types of learning:

- personal knowledge (Connelly & Clandinin, 1985; Elbaz, 1991), indicating that this knowledge is unique; wisdom of practice (Schwab, 1971);
- professional craft knowledge (Brown & McIntyre, 1993; Shimahara, 1998), referring to a specific component of knowledge that is mainly the product of the teacher's practical experience;
- action-oriented knowledge (Carter, 1990), indicating that this knowledge is for immediate use in teaching practice;
- content and context related knowledge (Cochran, DeRuiter & King, 1993; Van Drief, Verloop & De Vos, 1998);
- knowledge that is to a great extent tacit (Eraut, 1994; Calderhead & Robinson, 1991); and
- knowledge that is based on reflection on experiences (Grimmet & MacKinnon, 1992; Gunstone, 1999).

Ben-Peretz (2010) notes that the knowledge of teachers has become a focus of interest to educators and policymakers as reflected by Shulman (1986), attracting the attention of scholars and that education literature reflects this focus. She analysed nine papers published in TATE (Teaching and Teacher Education) distributed over a period of 20 years from 1988 to 2009, representing an international group of scholars and focusing on a variety of themes related to teacher education. The analysis of these nine TATE papers on teacher knowledge yielded some insights into the development of this concept over time. The following are some of the conceptualisations of teacher knowledge by different authors identified by Ben-Peretz (2010).

Grossman and Richert (1988) describe teacher knowledge as a body of professional knowledge that encompasses both knowledge of general pedagogical principles and skills, and knowledge of the subject matter to be taught. They observe that this complex understanding of subject matter is not perceived to be enough for teachers and maintain that what is needed is a specialised body of knowledge; that is, pedagogical content knowledge. This resonates with Shulman's (1987) categories.

Tamir (1991) suggests the distinction between the professional and personal knowledge of teachers. Professional knowledge is defined as that body of knowledge and skills which is needed in order to function successfully in a particular profession. Tamir (1991) concludes that the actual behaviour of a person in his or her professional field is a result of professional and personal knowledge.

Connelly and Clandinin (1996, 1997) focus on personal-practical knowledge. Their sustained inquiries into the personal, practical knowledge of teachers also prompted them to consider what is available for teachers to come to know what is held up as good teaching and who is authorised to produce knowledge. These queries led the research team to expand their programme and to develop their teachers' professional knowledge landscapes' conceptualisation. Located at the crossroads where teachers' personal knowledge and professional knowledge meet, the professional knowledge landscape metaphor deeply connects teachers' personal practical knowledge with the context of teaching. Clandinin and Connelly (1996: 5) depict the professional knowledge landscape in the following manner:

Landscape metaphor…allows us to talk about space, place, and time. Furthermore, it has a sense of expansiveness and the possibility of being filled with diverse people, things and events in different relationships … because we see the professional knowledge landscape as composed of relationships among people, places and things, we see it as both an intellectual and moral landscape.(ibid)

Clandinin and Connelly (1996) further argue that personal-practical knowledge is in the teacher's past experience, in the teacher's present mind and body, and in his/her future plans and actions. It is found in the teacher's practice.

As much as Edwards and Ogden (1988) relate to Shulman's concept of pedagogical content knowledge, they however, claim that Shulman's categorisation of teacher knowledge focuses on the knowledge structures, rather than on knowledge construction. They argue that instead, teachers should be able to position learners in relation to the curriculum in ways that allow these teachers to provide learners with the contingent cognitive and affective support required to enable them to engage with the discourse of the subject in question.

In trying to answer the question: What is it that teachers need to know? Shulman (1987) proposes the following categories of teacher knowledge: general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organisation that appear to transcend subject matter; knowledge of learners and their characteristics; knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; knowledge of educational ends, purposes and values and their philosophical and historical grounds; content knowledge; curriculum knowledge, with a particular grasp of the materials and programmes that serve as 'tools of the trade' for teachers; pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, with their own special form of professional understanding.

According to Ball *et al.* (2008) the first four categories: general pedagogical knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational ends address the general dimensions of teacher knowledge. These categories are not Shulman's main focus of work but rather function as placeholders in a broader conception of teacher knowledge that emphasises content knowledge. The remaining three categories: content knowledge, curriculum knowledge and pedagogical content knowledge define content specific dimensions. The first of these, content knowledge, includes knowledge of the subject and its organising structures.

Ball *et al.* (2008) draw on Schwab (1961; 1978) and Shulman (1986) to opine that knowing a subject for teaching requires more than knowing its facts and concepts. Teachers must also understand the organising principles and structures and the rules for establishing what is legitimate to do and say in a field. The teacher should not only understand that something is so; the teacher must further understand why it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened or denied. Moreover, [the teacher is expected] to understand why a particular topic is particularly central to a discipline, whereas another may be somewhat peripheral.

The second category, curricular knowledge, is represented by the full range of programmes designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programmes, and the set of characteristics that serve as both the indications and contraindications for the use of a particular curriculum or of programme materials, in particular circumstances (Ball *et al.,* 2008). Although curriculum knowledge was first introduced by Shulman (1987) as a separate domain, more recently it has been defined as a component of pedagogical content knowledge in many subsequent studies (e.g. An, Kulm & Wu, 2004; Chick, Baker, Pham & Cheng, 2006; Hill, Ball & Schilling, 2008). In the context of this study, the curriculum refers to the organisation of knowledge. It is the selection of knowledge and skills that students are expected to learn; that is, the lessons and academic content in schools. Pedagogy, on the other hand, is the form or mode of transmission of education; how the selection knowledge (content) is taught.

From the above it seems that the concept of teacher knowledge has been significantly expanded and broadened. What is interesting to note is that the conceptualisations relate to Shulman's (1986) categorisations, even though some authors have attempted to modify them. Teacher knowledge, therefore, focuses on enabling teachers to fulfil their central role; that is, teaching subject matter domains using appropriate pedagogical principles and skills (Ben-Peretz, 2010).

2.3 PEDAGOGICAL CONTENT KNOWLEDGE

Shulman (1986) addresses the dichotomy of treating content knowledge and pedagogical knowledge separately. Advanced thinking about teacher knowledge is introduced by the idea of pedagogical content knowledge (PCK). This knowledge represents the blending of content and pedagogy into an understanding of how particular aspects of subject matter are organised, adapted and represented for instruction.

Content knowledge is about the actual subject matter that is to be learnt or taught. Teachers must know and understand the subjects that they teach, including knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organise and connect ideas; and knowledge of the rules of evidence and proof (Shulman, 1986). Teachers must also understand the nature of knowledge and inquiry in different fields. In mathematics and science, teachers with more knowledge of content are more likely to present problems in contexts that are familiar to the students, as well as linking problems to what learners have already learnt. Teachers with deeper content knowledge understand multiple representations of mathematics and science concepts and are able to use these representations to further students' understanding. Deeper content knowledge also helps teachers to evaluate and use instructional materials. Therefore, it has an impact on teachers' instructional decisions when using materials.

Teachers who do not have these understandings can misrepresent those subjects to their students (Ball & McDiarmid, 1990). Such teachers would rather focus on algorithms rather that the underlying concepts. Teaching and helping students to understand mathematics and science requires more that delivering facts, formulas, and procedural knowledge. Teachers should be able to pose questions, suggest alternative explanations, and propose additional inquiries. If teachers are responsible for helping students learn worthwhile content, they must know and understand the subject they teach. In this regard, Feimann-Nemser (2001) identifies three aspects of subject matter knowledge for teaching as: knowledge of central facts, concepts, theories and procedures within a given field; knowledge of explanatory frameworks that organise and connect ideas; and knowledge of the rules of evidence and proof. Teachers also need to know how to teach their subjects. This includes understanding what students find confusing or difficult and having alternative explanations, models and analogies to represent core concepts and processes (Feimann-Nemser, 2001). Without content knowledge, understanding how subject matter is transformed into instruction and how lesson content relates to students' knowledge and ideas is impossible (Shulman, 1987).

Pedagogical knowledge is deep knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims. This is a generic form of knowledge that is involved in all issues of student learning, classroom management, and lesson plan development and implementation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge, acquire skills, and develop habits of mind and positive dispositions toward learning. As such, pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in the classroom.

Shulman (1986: 9) defines PCK as comprising:

> … the most useful forms of representation of those ideas, the most powerful analogies, illustrations – in a word, the most useful ways of representing and formulating the subject that make it comprehensible to others...Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and misconceptions that students of different ages and backgrounds bring to the learning of those most frequently taught topics or lessons.

Pedagogical content knowledge as an interactive knowledge category is used as an example of the rational stance (Gess-Newsome, 1999). Shulman challenges a widespread tacit assumption that the knowledge base for teaching involves two knowledges: the knowledge of disciplinary content, and the knowledge of pedagogical methods. He proposes rather that the requisite knowledge base for teaching involves the integration of the two; that is, knowing the substantive disciplinary area, but knowing it in terms of the pedagogical activities that would best enable learners to cope with the likely hurdles and block points.

In Shulman's view, pedagogical content knowledge is a form of practical knowledge that is used by teachers to guide their actions in highly contextualised classroom settings. This form of practical knowledge entails, among other things, knowledge of how to structure and represent academic content for direct teaching to students; knowledge of the common conceptions, misconceptions, and difficulties that students encounter when learning particular content; and knowledge of the specific teaching strategies that can be used to address students' learning needs in particular classroom circumstances. Pedagogical content knowledge builds on other forms of professional knowledge and, therefore, is a critical – and perhaps even the paramount – constitutive element in the knowledge base of teaching. If teachers are to be successful, they have to confront both the issues of content and pedagogy simultaneously by embodying the aspects of the content most germane to its teachability. At the heart of pedagogical content knowledge is the manner in which subject matter is transformed into teaching. This occurs when the teacher interprets the subject matter, finding different ways to represent it and make it accessible to learners (Shulman, 1986).

Cogill (2008) maintains that pedagogical content knowledge enables teachers to ease learning for students through the use of clear explanations, appropriate analogies and presenting learning in interesting, motivating and even entertaining ways. This resonates with Shulman's view of pedagogical content knowledge.

Pedagogical content knowledge, as defined by Shulman (1986: 333), requires the subject specialist to know "the most useful forms of analogies, illustrations, examples, explanations and demonstrations – in a word the ways of representing and formulating the subject in order to make it comprehensible to others". This is dependent on the type of knowledge that students gain from their programmes.

Shulman (1986) sees pedagogical content knowledge as also including an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those frequently taught topics and lessons.

Shulman's (1986; 1987) framework where he concentrates on the types of knowledge required in teacher training and the processes trainees need to go through to become teachers, informs this study.

Drawing from Shulman's (1987) seminal work, and after reviewing and analysing the literature defining PCK, Park and Oliver (2008: 264) arrived at what they consider a working definition:

> PCK is teachers' understanding and enactment of how to help a group of students understand specific subject matter using multiple instructional strategies, presentations, and assessments while working within the contextual, cultural, and social limitations in the learning environment.

2.3.1 Components of PCK

Various researchers have defined the components of PCK differently (Tamir, 1988; Grossman, 1990; Fernandez-Balboa & Stiehl, 1995). After an intensive literature review, Bukova-Guzel (2010) has developed a comprehensive framework of PCK consisting of three main categories and their components as shown in Table 2.1.

Table: 2.1: Bukova-Güzel's framework for pedagogical content knowledge

Knowledge of teaching strategies and multiple representations	**Knowledge of learner**	**Knowledge of curriculum**
□ Using appropriate activities in instruction □ Using real-life examples and analogies in instruction □ Utilising different instructional strategies in presentations	□ Having knowledge of students' prior knowledge □ Using real-life examples and analogies in instruction □ Having knowledge of the difficulties students will face during learning	□ Being aware of the elements of the mathematics curriculum (conception, purposes, etc.) □ Being aware of the varieties of instructional tools in the mathematics

□ Making use of different representations in instruction (graphics, tables, formulas, etc.)	□ Having knowledge of possible student misconceptions □ Having knowledge of student differences	curriculum and how to use them □ Being aware of the instruments to measure student learning and how to use them

Source: Bukova-Gǖzel (2010)

Bukova-Guzel *et al*. (2013) contend that while there is no consensus on how to determine PCK of mathematics teachers and pre-service teachers alike, focusing on as different components as possible can generate a more comprehensive knowledge about teachers' PCK. They further argue that identifying pre-service mathematics teachers' perceptions related to their PCK will serve as a significant clue for them to improve their PCK by showing them in what areas they need further improvement.

2.3.2 Development of PCK

Hurrell (2013) identifies research to support the fact that novice teachers possess a limited repertoire of PCK (Lee, Brown, Luft & Roehrig, 2007; Nason, Chalmers & Yeh, 2012; Wilson, Floden & Ferrini-Mundy, 2002) and that experience is a major influence on the shaping and development of a teacher's PCK (Kleickmann, Richter, Kunter, Elsner, Besser, Krauss & Baumert, 2013; Lee *et al*., 2007). There is further evidence to support that teaching experience alone is not sufficient and that experience, coupled with thoughtful reflection of instructional practices is required (Kleickmann *et al.,* 2013). Although experience is an important factor in the development of PCK, it is not as significant in contributing to PCK as a teacher's opportunity and disposition towards reflection on content knowledge. In this regard, Gess-Newsome and Lederman (1995: 321) state that:

> …teaching experience alone does not equate with teaching expertise, though the two are often mistakenly confused. Opportunities for a teacher to reflect on classroom practice and implement identified changes, however, greatly influence teaching "expertise". If teaching is to be a purposeful act, and if we want

teachers to be able to translate integrated understandings of content into classroom practice, the time and opportunity to develop, codify, and implement such beliefs into the classroom must be fostered.

Teaching expertise is exhibited when one possesses organised knowledge bases that can be quickly drawn upon while being engaged in the act of teaching (Silverman & Thompson, 2008: 501).

2.3.3 Models of PCK

Gess-Newsome (1999) proposes two theoretical models to explain the origin and development of PCK which are integrative and transformative (Figure 2.1). The two models represent the extremes of a continuum (Fernandez, 2014). The integrative model considers PCK as the intersection between educational, disciplinary and contextual knowledge. In the integrative model, the relevant knowledge bases used in teaching are developed separately (or possibly, in an incorporated manner), with the knowledge becoming integrated through the act of teaching. In the integrative model, PCK does not exist as a domain of knowledge on its own. Gess-Newsome (1999:11) notes that the task of the teacher is to selectively draw upon the independent knowledge bases of subject matter, pedagogy, and context, thus integrating them as needed to create effective learning opportunities.

The transformative model situates PCK as a result of the transformation of pedagogical knowledge, subject matter knowledge and context knowledge (Figure 2.1). It recognises the value of synthesised knowledge, the fundamental transformation of knowledge, and the creation of new knowledge. The transformative, according to Silverman and Thompson (2008) requires purposefully integrated experiences that allow teachers the opportunity to create connections and create new knowledge. The transformative model recognises that whilst the knowledge bases of content, pedagogy and context exist, they are useful only when transformed into PCK, which can only occur in the classroom.

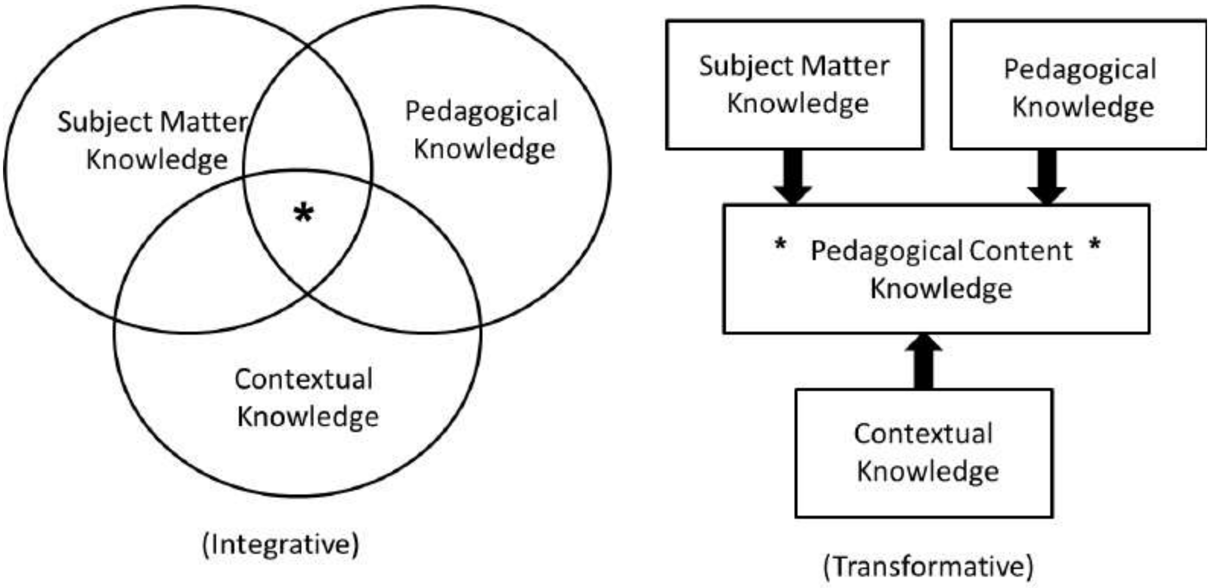

Figure 2.1: Two models of teacher knowledge (integrative model on the left and transformative model on the right (Gess-Newsome, 1999: 12))

These models have implications for the curriculum of teacher education. The more traditional training courses for teachers, organised into separate disciplines of content, pedagogy and practice often follow the integrative model of teachers' knowledge (Fernandez, 2014). On the other hand, in the transformative model, the practice of the classroom must be part of the initial training, as well as case studies and vignettes, among other practical activities. The importance of incorporating teaching practice in the training process is therefore affirmed.

It is postulated in this study that the transformative model of PCK is best suited for inclusion in teacher education programmes since it addresses the shortcomings of traditional teacher education programmes that employ the integrative model, which Masson describes as "often merely providing future and current teachers with an array of non-contextualized, unconnected activities, concepts and demonstrations" (1999: 277).

The Model of the PCK Summit is the latest model and is the result of a conference held in 2012, in which thirty researchers met and discussed the PCK, aiming to reach consensus in order to adopt the definition of PCK by several groups (Figure 2.2).

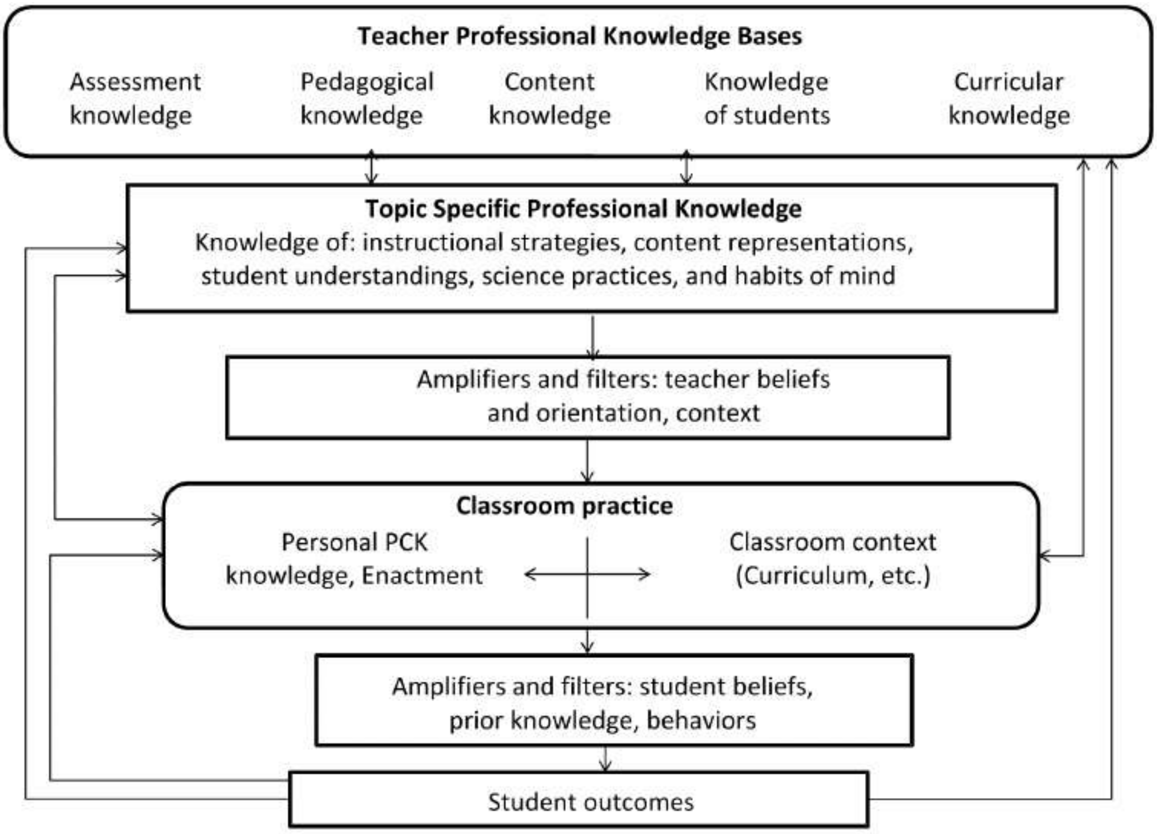

Figure 2.2: Consensus model of PCK Summit

In the PCK Summit model five main domains are defined for the teaching profession:

(i) Knowledge of assessment
(ii) Pedagogical knowledge
(iii) Content knowledge
(iv) Knowledge of students
(v) Curricular knowledge

These five knowledge(s) influence and are influenced by the professional knowledge of a particular topic. This professional knowledge includes knowledge of instructional strategies and representations of content, student understanding, scientific practices and habits of mind (Fernandez, 2014).

This specific professional knowledge passes through filters and amplifiers which are the teacher's beliefs, the context in which it is inserted and the orientations for teaching. After this filter, this specific professional knowledge will be transformed and adapted during the classroom practice into the personal PCK. Then, this knowledge passes through the filters and amplifiers of students, taking into account their beliefs, prior knowledge and their behaviour, followed by an assessment through student outcomes (Fernandez, 2014).

This model seems to have a theoretical PCK (specific professional knowledge of the topic) and a personal, idiosyncratic PCK, which manifests itself in the practice of the classroom. This practice influences and is influenced by the knowledge base, as by specific professional knowledge of the topic. Student outcomes, in turn, influence both the personal PCK from classroom practice and the topic's specific professional knowledge as the knowledge base (Fernandez, 2014).

The model of the PCK summit revisits the initial model from Shulman's both in terms of PCK and in terms of base knowledge and incorporates new elements that were brought by other models presented. In the PCK summit model, the assessment knowledge, which is ignored by Shulman and Grossman, is incorporated into the knowledge base (Fernandez, 2014). In addition, this knowledge appears as a base knowledge, agreeing with the initial idea of Shulman who describes it as the knowledge of the curriculum (separate from pedagogical knowledge as in Grossman's model) and the knowledge of students (separate from context as in Grossman's). The PCK summit model still represents the development of PCK with practice in the classroom and incorporates the role of the beliefs of teachers and students, while also taking into account the filter of the context. Thus, it reaffirms the initial idea of Shulman and Grossman and places PCK again in the centre of the knowledge base of teachers. For these reasons, the model of the PCK summit seems to be an improved model incorporating elements of previous models, having reworked the original idea of Shulman and Grossman.

2.4 TEACHER KNOWLEDGE OF MATHEMATICS AND SCIENCE IN TEACHER EDUCATION

2.4.1 Status of mathematics and science teaching

Mathematics is a language of science. Mathematics and science are part of human existence and development and, therefore, our collective culture. The pursuit of the knowledge of mathematics and science should be encouraged vigorously at all levels of education (Wilcox, 2003). Mathematics is not simply about counting and numbers, even though that is where it finds its origin, nor is it just about calculations. It concerns the abstraction of ideas; that is, identifying essential qualities from the full content for simplification and exactness. Things that have common properties, such as continuity, distance, size, shape, space, or a collection of things, are given more precise meaning in mathematics to prevent ambiguity, confusion or contradiction (Wilcox, 2003). They are translated into symbolic notation for simplicity. Science is very much like mathematics in the sense that it tries to abstract essential information or properties of phenomena in order to gain deeper understanding thereof. Special terminology is introduced in order to clarify the things or ideas under investigation. Wilcox (2003) argues that by logical manipulation and rational investigation we are able to state and prove (or corroborate) conjectures or theorems about abstract ideas and how these ideas interrelate, develop theories about abstract concepts, solve problems based on information abstracted from problems, or gain insight into the workings of reality via abstract descriptions, models and theories about reality. The Further Education and Training (FET) Phase Mathematics CAPS document (DOE, 2011) provides teachers with a definition of mathematics, its specific aims, specific skills, focus and weighting of content areas. According to this document, mathematics is a language that makes use of symbols and notations for describing numerical, geometric and graphical relationships. It is a human activity that involves observing, representing and investigating patterns and qualitative relationships in physical and social phenomena and between mathematical objects themselves.

Wilcox (2003) likens mathematics to science in the sense that science attempts to abstract essential information on properties of phenomena in order to gain deeper understanding. He (2003) further maintains that by using special terminology, ideas are discussed and clarified and by logical manipulation and rational investigation of these ideas, we are able to state and prove (or corroborate) conjectures or theorems about abstract ideas and how these interrelate; develop theories about abstract concepts; solve problems based on information abstracted from problems; or gain insight into the workings of reality via abstract descriptions, models and theories about reality. The above discussion indicates that mathematics and science cannot be separated; therefore, what is discussed in this study about mathematics should also apply to science.

The transition from initial teacher education to school teaching is a process that begins early in teachers' own experiences (Wolf-Waltz, 2004). When student teachers or indeed new teachers meet existing classroom practices, a complex reality emerges. Ernest (1989), in supporting this idea, asserts that theoretical knowledge is not enough for practical knowledge, which includes the pedagogical knowledge of teaching mathematics and science, curriculum knowledge, organisation management and context knowledge of school and learners.

Adler and Davis (2006) posit that there is growing support for the notion that there is specificity in the way that teachers need to grasp and use mathematics, in order to teach mathematics. This way of knowing and using mathematics differs from the way that mathematicians grasp and use mathematics. They argue that both mathematics and teaching are implicated in how mathematics needs to be grasped so that it can be used effectively to teach. They further state that this has significant implications for mathematics teacher education as it raises questions as to whether the mathematical education of teachers can and does provide opportunities to learn these ways of knowing and using mathematics. The question is whether initial teacher preparation programmes in universities provide such opportunities.

McGraner, Van Der Heyden and Holdheide (2011) identify the following as key components of effective mathematics instruction: subject-matter knowledge in mathematics (or the teacher's knowledge of the content being taught); mathematics topics for student mastery; and knowledge about how to most effectively teach mathematics (or the teacher's knowledge and use of effective instructional strategies in teaching mathematics).

McGraner *et al.* (2011) further identify research on mathematics teaching that suggests that many teachers do not possess the requisite subject matter knowledge to implement high quality instruction. They maintain that teachers must know in detail and from a more advanced perspective the mathematical content, for which they are responsible for teaching and the connections of that content to other important mathematics, both prior to and beyond the level they are assigned to teach. The logic herein, they maintain, is that teachers who possess strong mathematical knowledge at a greater depth and extent are more likely to foster students' ability to reason, conjecture and problem-solve, while also being able to more accurately diagnose and address students' mathematical (mis)conceptions and computational (dys)fluencies.

Helping students to learn subject matter involves more than the delivery of facts and information. There seems to be a tension between content knowledge and pedagogical knowledge in teacher education programmes (Davies & Simmt, 2006). One line of thought is that teachers need to have a solid foundation and understanding of subject matter, not only what they have to teach but well beyond its limits (Baker, Bressound, Epp, Ganter, Haver, & Pollasek, 2004; Even, 1993; Leitzel, 1991). On the other hand, there are others who believe that teachers should focus on the materials they will teach in the classroom and focus more on delivering the content (Hill, Ball & Schilling, 2008). Most research, however, places emphasis on streamlining the two approaches (Davies & Simmt, 2006; Grossman, Stodolsky & Knapp, 2004).

McGraner *et al.* (2011) argue that mathematics and science teachers must know not only the content they teach, but also how students' knowledge of mathematics and science is developed and structured. They must know how to manage internal and external representations of mathematical and scientific concepts. They must know how to make students' understanding of mathematics and science visible and how to diagnose student misunderstandings and misconceptions, correct them and guide them in reconstructing the complex, conceptual knowledge of mathematics and science. They further contend that teachers must understand how students reason and employ strategies for solving mathematical and scientific problems and how students apply or generalise problem-solving methods to various mathematical and scientific contexts. This can happen only if mathematics and science teachers are adequately qualified to teach these subjects.

The low level of output in these subjects at high school has a direct impact on the capacity of the system to produce qualified teachers in mathematics and science. In most cases, those that obtain a good pass in these subjects find it less attractive to choose teaching as a career, thus creating a vicious cycle in the undersupply of teachers of mathematics and science (McGraner *et al.*, 2011).

2.5 MATHEMATICS TEACHERS' PCK

It is widely accepted that teachers of mathematics need a deep understanding of mathematics (Ball, 1993; Grossman, Wilson, & Shulman, 1989; Ma, 1999; Schifter, 1995). However, it is axiomatic that teachers' knowledge of mathematics alone is insufficient to support their attempts to teach for understanding (Silverman & Thompson, 2008: 3). According to Hurrel (2013), it is well documented that many teachers exhibit weakness and lack a deep conceptual understanding of mathematics. Content-specific knowledge domains for mathematics teachers can be named as mathematics subject-matter knowledge, mathematics curriculum knowledge, and mathematical pedagogical content knowledge (Bukova-Guzel, Canturk-Gunhan, Kula, Ozgur & Elci, 2013). Research has refuted the idea that knowing the subject is enough for teaching that subject (Ball & Bass, 2000; Ball, Thames & Phelps, 2008) and that the structure and type of mathematical knowledge that a mathematics teacher needs to possess has been shown to be different from what a mathematician would need to possess (Ball & Bass, 2000; Ball *et al*., 2008: Noss & Baki, 1996). These arguments have led the mathematics education community to highlight mathematical pedagogical content knowledge. Mathematical pedagogical content knowledge enables teachers to transform their own subject-matter knowledge into a form that is comprehensible to students; draw on resources; effectively use various representations and analogies; understand students' thinking; and explain mathematical concepts well (Bukova-Guzel *et al*., 2013).

Ball & Bass (2000) further argue that mathematical pedagogical content knowledge includes knowing on which aspects of a concept to focus, in order to make it interesting to a particular grade level and knowing where students may possibly experience difficulties when problem-solving. In addition, it includes being able to modify problems according to the students' levels and being able to facilitate mathematical discussions.

Ball, Thames and Phelps (2008) aver that although the term PCK is very widely used, it lacks clarity of definition, and its potential has not yet been fully realised. Their refinements of the concept of PCK and its attempt to reframe the study of teaching knowledge are predicated on placing the emphasis on the use of "knowledge in and for teaching rather than on teachers themselves" (2008: 394)

2.5.1 Mathematical knowledge of teaching

The framing of knowledge for teaching mathematics has centred on the question: What mathematical reasoning, insight, understanding and skills are required for a person to teach mathematics? This has led to the development of theoretical models and measures to address this question. In their work, Ball, Thames and Phelps (2008) and Hill, Ball and Schilling (2008) have proposed three types of subject-matter knowledge (SMK) and three types of pedagogical content knowledge (PCK) as non-overlapping categories in the domain of *mathematical knowledge for teaching* (MKT) as shown in Figure 2.3 below.

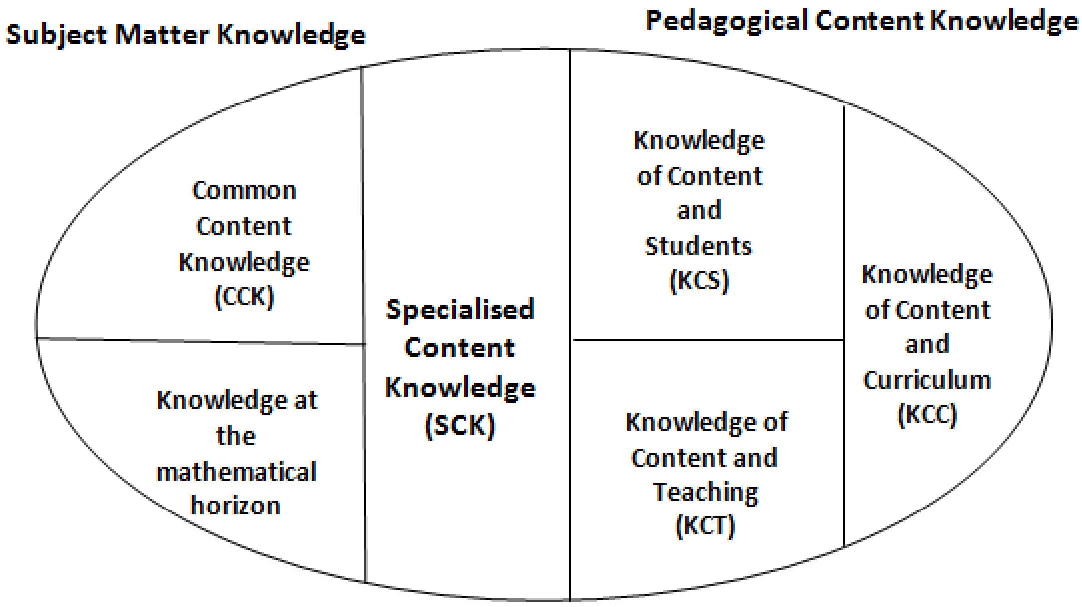

Figure 2.3. Mathematical knowledge for teaching (Hill *et al*., 2008, p. 377)

In discussing what teachers need to do in teaching mathematics, Ball *et al.* (2008) suggest a concept of mathematical knowledge entailed in teaching – in other words, mathematical knowledge needs to perform the recurrent tasks of teaching mathematics. They further propose four domains of mathematical knowledge for teaching: common content knowledge (CCK); specialised content knowledge (SCK); knowledge of content and students (KCS); and knowledge of content and teaching.

Common content knowledge (CCK) refers to the mathematical knowledge and skills used in settings other than teaching. Teachers need to know the material they teach; they must recognise when their students give wrong answers or when a textbook gives an inaccurate definition. The word ‘common’ is used to indicate that this is knowledge of a kind used in a wide variety of settings – in other words, not unique in teaching (Ball *et al.*, 2008).

Specialised content knowledge (SCK) is the mathematical knowledge not typically needed for purposes other than teaching. This is premised on the assertion that teaching requires knowledge beyond that being taught to students. For instance, it requires understanding different interpretations of the operations in ways that students need not explicitly distinguish (Ball *et al.*, 2008).

Knowledge of content and students (KCS) is knowledge that combines knowing about students and knowing about mathematics. Teachers must anticipate what students are likely to think and what they will find confusing. It requires an interaction between specific mathematical understanding and familiarity with students and their mathematical thinking. This involves knowledge of common student conceptions and misconceptions about particular mathematical content (Ball *et al.*, 2008).

Knowledge of content and teaching (KCT) combines knowing about teaching and knowing about mathematics. Many of the mathematical tasks of teaching require a mathematical knowledge of the design of instruction. The tasks that teachers perform in this domain, such as sequencing particular content for instruction; choosing which examples to use to take students deeper into the content; evaluating the instructional advantages and disadvantages of representations used to teach a specific idea; identifying what different methods and procedures in instruction require an interaction between specific mathematical understanding and an understanding of pedagogical issues that affect student learning. Ball *et al.* (2008), however, concur that the definitions of the above domains are evidence that their work may be understood as elaborating on, and not replacing the construct of pedagogical content knowledge identified by Shulman (1986).

Hill *et al.*'s (2008) construct of MKT has been described by Depaepe, Verschaffel and Kelchtermans (2013) as the most influential reconceptualisation of teachers' PCK within mathematics education. Depaepe *et al*. cite three merits of MKT: that it was borne out of empirical research on the knowledge teachers require to teach mathematics; that MKT took Shulman's (1986) heuristic and turned it into a valid measure of teachers' mathematical knowledge for teaching; and lastly, that it provides empirical evidence of a positive relationship between student learning and teachers' PCK. Ball, Thames and Phelps (2008) have proposed domains of professional knowledge which, if accepted by educators as being necessary, may pave the way for framing questions which may be used to audit where professional development might be appropriate. Some examples of such questions are provided in Table 2.2 below.

Table 2.2: Domains of Knowledge and supporting questions

Domain	**Examples.** Are you able to :
Common Content Knowledge (CCK)	□ calculate an answer correctly? □ solve mathematical problems correctly? □ understand the mathematics you teach? □ recognise when a student gives a wrong answer? □ recognise when a text book is inaccurate or gives an inaccurate definition? □ use terms and notations correctly?
Specialised Content Knowledge (SCK)	□ present mathematical ideas? □ respond to students' why questions? □ find an example to make a specific mathematical point? □ recognise what is involved in using a particular representation? □ link representations to underlying ideas and to other representations? □ connect a topic being taught to topics from prior or future years? □ explain mathematical goals and purposes to parents? □ appraise and adapt the mathematical content of textbooks? □ modify tasks to be either easier or harder? □ evaluate the plausibility of students' claims? □ give or evaluate mathematical explanations? □ choose and develop useable definitions? □ use mathematical notation and language and critique its use? □ ask productive mathematical questions?

	□ select representations for particular purposes?
Knowledge at the mathematical horizon	□ make connections across the topics in mathematics? □ make connections between the different strands in mathematics? □ articulate how the mathematics you teach fits into the mathematics which comes later?
Knowledge of Content and Students (KCS)	□ anticipate what students are likely to think? □ predict what students will find interesting and motivating when choosing an example? □ anticipate what a student will find difficult or easy when completing a task? □ hear and interpret students' emerging and incomplete ideas? □ recognise and articulate misconceptions students carry about particular mathematics content?
Knowledge of Content and Teaching (KCT)	□ sequence mathematical content? □ select examples to take students deeper into mathematical content? □ select appropriate representations to illustrate the content?
Knowledge of Content and Curriculum (KCC)	□ articulate the strands in the curriculum? □ articulate the proficiencies from the mathematics curriculum? □ articulate a familiarity with the structure of the mathematics curriculum?

Source: adapted from Ball, Thames and Phelps (2008)

2.6 SCIENCE TEACHERS' PCK

Magnusson, Borko, and Krajcik, (1999) opine that teaching science is a demanding task, requiring teachers to understand not only the science content but also how to translate the content and methods of science into analogous instructional practices. They further argue that the defining feature of pedagogical content knowledge is its conceptualisation as the result of a transformation of knowledge from other domains.

Drawing from the work of Grossman (1990) and Tamir (1988), Magnusson *et al*. (1999) conceptualise pedagogical content knowledge for science teaching as consisting of five components: (a) orientations towards science teaching; (b) knowledge and beliefs about the science curriculum; (c) knowledge and beliefs about students' understanding of specific science topics; (d) knowledge and beliefs about assessment in science; and (e) knowledge and beliefs about instructional strategies for teaching science. They propose a science-specific PCK model as shown in Figure 2.4 below:

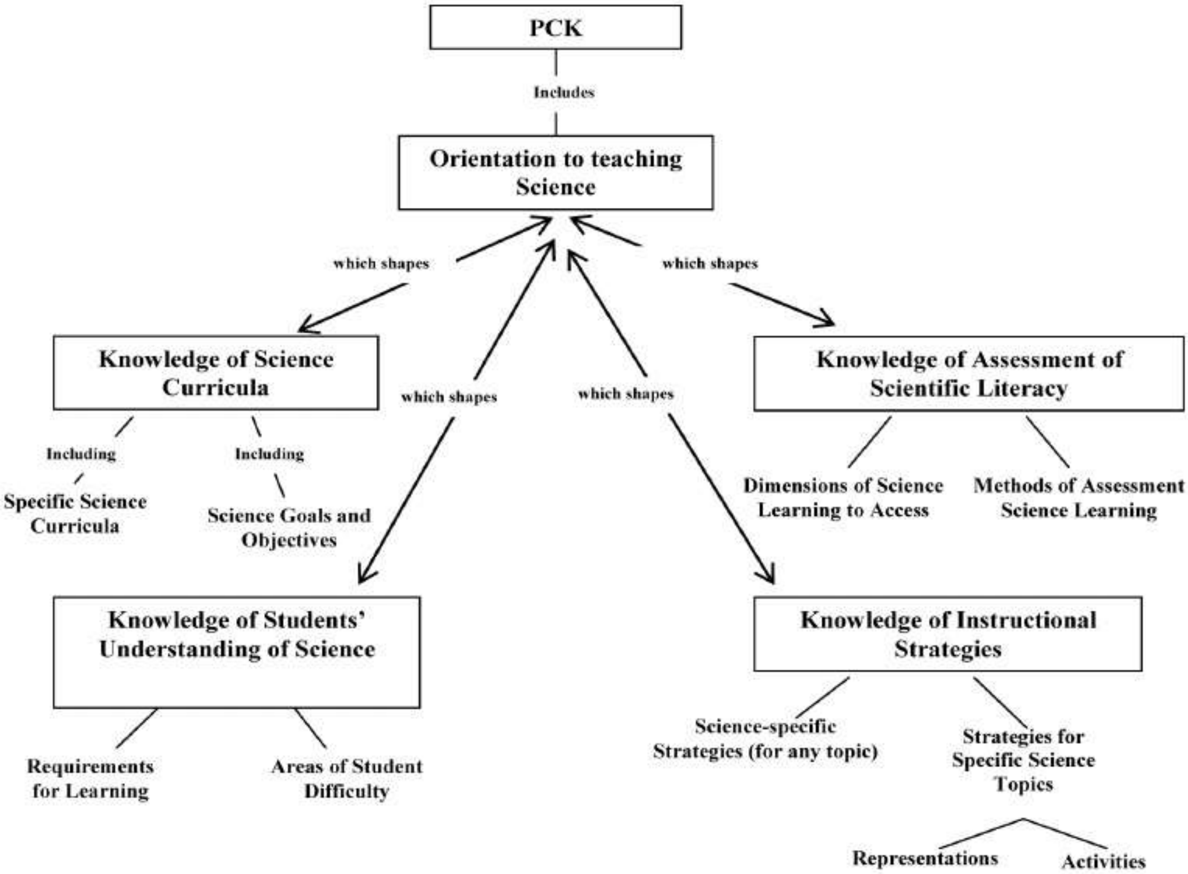

Figure 2.4: PCK model for science teaching. From Magnusson, Borko, and Krakcik, 1999

Magnusson *et al.'s* (1999) model of PCK is useful in providing guidance in that it defines each orientation by providing the goal of teaching science and the characteristics of instruction for that orientation.

Friedrichsen, Van Driel and Abell (2011), after reviewing 24 studies that used the Magnusson *et al*. (1999) model to define PCK, found that the definition of orientations of science teaching was different or simply unclear in many of the studies (Boesdorfer & Lorsbach, 2014). Friedrichsen *et al*. (2011) then proposed that orientations to science teaching should be redefined to include three parts: teachers' beliefs about (1) the goals and purposes of science teaching; (2) the nature of science; and (3) science teaching and learning (Boesdorfer & Lorsbach, 2014). Figure 2.5 below shows the definition of PCK used in Magnusson *et al*. (1999) adapted by Friedrichsen *et al*. (2011).

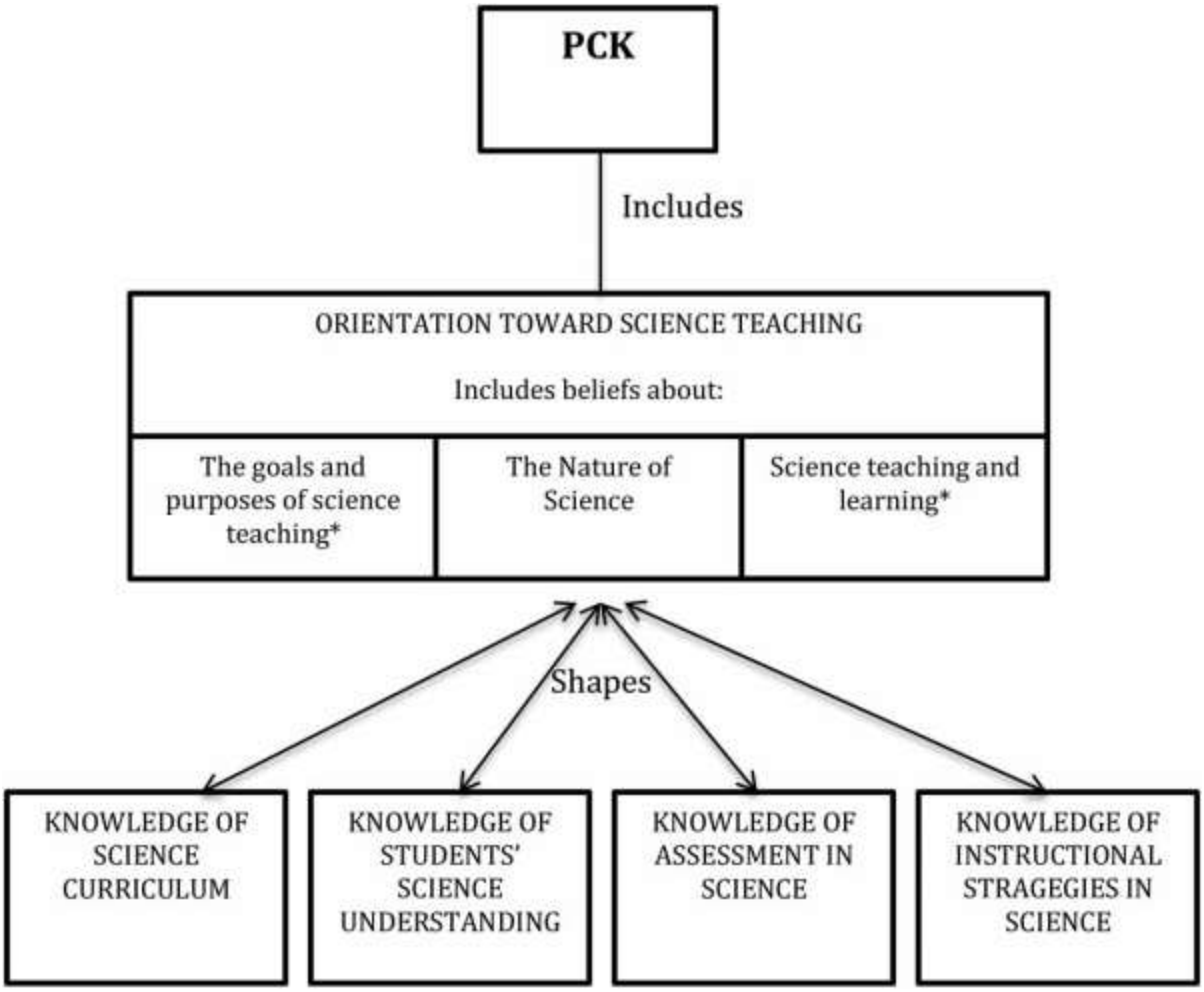

Figure 2.5. Definition of PCK used in Magnusson *et al*. (1999) adapted by Friedrichsen *et al*. (2011)

2.6.1 Representations of science teachers' topic specific PCK

To represent successful science teachers' PCK about a particular science topic, Mulhall, Berry and Loughran (2003) developed two different but complementary formats. These are the CoRe (Content Representation) and the PaP-eRs (Pedagogical and Professional-experience Repertoires). A CoRe provides an overview of teachers' pedagogical content knowledge related to the teaching of a topic in the form of propositions (Mulhall *et al*., 2003); that is, what content is taught and how and why. A PaP-eR is a narrative account that offers insight into the interacting elements of a teacher's thinking about a small piece of this PCK. PaP-eRs are intended to represent the teacher's reasoning; that is, the thinking and actions of a successful science teacher in teaching a specific aspect of science content. Both representations are generalisations of teachers' pedagogical content knowledge about teaching science content to a particular group of students and as such, are potentially valuable contributions to the knowledge base of teaching. This is crucial to South African teachers, considering the diversity of their learners. Most learners in South Africa are taught in mixed ability classes.

This study argues that Pedagogical content knowledge is crucial for the teaching of mathematics and science and that a lack of PCK might be a limiting factor to improved teaching and learning practices. Based on the interconnectedness of the components of PCK, deficiency in one component can have significant outcomes for the enactment of mathematics and science teachers' PCK. For instance, knowledge of assessment strategies provides critical feedback to teachers about the effectiveness of their teaching practices, which allows mathematics and science teachers to adjust and respond to their learners' understanding of what is taught.

Mathematics and science teachers need to be able to transform their knowledge of content into content of instruction. They also need to know which preconceptions or alternative conceptions their learners have for different topics, and which strategies they can use to overcome these alternative conceptions. Mathematics and science teachers should not only be masters of procedure but should also be masters of content and how to teach it.

2.7 THEORETICAL FRAMEWORK

Three theoretical strands that may contribute to teacher knowledge have been identified. These are social realism, practical rationalism and social constructivism.

2.7.1 Social realist framework

The aim of the social realist approach is to see through appearances to the real knowledge and its role in education. This theoretical framework suggests that knowledge is the basis of education as a social field of practice; it is the production, recontextualisation, teaching and learning of knowledge that makes education a distinct field (Van Krieken *et al.,* 2010), particularly in mathematics and science teaching.

Bernstein (1996) provides conceptual tools to distinguish different forms of knowledge. He distinguishes between vertical and horizontal knowledge structures and within the latter, strong and weak grammars. Physics for example, is a knowledge domain with a vertical knowledge structure and a strong grammar. Conversely, education (and so teaching), as a field of knowledge, is structured horizontally, but has a weak grammar. This is so because recognition of what is and is not the language of scholarship and knowledge development in education is contested and far less clear than in physics (Bernstein, 1996).

The horizontal discourse refers to everyday or 'common sense' knowledge, where meaning is largely dependent on the context, such that knowledges may be segmented strongly from one another; for example, learning to tie one's shoes bears little relation to learning how to use a lavatory correctly (Bernstein, 1996).

The vertical discourse refers to educational, formal or official knowledge and takes the form of a coherent, explicit and systematically principled structure where meanings are related to other meanings, rather than to a specific social context.

Bernstein (1996) contends that there are two structures within the vertical discourse: the hierarchical knowledge structures, and the horizontal knowledge structure. The hierarchical knowledge structures, such as physics, develop through integrating past knowledge within more overarching ideas that attempt to explain a greater number of phenomena than previously achieved. The horizontal knowledge structures, such as the humanities and sociology, are those that develop through the addition of a new approach or theory alongside existing approaches and from which it is strongly bounded. This model of different forms of knowledge, according to Krieken *et al*. (2010), proves to be effective in analysing issues concerning the nature of both academic inquiry, and teaching and learning in classrooms.

Bernstein (2000) differentiates between *singular* forms of knowledge and *region*s of knowledge. In addition to the nuanced distinction between disciplines in singulars and fields of practice in regions, are *classification* and *framing* that particularly shed light on the differentiation of knowledge and knowledge boundaries in curricula of professional fields of practice. *Classification* and *framing* vary independently as stronger or weaker, giving educational knowledge codes underlying school practices. They also determine the structure of curriculum (knowledge), pedagogy and evaluation in any education system (Bernstein, 1971). Knowledge can be externally and internally strongly or weakly classified, and externally and internally strongly or weakly framed.

2.7.1.1 Classification

Classification of knowledge refers to the way in which knowledge is defined in different fields and how these fields are distinguished and insulated from one another. The specialisation of different fields of knowledge is maintained by the strength or weakness of the boundaries and the degree of insulation between them. It embodies power relations and is concerned with the strength of the boundaries or the degree of insulation among the categories, agents, actors or discourses. It is also concerned with the organisation of knowledge in the curriculum (Bernstein, 2000).

The strength of classification refers to the relative strength of the boundaries between contexts or categories (such as academic subjects in a curriculum); for example, in a school where subject content is taught in isolation from one another, such as in science and English. Mathematics and science are distinct from other subject areas; there is a strong degree of boundary between them and other subjects; therefore, the classification can be described as strong (C+). Mathematics and science deal with very different content and concepts, use different kinds of language, and investigate the world using different kinds of methods as opposed to subjects, such as history. Strongly classified knowledge means that knowledge learnt within the educational institution is strongly distinguished from knowledge of the everyday world (Wheelahan, 2010). Strong classification also means that areas of knowledge and subject content are well insulated from traditional subjects (Sadovnik, 2001; Bernstein, 1971), such as mathematics and science, which are differentiated from others, such as history. To learn mathematics and science one needs to understand abstract mathematical content, concepts and mathematical language; for example understanding words, such as addition, equation and acceleration. Mathematics and science are interconnected however, since one needs mathematics to solve scientific problems, such as those relating to Newton's Law of Motion. An integrated curriculum in which disciplines are interconnected would demonstrate weaker classification (C-). In weakly classified disciplines, there are blurred boundaries between contents, such as in history and English. These subjects do not have many special terms or language to understand them.

2.7.1.2 Framing

Framing is concerned with the 'how' of knowledge, referring to the locus of control over the selection, pacing, sequencing and evaluation of knowledge and can also be strongly or weakly framed. The strength of framing, on the other hand, refers to the relative strength of control within these contexts or categories (relatively strong framing indicates strong control from above, such as by the teacher in a classroom) (Cause, 2010).

Strongly framed knowledge is knowledge in which students have little or no control over the selection of knowledge in the curriculum and its pacing, sequencing and evaluation, such as in physics. There is visible pedagogic practice; the rules of instructional and regulative discourse are explicit and the transmitter has explicit control over the selection, pacing and criteria. This means that there is a sharp boundary between what may be or may not be transmitted. In contrast, in weakly framed knowledge, students have a much greater control over their own learning process with pedagogic practice likely to be invisible. The acquirer has control that is more apparent and the rules of regulative and instructional discourse are implicit and largely unknown to the acquirer (Bernstein, 1996; Wheelahan, 2005; 2010).

Bernstein (1996) argues that there are two principal codes: namely, a collection code of stronger boundaries and stronger control, and an integrated code where boundaries between disciplines and between educational and everyday knowledge are blurred. With regard to the latter, pupils have more control over the selection, sequencing and pacing of their learning. Each code is associated with different forms of school organisation, curriculum, pedagogy and evaluation and each has its own attributes.

The *classification* and *framing* of knowledge is mediated through distributive rules which define and distribute access to different knowledges; recontextualisation rules, which are the rules that determine what knowledge and skill is to be selected from the field in which it was produced and translated to pedagogic knowledge and practice; and evaluation rules, in which acquirers (students) demonstrate that they can produce the required 'text' called for by the implementation of the pedagogic code. In other words, students implicitly understand the assessment process and how to produce the right outcome (Wheelahan, 2005; 2010). For Bernstein, the power (classification) and the control (framing) relations of any pedagogic practice regulate the acquisition of pedagogic identity. The selection of knowledge(s) performances and practices and their evaluation rules (criteria for recognition and realisation) relay a particular social order and way (mode) of knowing and being, whether tacitly or explicitly.

Feimann-Nemser (2001) postulates that the quality of a nation's schools depends on the quality of its teachers; that is, what teachers know and are able to do is one of the most important factors influencing student learning. The training programmes with which student teachers are provided in their preparation as teachers, in turn, enhance this quality.

2.7.2 Practical rationalist framework

Shulman's (1986) work attempts to answer the question: How does the successful college student transform his or her expertise into the subject matter form that high school students can comprehend? He argues that in order for a teacher trainee to teach, he/she needs to transform his/her understanding or comprehension of the subject matter. Shulman's conceptual work is based on the now well-known distinction between subject content knowledge, curricular knowledge, and the category of pedagogic content (Banks & Moon, 2005).

2.7.3 Social constructivist framework

The social constructivist strand allows for the possibility that different contexts set different epistemic standards and contextualists maintain that the standards, in fact, do vary from context to context. Social constructivism is based on assumptions about reality, knowledge and learning (Kim, 2001):

- Reality − social constructivists believe that reality is constructed through human activity and that members of a society together invent the properties of the world (Kukla, 2000). Truth and reality, according to Adams (2006), will be accorded only to those constructions on which most people of a social group agree.
- Knowledge − to social constructivists, knowledge is also a human product and is socially and culturally constructed. Individuals create meaning through their interactions with one another and with the environment in which they live.
- Learning − social constructivists view learning as a social process. It does not take place only within an individual, nor is it a passive development of behaviours that are shaped by external forces. Meaningful learning occurs when individuals are engaged in social activities.

The above discussion indicates that the three strands of the theoretical framework, therefore, are crucial for course designers, trainers and trainees. The important implication of these frameworks is that they are all concerned with how trainees grapple with knowledge of the curriculum and the skills required to teach mathematics and science.

Both social and critical realists acknowledge epistemological peculiarities of the theoretical aspects of knowledge (teacher knowledge) and the everyday (knowledge derived from the context), which rationalism and social constructivism, discussed above, have not conceded, as well as their respective significance to the discussions of teacher knowledge(s). This distinction resonates with Bernstein’s (2000) argument not only on the importance of the structures of knowledge, but more significantly, on the social practices used to produce knowledge implied in the discursive theory

(Wheelahan, 2010). In this sense, social relativism recognises the value of everyday knowledge (knowledge that emerges from contexts) on the one hand, and theoretical knowledge on the other, when analysing teacher knowledges and learnings.

Two issues on which the social realist position agrees with social constructivism are first, a rejection of the conservative view, that knowledge (and teacher knowledges and learnings) are timeless and independent of the context. Secondly, it accepts the constructivist position that knowledge is socially produced by communities of knowledge producers and that these communities are characterised by struggles around power and competing interests, as Young (2008) maintains and is corroborated by Wheelahan (2010). Consequently, the practice of creating new knowledge includes using pre-existing knowledge, which is the outcome of past agents' practice used in exploring the world and in the process, transforming that knowledge (Wheelahan, 2010).

Drawing from social constructivism, Van Dijk (2009) asserts that knowledge has inherent cultural and social dimensions of particular contexts where knowledge and experiences of what constitute it, is shared by for example, a community of practice. Notable features of this aspect within the context model are "social situations, social actors, social beliefs, social interactions and social groups and of language, discourse and communication" (Van Dijk, 2009: 31).

According to the sociocognitive perspective and its social psychological dimension, knowledge is constructed socially and, therefore, should be understood within particular contexts and from an individual's point of view (Van Dijk, 2009).

Social constructivists, according to Creswell (2009), assume that individuals seek understanding of the world in which they live and work; that individuals develop subjective meanings of their experiences-meanings directed toward certain objects or things. The evident autonomy of learners in knowledge construction makes it difficult, if not impossible, to predict how learners will learn or how to plan instructional material. The translation of constructivism into practice constitutes an important challenge for instructional designers (Karagiorgi & Symeou, 2005).

This study, therefore, is underpinned by social realism, the approach that draws on the original work of Bernstein (2000), expanded on and modified by Young (2003;

2008), and Wheelahan (2007; 2010) both of whom introduced critical realist ontology on Bernstein's original work. Secondly, pedagogical content knowledge (PCK) draws on practical rationality, ontology and epistemology. Constructivists offer the learner almost unlimited discretion to select what is studied from among resources, and how it is studied. This creates problems of accountability that students will learn. Students might construct wrong knowledge, skills and abilities, since some students simply want to be told what they need to learn. Social constructivism, therefore, is not appropriate for this study.

The above discussion on social constructivism suggests criticism of several sites of knowledge production, construction, dissemination, and types of teacher knowledges and learnings. Thus, there is no one perspective of what constitutes teacher knowledges and learnings; that there are several players in the construction thereof and in how these knowledges and learnings unfold in practice. The discussed frameworks of Bernstein (2000) and Shulman (1986) are not too disparate to see them as disconnected approaches, especially with regard to curriculum and delivery. Bernstein's framework has the advantage of offering a more rigorous approach to course structuring, while Shulman provides the finer details of how teacher trainees transform curriculum knowledge into ways of teaching learners.

2.8 TEACHER EDUCATION POLICY IN SOUTH AFRICA

Education and training during apartheid, according to Mji and Makgato (2006), was characterised by the underdevelopment of human potential generally and that of Blacks in particular. The teaching and learning of mathematics, science and technology were the hardest hit. Lecturers in the post-apartheid South Africa were asked to re-conceptualise and re-design their pre-service teacher education programmes to respond to new national policies in teacher education. These curriculum-related reforms were intended to democratise education and eliminate inequalities in the post-apartheid education system.

Adler and Davis (2006) argue that in South Africa, the demands of transformation entail working simultaneously with redress (apartheid education was constituted by racial and economic inequality, with Black teachers, in the main, receiving poor opportunities to learn mathematics and teaching) and repair the damage done by apartheid education. They further observe the existence of ideological considerations of Blacks learning mathematics, such as the one expressed by apartheid's own architect (Verwoerd) who deemed training in mathematics for Blacks irrelevant. Verwoerd claimed in one of his infamous speeches that there is no use in teaching the Bantu child mathematics when it cannot use it in practice. This statement undermined the capabilities of Black people in learning mathematics and showed that Verwoerd's regime did not realise the importance of equal educational opportunities for all South Africans.

The process of establishing a regulatory framework for teacher education programmes began in 1995 (Robinson, 2003). After its publication for discussion in 1998, it was gazetted as Norms and Standards for Educators in 2000, supplemented later by Criteria for the Recognition and Evaluation of Qualification for Employment in Education. These policies created, for the first time, frameworks and a procedure for the approval of teacher education programmes. Knowledge, skills and values are outlined in this policy as the hallmarks of a professional and competent educator (Robinson, 2003). According to this policy document, teachers are expected to be able to develop the knowledge of the specialism (discipline, subject, learning area, phase of study) that embraces: content knowledge (knowing that); concepts and theories (knowing why); procedural knowledge (knowing how); and strategic knowledge (knowledge about why, when, where and who).

An effective pedagogy for teacher education should establish links between the knowledge about learning and teaching and the practical knowledge of (doing) learning and teaching (Ure, 2010). Teacher candidates need to learn to develop an integrated theoretical framework about teaching and learning.

The Norms and Standards for Educators policy (NDoE, 2000) signalled the state's intention to adopt a new non-technical approach to teacher education (Schafer & Wilmot, 2012). The policy adopts a competency-based approach and sets out the knowledge, skills, and values that teachers must acquire and the roles they must perform. These roles and competencies must be integrated in the learning programme and should inform the exit level outcomes of a qualification and their associated assessment criteria. The roles that teachers must perform are learning mediator; interpreter and designer of learning programmes and materials; leader, administrator and manager; scholar, researcher and lifelong learner; community citizenship and pastoral role; assessor; and learning area/subject/discipline/phase specialist. This policy led to the adoption of an outcomes-based (OBE) orientation to education and training. OBE was adopted because it was seen as providing access to education and training for many Black South Africans whose schooling had been interrupted during the boycotts of the 1970s and 1980s (Schafer & Wilmot, 2012). OBE was also seen as providing the flexibility needed for enabling a system to transform. Together with learner-centred education and integration, OBE was a key design feature of the post-apartheid national curriculum and it shaped the design of teacher education policy (NDoE, 2000). The Norms and Standards for Educators policy was used as guiding framework for initial and in-service teacher education programmes offered by university education faculties.

The Minimum Requirements for Teacher Education Qualifications (DoE, 2011) is a regulatory framework for teacher education programmes that defines agreed-upon standards at different levels. It selects suitable qualification types from the Higher Education Qualifications Frameworks (HEQF) for different purposes in teacher education; selects the National Qualifications Framework (NQF) level for each qualification type; defines the designator for all degrees; identifies the list of qualifiers for all qualifications and thus, identifies purpose; describes the knowledge mix appropriate for teacher qualifications; sets minimum and maximum credit values for learning programmes leading to qualifications in terms of the knowledge mix and different levels; and defines a minimum set of agreed-upon competencies for initial teacher education (ITE) programmes. It pays close attention to the various types of knowledge that underpin teachers' practice, while encapsulating all of these in the notion of integrated and applied knowledge. It explicitly places knowledge, reflection, connection, synthesis and research in the foreground, thereby giving renewed emphasis to what is to be learnt and how it is to be learnt. In this policy, competent learning is seen as representing the acquisition, integration and application of different types of knowledge, and each type of knowledge, in turn, implies the mastering of specific related skills.

This policy framework signals a shift from applied competence and roles to a framework encapsulating notions of applied and integrated knowledge (NDHET, 2011). Integrated and applied knowledge should be understood as being both the condition for and the effect of scrutinising, fusing together and expressing different types of knowing in the moment of practice. By explicitly placing knowledge, reflection, connection, synthesis and research in the foreground, it gives renewed emphasis to what is to be learnt and how it is to be learnt.

In this policy, the following are identified as the learning types that are associated with the acquisition, integration and application of knowledge for teaching purposes: namely, disciplinary learning; pedagogical learning; practical learning; and situational learning.

Disciplinary learning refers to disciplinary or subject matter knowledge that can be presented in two components within a teaching curriculum, namely, the study of education and its foundations, and the study of specific specialised subject matter that is relevant to the academic disciplines underpinning teaching subjects or specialisations. The recognition of disciplinary learning leans more towards practical rationality, rather than social constructivism and the social and critical realist strand. Thus, the disciplinary learning in the MRTEQ policy centralises subject content and the unique pedagogy that goes with this content as the foundation of teacher learning. This type of knowledge in the MRTEQ resonates with the tenets of the practical rationality in learning (cf. Shulman, 1987; Ellett, 2012).

In this study pedagogical learning incorporates general pedagogical knowledge (which includes knowledge of learners, learning, curriculum and general instructional and assessment strategies) and specialised pedagogical content knowledge (which includes knowing how to represent concepts, methods and rules of a discipline in order to create appropriate learning opportunities for diverse learners, as well as how to evaluate their progress). Mathematics and science teachers need to know how to deliver instruction effectively. They need to know what to teach after what, which is in line with Bernstein's (1971) sequencing.

Practical learning involves learning in and from practice. Learning from practice includes the study of practice, using discursive resources to analyse different practices across a variety of contexts. Learning in practice involves teaching in authentic and simulated classroom environments. Work-integrated-learning (WIL) takes place in the workplace and can include aspects of learning from practice, as well as learning in practice. One critical aspect of WIL is the integration of micro lessons in the teacher education programme to prepare student teachers for the classroom environment. During these micro-lesson presentations, student teachers learn individual skills until they master them. Practical learning is seen as an important condition for the development of tacit knowledge, which is an essential component of learning to teach.

Fundamental learning, which, in the South African context, refers to learning to converse competently in a second official language; the ability to use information and communication technologies (ICTs) competently; and the acquisition of academic literacies, which lay the foundation for effective learning in higher education contexts.

Situational learning refers to knowledge of the varied learning situations, contexts and environments of education (classrooms, schools, communities, districts, regions, countries and globally), as well as to prevailing policy, political and organisational contexts (NDHET, 2011). Learning in practice, experiential learning and situated learning theories all draw on the constructivist strand and reflect constructivist oriented learning.

It is further stipulated in the Minimum Requirements for Teacher Education Qualifications (NDHET, 2011) policy that for one to specialise in teaching mathematics at FET level, the acceptable basis is to have done numeracy analysis, statistics, dynamics and mechanics as part of applied mathematics. Specialising in physical sciences teaching competence in both physics and chemistry requires that at least one is taken to NQF level 6 and the other to NQF level 7; for example, Physics II and Chemistry I. To specialise in life sciences teaching, a combination of any two of the following is necessary: biochemistry, microbiology, physiology, biology and zoology, with one taken at NQF level 7 at least, provided that an NQF level 6 module in biology or botany and zoology is also included (NDHET, 2011).

2.9 CONCLUSION

This chapter reviewed the literature on teacher knowledge of mathematics and science. First, the knowledge bases of mathematics and science teaching were explored. This was done by discussing the different types of knowledge. The sources of knowledge relevant to teaching were discussed, followed by an analysis of how different authors categorise teacher knowledge and teacher knowledge of mathematics and science. Secondly, the theoretical frameworks that are relevant to teacher education and to this study in particular, were examined. These are social realism, with some aspects of critical realism found to be relevant; practical rationality; and social constructivism. Lastly, the teacher education policy documents in South Africa, such as the Norms and Standards of Educators and the Minimum Requirements for Teacher Education Qualifications were interrogated. In the next chapter, a description of the research design is provided.

CHAPTER THREE
RESEARCH DESIGN

3.1 INTRODUCTION

This chapter describes the research design of the investigation. It includes an analysis of the selected paradigm, perspectives, methods and approaches used in this study. It also discusses the research questions, propositions, sampling strategies and procedures for dealing with the data.

3.2 RESEARCH PARADIGM, METHODS AND APPROACHES

3.2.1 Research paradigm

This study is underpinned by an interpretive paradigm. Kuhn (1962, 1970) argues that scientific research and thought are defined by paradigms, or conceptual world views that consist of formal theories, classical experiments and trusted methods. In Kuhn's sense of the term, a paradigm is an implicit, unvoiced and pervasive commitment by a community of scholars to a conceptual framework (Shulman, 1986). A paradigm, according to Denzin and Lincoln (1994), may be viewed as a set of basic beliefs (or metaphysics) that deal with ultimate or first principles. It represents a worldview that defines, for its holder, the nature of the world, the individual's place in it and a range of possible relationships to that world and its parts, as for example, in cosmologies and theologies. Denzin and Lincoln (1994) further contend that paradigms in the human and social sciences therefore, help us understand phenomena; they advance assumptions about the social world, of how science should be conducted and what constitutes legitimate problems, solutions and criteria of proof.

One of the activities, which define the research process, is the articulation of the researcher's individual worldview or basic belief system (in relation to the research domain). However, underpinning this activity is the nature of the biographically situated researcher [who] speaks from within a distinct interpretive community (Denzin & Lincoln, 1994; Simmons, 1995).

3.2.2 Assumptions underlying interpretive paradigm

Interpretive research assumes that reality is socially constructed; that is, there is no single, observable reality. Rather, there are multiple realities, or interpretations of a single event. Researchers do not find knowledge, they construct it (Creswell, 2007; Merriam, 2009). The interpretive paradigm developed as a critique of positivism in the social sciences. The ontological, epistemological and methodological dimensions of this paradigm are discussed below.

3.2.2.1 The nature of reality

The proponents of interpretivism, in answering the question based on the ontological dimension, that is, what the form and nature of reality is, argue that realities are apprehendable and mind-dependent. Mind dependence here does not mean that the mind creates what people say and do, but rather, how they interpret their movements and utterances (Denzin & Lincoln, 2011). In other words, social reality is the interpretation; the proponents of interpretivism also contend that there are multiple realities, with the mind playing a central role by determining categories and shaping or constructing realities. The researcher concurs that there is no separation of mind and objective since the two are linked together inextricably – the knower and the process of knowing cannot be separated from what is known and the facts cannot be separated from values (Denzin & Lincoln, 2011).

3.2.2.2 Inquirer-subject relationship

The epistemological question seeks to establish the nature of the relationship between the knower or would-be knower and what can be known. In other words, it is the relationship of the researcher to that being researched. In answering this question, the interpretivist argues that the investigator and the object of investigation are assumed to be linked interactively, so that the findings are literally created as the investigation proceeds (Denzin & Lincoln, 1994).

3.2.2.3 *Inquirer's interaction with respondents*

The methodological question seeks to examine how the inquirer (would-be knower) would go about finding out whatever he or she believes can be found out. On this issue, the interpretivist's argument would be that the variable and personal nature of social constructions suggests that individual constructions can be elicited and refined only through interaction between and among investigator(s) and respondent(s) (Denzin & Lincoln, 1994). Following this disruption, the researcher interacted with the respondents through one-on-one interviews.

The interpretive paradigm was considered most suited to this study, since it recognised participants' views on the types of knowledge required in teaching mathematics and science and the impact on the research of their own background and experiences (Creswell, 2003). It was considered relevant to this study because it assumes that reality cannot be separate from our knowledge of it; that is, there is no separation of subject and object; that the researcher's values are inherent in all phases of the research process and that truth, therefore, is negotiated through dialogue. The researcher engaged in dialogue with lecturers (sometimes referred to as teacher educators) and teachers through interviews. Fostering dialogue between researchers and respondents was critical. It was through this dialectical process that a more informed and sophisticated understanding of the social world was created (Denzin & Lincoln, 1994). Findings that emerged from these dialogues helped members of this community in negotiating conflicting interpretations (Denzin & Lincoln, 1994).

3.3 METHODS AND APPROACHES

The methods and approaches used in this study were those associated with the interpretive paradigm. Therefore, the research relied upon the participants' views regarding mathematics and science education (Creswell, 2003). Interviews with lecturers from different universities offering mathematics and science education provided views on the type of knowledge acquired at universities and how this knowledge is developed. Interviews with mathematics and science teachers on the other hand, provided views on the types of teacher knowledge acquired at universities and how it is translated into practice.

3.4 RESEARCH QUESTIONS

The main research question for this study was:

What is the teacher knowledge of mathematics and science in BEd programmes; how is this knowledge integrated into the curriculum, and how is theoretical knowledge acquired at universities, navigated to practice to enhance effective teaching and learning?

The main research question was broken down into the following subsidiary questions:

- What are the different kinds of teacher knowledges; how do they relate, and how are they acquired and developed?
- How do employers' prescriptions shape the curriculum content of mathematics and science and their pedagogy?
- To what extent does theoretical knowledge in the curriculum of BEd (Bachelor of Education) provided in schools of teacher education, adequately prepare students to teach mathematics and science effectively?
- How does the training of teachers to teach mathematics and science in universities of technology (UoTs) differ from similar training in conventional universities?

3.5 PROPOSITIONS

The following propositions guided the study:

- An adequate understanding of teacher knowledges is critical to producing teachers who can teach mathematics and science.
- The notion of framing (locus of control over selection, pacing, sequencing and evaluation of knowledge) might assist in closing the gap between theory and practice of mathematics and science.
- The current curriculum of BEd programmes provided in schools of teacher education has not sufficiently integrated theoretical knowledge that teachers need to teach mathematics and science.

- Universities of technology are better placed to train teachers to teach mathematics and science.

Propositions were considered most suitable for this study mainly because of the qualitative nature of this study. The terms, proposition and hypothesis both refer to the formulation of a possible answer to a specific scientific question. In particular, a proposition deals with the connection between existing concepts. The main difference between the two is that a hypothesis must be testable, measurable and falsifiable, while a proposition deals with pure concepts for which no laboratory test is currently available. Hypotheses are used in quantitative research to measure what impact a specific change will have on existing norms and assumptions; that is, they are used in causal studies (Charles, 2014).

3.6 SAMPLING

A purposive sampling was used for this study (Denzin & Lincoln, 2005; Patton, 2002a, 2002b; Creswell, 2007). Purposive sampling is a non-probability sampling where decisions concerning individuals to be included in the sample are taken by the researcher, based upon a variety of criteria, which may include specialist knowledge of the research issue or capacity, and a willingness to participate in the research. Individual participants are most likely to contribute appropriate data, both in terms of relevance and depth. The type of data on teacher knowledge of mathematics and science that the researcher wanted could best be provided by those individuals who offer instruction to teacher trainees and the recipients of this knowledge; that is, teacher practitioners who are products of such universities.

Following the chosen paradigm, this study focused on faculties or schools of education, which offer BEd (FET) programmes for the preparation of teachers to teach mathematics and science. Five faculties or schools of education from five universities nationally were selected to participate in the research study. Of these five faculties, one faculty or school of education was chosen from formerly English-speaking universities, one from formerly Afrikaans-speaking universities and three from former technikons, now transformed into universities of technology.

The first category comprised seven lecturers. Of each university faculty or school of teacher education the intention was initially to interview two lecturers, one offering instruction in mathematics and the other in science, but one lecturer was accessed per institution, even though in some cases two were available. These lecturers were requested to provide their personal experiences in the preparation of mathematics and science teachers.

The second category comprised six experienced mathematics and/or science teachers in the schools who had graduated with a BEd (FET) degree. The criterion for inclusion was that they had gone through the process of teacher training to teach mathematics and science and as a result, were assumed to be in a better position to provide informed comments on how they were taught and how they acquired the requisite knowledge to be mathematics and science teachers.

3.7 INSTRUMENTATION

In accordance with the interpretive paradigm interviews, document analysis and a literature review were used as instruments to collect data. These instruments were chosen because of their suitability to collect the qualitative type of data required for this study.

3.7.1 Interviews

Interviewing is a flexible way of gathering qualitative data that are detailed and personal. Law, Steward, Letts, Pollock, Basch, and Westmerland, (1998) observe that qualitative interviews place an emphasis on listening and on following the direction of the participant. Interviews provided the researcher with an opportunity to interact with the research participants on a personal level. Interviews were considered suitable for collecting data and using them as a research instrument. They enabled the researcher to gather highly personalised data and provided opportunities for probing, with a good return rate being ensured. Interviews can range in structure from those in which questions and the order in which they are asked, are predetermined to unstructured interviews in which nothing is set ahead of time (Gray, 2004). In this study, a research question schedule was formulated for both lecturers and teachers. These included questions and the order in which these questions were asked.

3.7.2 Types of interviews

Interviewing includes a wide variety of forms and a multiplicity of uses. The most common form of interviewing involves an individual, face-to-face verbal interchange, but interviewing can also take the form of face-to-face group interchange, mailed or self-administered questionnaires and telephone surveys (Flick, 1998; Taylor & Bogdam, 1998; Reis & Judd, 2000; Silverman, 2001; Denzin & Lincoln, 2003; Creswell, 2007, 2009). They can be structured, semi-structured, or unstructured. Semi-structured and focus group interviews were conducted for this study with both lecturers and teachers.

In structured interviews, the respondent is asked a series of pre-established questions, with pre-set response categories (Denzin & Lincoln, 2003; Gray, 2004; Punch, 2005; Merriam, 2009). This type of interview was not used in this study, since it provides little room for variation in response, though open-ended questions may sometimes be used. This is the type of interview where all respondents receive the same questions in the same order, delivered in a standardised manner. Denzin and Lincoln (2003) further highlight that in this type of interview, the interviewer attempts to play a neutral role.

Unstructured interviews provide a greater breadth of data than those of the other types (Denzin & Lincoln, 2003). The traditional type of unstructured interview is the non-standardised, open-ended, in-depth interview. It is used as a way of understanding the complex behaviour of people without imposing any *a priori* categorisation that might limit the field of inquiry (Punch, 2005).

The semi-structured interview is a middle ground between the structured and the unstructured interview (Merriam, 2009). In this type of interview, either all of the questions are more flexibly worded or the interview is a mix of more or less structured questions. Usually, specific information is desired from all the respondents, in which case there is a more structured section to the interview, but the largest part of the interview is guided by a list of questions or issues to be explored (Merriam, 2009).

In this study, individual (person-to-person), semi-structured interviews proposed by *inter alia* Miles and Huberman (1994), Denzin and Lincoln (1994), and Patton (2002) were conducted using a prepared schedule of questions. The interviews were recorded first and transcribed later. This practice ensured that everything said was preserved for analysis. The verbatim transcription of recorded interviews provided the best database for analysis. Throughout the data collection process, the researcher suspended any preconceived notions or personal experiences that may have unduly influenced what the researcher heard the participants expressing; this may be referred to as bracketing or *epoche* (Leedy & Ormrod, 2010).

3.8 DOCUMENT ANALYSIS

Documents, which sometimes are referred to as artefacts, are useful in understanding a situation and in setting a context (Gray, 1998). The Curriculum and Assessment Policy Statements (CAPS) for both mathematics and physical sciences, the Norms and Standards for Educators (NDHET, 2000) and the Minimum Requirements for Teacher Education Qualifications (NDHET, 2011) documents were analysed for this study. Document analysis as a data collection technique is accurate; in other words, it provides a clear, tangible record. Gray (1998) acknowledges that documents, at least in educational situations, are seldom created for the purpose of misleading future researchers. Therefore, the researcher received unbiased information.

Documents can be important in triangulation, where an intersecting set of different methods and data types is used in a single project. The range of documents, which might be used by social scientists, according to Punch (2005), includes diaries, letters, essays, personal notes, biographies and autobiographies, institutional memoranda and reports and government pronouncements and proceedings. The CAPS is not a new curriculum, but an amendment to the National Curriculum Statement Grades R-12 Subject Statements. It is an adjustment to what is taught (curriculum) and not how it is taught (teaching methods). The Norms and Standards for Educators policy described the roles, their associated set of applied competencies (norms) and qualifications (standards) for the development of educators. It also established key strategic objectives for the development of learning programmes, qualifications and standards for educators. The Minimum Requirements for Teacher Education Qualifications (2011) policy document was seen as the pronouncement of the government of South Africa. It provided the researcher with insight into the expected outcomes of teacher preparation at universities. Reviewing the literature on the knowledge bases of mathematics and science, helped in establishing the background and context of teacher knowledge in mathematics and science in South Africa. This was done by discussing types of knowledge, sources of knowledge, teacher knowledge, and lastly, teacher knowledge of mathematics and science.

3.9 DATA REDUCTION AND ANALYSIS

The objective of data reduction is to reduce data without a significant loss of information. Data should not be stripped from their context. Data analysis is the process of making sense out of the data (Merriam, 2009). In this study, data were analysed through consolidating, reducing and interpreting what people have said and what the researcher has seen and read. This is, according to Merriam (2009), the process of making meaning. It involved moving back and forth between concrete bits of data and abstract concepts, between inductive and deductive reasoning, and between description and interpretation. In this study, data reduction and analysis were carried out within the analytical framework proposed by Miles and Huberman (1994). This analysis was directed at tracing out lawful and stable relationships among social phenomena, based on regularities and sequences that link these phenomena. Miles and Huberman (1994) label their approach transcendental realism. Their analysis has three main components, namely: data reduction; data display and drawing; and verifying conclusions.

3.9.1 Data reduction

According to Miles and Huberman (1994), data reduction occurs continually throughout the analysis. Data in this study were reduced through editing, segmenting and summarising. The research questions were used as predetermined themes. Information obtained from the transcripts was then segmented accordingly. The transcripts of the interviews of lecturers of a specific subject at university were grouped together. Similarly, transcripts from interviews with teachers were also grouped together. Text information relating to each research question was then identified.

3.9.2 Data display

This is the second and inevitable part of analysis. It is defined as an organised, compressed assembly of information. Miles and Huberman (1994) suggest the following ways of displaying data: graphs; charts; networks; diagrams of different types, such as Venn diagrams; and causal models. These ways of displaying data were not used in this study however, because of the nature of the study. Instead, data were organised into themes emanating from both teachers' and lecturers' responses (see appendices 1 – 12).

3.9.3 Drawing and verifying conclusions

Conclusion drawing and verification involves the researcher in interpretation, which is drawing meaning from displayed data (Miles & Huberman, 1994). Reducing and displaying data assisted in drawing conclusions for this study. Tactics used in this study ranged from the typical and wide use of comparison/contrast; noting of patterns with regard to responses to research questions; looking for negative cases; following up surprises; and checking results with respondents.

3.9.4 Thematic analysis

A step-by-step process of interview data analysis that was used in this study was drawn from the works of Merriam (2009), and King and Horrocks (2010). They identify steps that need to be followed in analysing interview data. King and Horrocks (2010) break down the process into a series of stages (and steps within these). The following stages were identified for this study, namely: stage one is the descriptive coding; stage two is the interpretive coding; and stage three is the overarching themes.

3.9.4.1 Stage one: descriptive coding

The goal of this stage was to identify those parts of the transcript data that were likely to be helpful in addressing the research question. The emphasis was on trying to describe what was of interest in the participants' accounts, rather than seeking to interpret its meaning. The first step was to read the first transcript to be analysed at least once without attempting to code it. The second step was to highlight anything in the transcript that might help the researcher to understand the participant's views, experiences and perceptions as they related to the topic under investigation. Brief comments, notes, observations and queries were jotted down in the margins. The final step in this stage was to use the preliminary comments to define descriptive codes. Assigning codes to pieces of data helped identify those that belonged to the predetermined categories in the form of research questions. The process was repeated for each transcript, thus refining descriptive codes further.

3.9.4.2 Stage two: interpretive coding

At this stage, the codes that went beyond describing relevant features of the participants' accounts were described and the focus was more on the interpretation of their meaning. This was done by grouping together descriptive codes that seemed to share some common meaning and creating an interpretive code that captured it.

3.9.4.3 Stage three: defining overarching themes

At this stage of coding, a number of overarching themes that characterised key concepts in the analysis were identified. These were built upon the interpretative themes, but are at a higher level of abstraction than they are. At this stage, the researcher drew directly on the theoretical ideas that guided the study and were supported by the analysis.

3.10 DEALING WITH DATA

The trustworthiness of a research study is important to evaluating its worth (Lincoln & Guba, 1985). To ensure trustworthiness in this study, the following criteria were established: credibility (confidence in the truth of the findings); transferability (showing that the findings have applicability in other contexts); dependability (showing that the findings are consistent and could be repeated); and confirmability (a degree of neutrality or the extent to which the findings of a study are shaped by the respondents and not researcher bias, motivation or interest) (Lincoln & Guba, 1985).

3.10.1 Credibility

Credibility refers to the "adequate representation of the constructions of the social world under study" (Bradley, 1993: 436). The following activities recommended by Lincoln and Guba (1985) helped improve the credibility of the research results in this study: prolonged engagement in the field; persistent observation; triangulation; peer debriefing; negative case analysis; referential adequacy; and member checks.

3.10.1.1 Prolonged engagement

The researcher spent a day at each school and a day at each university. The time was considered adequate to talk to both teachers and lecturers to learn how mathematics and science was taught. This helped the researcher to become oriented to the situation so that the contexts could: be appreciated and understood; be able to detect and account for distortions that might have been in the data; be able to rise above his own preconceptions; and to build trust.

3.10.1.2 Persistent observation

The characteristics and elements of mathematics and science education that are most relevant to the problem were identified and a detailed focus was placed on them. Persistent observation, therefore, provided depth (Lincoln & Guba, 1985).

3.10.1.3 Triangulation

This involved using multiple data sources in this investigation to produce understanding and to ensure that the account was rich, robust, comprehensive and well developed. Four basic types of triangulation as identified by Denzin (1970; 1978) and Patton (1999) were used to enhance the credibility and trustworthiness of the results of this study. They are: data triangulation; investigator triangulation; theory triangulation; and methodological triangulation.

Data triangulation depicts the use of multiple data sources in the same study for validation purposes. According to Denzin (1978), there are three types of data triangulation, namely: time; space; and person. These types of data triangulation come as the result of the idea that the robustness of data can vary, based on the time that data were collected; the people involved in the data collection process; and the setting from which the data were collected. A variety of data sources, such as teachers of mathematics and science, lecturers of mathematics and science education and policy documents were used in this study.

Investigator triangulation can be defined as the use of more than two researchers in any of the research stages in the same study. It involves the use of multiple observers, interviewers, or data analysts in the same study for confirmation purposes (Denzin cited in Thurmond, 2001). However, in the case of this research, one researcher was involved in all the stages of the research.

Theory triangulation is defined as the use of multiple theories in the same study for the purpose of supporting or refuting findings, since different theories help researchers to see problems at hand, using multiple lenses (Denzin cited in Thurmond, 2001). Both related and/or competing theories can be used in formulating hypotheses for the purpose of providing a broader and deeper understanding of the research problem at hand (Banik, 1993). Multiple perspectives from realism (social and critical), rationality and constructivism were considered in this study.

Methodological triangulation is defined as the use of more than two methods in studying the same phenomenon under investigation (Mitchell, 1986). However, only the qualitative research method was used in this study.

3.10.1.4 Peer debriefing

This process involved exposing the researcher to a disinterested peer in a manner paralleling an analytical session for the purpose of exploring aspects of mathematics and science teaching that might otherwise remain only implicit within the researcher's mind (Lincoln & Guba, 1985). An example of such aspects was the language of teaching mathematics and science. The researcher expected teachers to use English in their teaching, since English is the official language of teaching and learning and questions in examination papers are asked in English. This was not the case; rather, teachers of mathematics and science were more inclined towards teaching in indigenous languages.

3.10.1.5 Negative or deviant case analysis

Elements of the data that did not support or appear to contradict patterns or explanations that emerged from data analysis, such as how teachers deal with the lack of computational skills of learners were discussed. Another element that did not appear to support or contradict patterns concerned measures that were used to ascertain maximum class attendance, such as where students were made to sign logbooks and attendance registers.

3.10.1.6 Member checks

Data, analytic categories, interpretations, and conclusions were tested with members of those groups from whom the data were originally obtained. These included the researcher's colleagues who participated in the study. This was done informally during the normal course of observation or conversation. For instance, the researcher established what informants knew about different types of knowledge.

3.10.2 Transferability

This refers to the degree to which the findings of a study can transfer beyond the project (Lincoln & Guba, 1985; Bradley, 1993). One technique that was used to establish transferability is 'thick description'. This refers to the detailed account of field experiences in which the researcher made explicit the patterns of cultural and social relationships and put them in context (Holloway, 1997).

Teacher knowledge of mathematics and science was described with sufficient detail to help the researcher to evaluate the extent to which the conclusions drawn were transferable to other times, settings, situations and people.

3.10.3 Dependability

Dependability is an assessment of the quality of the integrated processes of data collection, data analysis, and theory generation (Lincoln & Guba, 1985; Creswell, 1998; Miles & Huberman, 1994). One technique to establish dependability is through external audits. External audits provide an opportunity for an outsider to challenge the process and findings of this research study, as discussed by Lincoln and Guba (1985) and Bradley (1993). In this study, the external audit involved having a researcher not involved in the process examine both the process and product of the research study. The purpose was to evaluate the accuracy and evaluate whether or not the findings, interpretations, and conclusions were supported by the data.

3.10.4 Confirmability

Confirmability is a measure of how well the inquiry's findings are supported by the data (Lincoln & Guba, 1985). The techniques used in this study for establishing confirmability were: confirmability audit; audit trail; triangulation; and reflexivity (an attitude of attending systematically to the context of knowledge construction, especially to the effect of the researcher, at every step of the research process).

3.11 CONCLUSION

This chapter outlined and described the research design of the study. Aspects of the research design discussed were firstly, the description of a paradigm. Secondly, a discussion on the assumptions underlying interpretive paradigm as the adopted paradigm of this study followed. Justification of the choice of the interpretive paradigm was also done. Thirdly, the methods and approaches used in this study were described. Fourthly, the research questions and propositions for this study were outlined. Lastly, sampling strategies and procedures for trustworthiness were discussed. This research design helped the researcher to address the meaning that lecturers and teachers ascribed to the different types of knowledge required to teach mathematics and science. In the fourth chapter which follows, the results of the study are reported.

CHAPTER FOUR
RESULTS OF THE STUDY

4.1 INTRODUCTION

This chapter reports the results of the study. The report is organised in terms of the four research questions underlying the study. The themes and trends emerged from data collected through the following instruments: semi-structured interviews with university lecturers giving instructions in mathematics and/or science education in both traditional universities and universities of technology for the BEd (FET) qualification; and semi-structured interviews with mathematics and/or physical sciences teachers in schools who graduated with a BEd (FET) degree. In addition, themes and trends also emerged from an analysis the National Curriculum Statements Grades R-12 (especially the curriculum and assessment policy statements for mathematics and physical sciences); the Norms and Standards for Educators; and the Minimum Requirements for Teacher Education Qualifications (MRTEQ), as well as from a literature review on the broad teacher knowledge base and the specific types of knowledge required to teach mathematics and science.

Informants who provided information were assigned alphanumeric designators in order to ensure anonymity, where the letter ‘L’ represented lecturer and the letter ‘T’ represented teacher (see appendices 1 to 13).

4.2 FINDINGS

The following are the findings relating to the research questions:

4.2.1 Kinds of teacher knowledge

RESEARCH QUESTION 1

What are the different kinds of teacher knowledges; how do they relate and how are they acquired and developed?

This question sought to explore the different kinds of teacher knowledge that enable teachers to teach effectively at school and how knowledge is acquired and developed at universities. The question was further broken down into subsidiary questions. First, lecturers were asked what admission requirements prospective teachers of mathematics and science should meet, in order to enrol at their institutions. Secondly, what they wanted their students to accomplish at the end of their training. Thirdly, they were asked to elaborate on the specific types of knowledge that they wished their students to master.

In relation to the first question, it emerged that different institutions had different entry requirements for students who wished to train as prospective mathematics and science teachers, at the time of conducting this research, . Some institutions used only the admission point (AP) score of 30, while others used the AP score of 28 combined with a minimum of 50 percent in mathematics and 50 percent in the physical sciences as the minimum entry requirement. The variation on admission requirements was articulated by participants as follows:

L5: We are only working on AP score of 30.

L2: Basically, we have criteria that we have set and the students who have 4 in mathematics, as well as the ones who have 4 in physical science are the ones we select for the programme, so that they can be students who can study FET, physical science and mathematics.

L6: We are basically looking at the at grade 12 subjects. It must be 50 percent maths and 50 percent physical sciences. And nonetheless, 28 points for them to qualify ... that qualifies them with an entry to Bachelor degree. (See appendices 2, 5 and 6)

The right for institutions to prescribe their own entry requirements for students intending to enrol for Bachelor degrees is reflected in the Minimum Requirements for Teacher Education Qualifications (MRTEQ) document, which stipulates that:

> The minimum entry requirement is a National Senior Certificate (NSC), (with endorsement for entry into Bachelor studies) with appropriate subject combinations and levels of achievement as prescribed by institutions accredited to offer learning programmes that lead to the attainment and awarding of the qualification [BEd (FET)].

Lecturers were asked what they expected their students to accomplish at the end of their training as teachers. This question was intended to establish the lecturers' expectations of what students would gain after being trained as mathematics and science teachers.

There were variations on the expectations of lecturers on what students need to accomplish at the end of their training. In some institutions, students were expected to simply be able to teach mathematics and science up to grade 12. For example, L3 had this to say about this point:

> *The students are teaching; they are training to become educators so the mathematics we are teaching them is to enable them to teach maths up to matric level and also for the technical colleges, so they are able to teach at high school as well as technical colleges at FET*. (See appendix E3)

In one institution, lecturers expected students to have passion and dedication to teaching. L1 had this to say:

> *L1: I can say what we expect them and what they should know; eh, first of all I think they should have passion and dedication to mathematics. I can teach them all the content and all the methodologies; if they don't have the passion and the dedication for the subject I have missed my whole goal.* (See appendix E1)

In another institution, lecturers expected students to have confidence in dealing with the syllabus of grade 10 to 12 content. This desire was articulated thus:

> *L6: Uhm, since we are looking at the FET phase, I would really be happy if my student can be confident in taking teaching the syllabus from grade 10 to grade 12.* (See appendix E4)

In yet another institution, students were expected to have skills and embrace diversity as alluded to by L4 below:

> *... thirdly, eh, the social justice focus where we would like our students to embrace diversity.* (See appendix E6)

The above responses indicate that while knowledge of the subject matter was a priority for some lecturers, empathy attributes seemed to be a priority for others.

The main aim of a Bachelor of Education, according to the Norms and Standards for Educators policy, was such that upon completion of this degree, the student would have strong practical and foundational competence with the reflective competence to make judgements in a wide context. The qualification was intended for candidates seeking a teaching degree with strong subject and educational theory competence. According to the MRTEQ document however, the Bachelor of Education degree (BEd) has the primary purpose of providing a well-rounded education that equips the graduates with the required subject content knowledge base, educational theory and methodology that will enable them to demonstrate competence and responsibility as academically and professionally qualified novice teachers.

Regarding the specific types of knowledge that lecturers expected their students to master, one lecturer indicated that teachers experience difficulty in teaching science subjects because their content knowledge is limited. L6 had this to say:

> *I have since realised that uhm ... teachers out there have a lot of difficulties in teaching, especially the science subjects ... I realise that teachers' knowledge is quite limited.* (See appendix E6)

The above view was shared by McGraner *et al.* (2011) who suggest that many teachers do not possess the requisite subject matter knowledge to implement high quality instruction.

Most of the lecturers agreed that it is essential for prospective teachers of mathematics and science to master subject content knowledge and pedagogical knowledge (presented as methodology in various institutions). This was captured as follows:

> *L3: I don't know if I understand the question well, firstly to be able to teach maths up to grade 12 at school level to have the content, to be able to teach the content, the mathematics content and also we*

go beyond the grade 12 maths, so basically we focus on the skills, problem-solving skills.

L2: What I would like them to accomplish is to have a rich or an in-depth content knowledge. The second thing that I would like them to have is the pedagogical content knowledge of a specific subject content, meaning that they must not learn only the generic part of methodology but they must have knowledge that is more specific on the issue of mathematics. (See appendices E2 and E3)

L1 concurred with other lecturers on the need to have content knowledge but went further to indicate that this content should be in line with the CAPS document; that is content not too different from what is done in the schools. L1 had this to say:

I really believe they should have definitely the content knowledge and a little bit more than what the CAPS is telling them; a little bit more of one's mathematics but not too different from what is being done in schools.(See appendix E1?)

This resonates with Shulman's (1999: xi) suggestion that "teaching, like research is domain specific". This implies that teaching as "the transformation of understanding rests on depth, quality and flexibility of content knowledge and on the capacity to generate powerful representations and reflections on that knowledge" (1999: xi).

Tamir (1991) and Shulman (1987) also recognise the importance of subject matter/content knowledge for pre-service teachers. The above views are corroborated by Kennedy (1998) who asserts that although knowledge of the subject matter is probably the most self-evident kind of knowledge needed to teach, the amount of subject matter knowledge really needed to help children learn is a contested issue. She maintains that for those who believe the best source of knowledge is the curriculum materials and not the teacher, the most important knowledge to have is the ability to read and follow instructions. She further observes that some authors state that assessments require teachers to know only the subject matter actually covered by the curriculum, reasoning that this knowledge is exactly what teachers will be teaching. She however, indicates that if students can ask questions that extend far beyond the formal curriculum and if teachers have to respond to these questions, then teachers need knowledge that is far beyond the content officially being taught.

Other lecturers however, went further to indicate that they also expected students to master pedagogical content knowledge. They had this to say:

> *L1: We go through all the content and the PCK in maths.*

> *L7: … such that the content that they teach, they must do that diligently. It is very important because there are a whole of uhm, misconceptions or alternative conceptions that might come up from the learners.* (See appendices E1 and E7)

The above statements are corroborated by Shulman (1986, 1987), who argues that in addition to teachers' subject matter (content) knowledge and their knowledge of general instructional methods (pedagogical knowledge), teaching expertise should be described and evaluated in terms of pedagogical content knowledge. Through PCK, teachers relate their pedagogical knowledge (what they know about teaching), to their subject matter knowledge (what they know about what they teach). This is further highlighted by Grossman and Richert (1988) who suggest that teacher knowledge encompasses both the knowledge of general pedagogical principles and skills, and knowledge of the subject matter to be taught.

Question 2 was also broken down into the following subsidiary questions when directed to teachers. First, they were asked what requisite knowledge teachers of mathematics and science needed to teach these subjects effectively. Secondly, they were asked what skills they considered critical for the teaching of mathematics and science.

Most teachers seemed to agree with lecturers that content knowledge and pedagogical knowledge are central to the teaching of mathematics and science, as indicated by the responses given by one lecturer and one teacher, below:

> *L5: They must know content because each and every now and then the content change. So before you go to class you must know what the expectations of the learners are. You can't stand in front of learners*

without anything, so content knowledge is very, very, much important.

T2: Actually what I'm, according to my view, I think the knowledge of the content and how to present the content is very important. (See appendices E5 and E9)

Some lecturers identified skills they consider critical in teaching mathematics and science. The skill of problem-solving was perceived to be one of the most critical skills for teaching both mathematics and science as indicated by L2, below:

The second thing that I would like them to have is ... problem solving; how to teach a child in mathematics in terms of problem solving, then those are basically things that a student when he has to leave must have them. (See appendix E2)

Maths so basically we focus on the skills, problem-solving skills because mathematics basically is about problem solving, so this is what we mainly focus on and the explanation of concepts and mainly problem solving, and also we got the didactics part; that is the how to teach content at school level. (See appendix E3)

The above view substantiates Ernest's (1989) view that there is a problem-driven view of mathematics as a continual field of human creation and invention, in which patterns are generated and then distilled into knowledge. Thus, mathematics is a process of inquiry and coming to know, adding to the sum of knowledge. Mathematics is not a finished product because its results remain open to revision (the problem-solving view).

The skill of conducting practicals (experiments) was also perceived as critical in the teaching of science. L7 and T5 had this to say about the skill of conducting experiments:

L7: So it is very important for them to be in a position to master the basic skills in the lab. Remember, it is a different setup from when they are performing their practicals as we train them. They are doing them to get the results that they are going to write for their *lab reports, but when they get to school setup they must be in a position to help learners to understand the whole idea behind a particular experiment that they are going to work on. It's not only about the lab report but it's about helping learners to see that there is a link between theory and practical that enforce their own understanding of the content in a way.* (See appendix E7)

T5: The important thing is to be able to conduct the practical work and its challenges because lesson delivery is quite easy; you can just read, make notes, but incorporating the practical aspect you need a lot of experience there. (See appendix E12)

The above view indicates how important it is for student teachers to acquire the knowledge to conduct practical activities and be able to use them in their teaching of concepts. According to the CAPS (physical sciences) document for Further Education and Training Grades 10-12, practical activities refer to practical demonstrations, experiments or projects used to strengthen the concepts being taught. Experiment refers to a set of outlined instructions for learners to follow in order to obtain results to verify established theory. Therefore, practical work must be integrated into theory to strengthen the concepts being taught.

Teachers of mathematics and science are also expected to master the selection, sequencing and pacing of content, as discussed in Chapter Two of this study; that is, determining what to teach, when to teach it, and how to teach it. L7 alluded to this by stating:

L7: ... to know what to teach, how to teach, when to teach and what specifically to look at in terms of their content. (See appendix E7)

This aspect correlates with Bernstein's (2000) strongly-framed knowledge where the teacher selects the knowledge that matters in the curriculum; that is, the knowledge that learners need to acquire.

Time management and being able to link theory and practice are skills that generally were regarded as essential for teaching. The skill of time management was noted as lacking in most learners. T1 had the following to say about the inability of learners to manage their own time:

> *T1: They can't manage their time like students at university. They can't! They can't! They, after school they want to play. They have all stuff they want to do.* (See appendix E8)

Teachers were asked how they develop their knowledge in the subjects that they teach. Most of the teachers indicated that they develop their knowledge in the subjects by engaging in further studies in these subjects. Others referred to different sources and also consulted with fellow teachers, as alluded to below:

> *T2: Normally I'm teaching in grades 10 and 11; therefore, in terms of me knowing much more in this knowledge, eh, besides studying and other things, I normally eh, ask for more help in terms of people who have been doing it for more than the years that I have been here.* (See appendix E9)

> *T1: Okay! I make a lot of references. Yeah, I don't sit around; I refer to different sources to get it in a different way so that if it is asked in a different way I am able to answer it; that is how I develop myself.* (See appendix E8)

4.2.2 Curriculum content of mathematics and science teaching

RESEARCH QUESTION 2

How do the employers' (DoE) prescriptions shape the curriculum content of mathematics and science and their pedagogy?

This question sought to examine how curriculum reform and the transformation of teaching at school level from the introduction of Curriculum 2005 up to the most recent attempt – the Curriculum and Assessment Policy Statements (CAPS) - has affected both lecturers and teachers in the manner in which they teach.

When asked about the ways in which the Department of Education, through its policies, influenced the curriculum content and pedagogy of mathematics and science in universities, some lecturers indicated that when they compiled the modules, they took notice of what is contained in the policy documents; therefore, they have had to move with the curriculum changes. This is what some of them said in this regard:

> *L7: You know what? One might say that contributes more in terms of methodologies because we also had to move from OBE to NCS to CAPS whatever that may be and the sad part is that it also goes back to the previous question. We only work on the final documents that you know being imposed on us to form the part of our teaching, so we just have to go with the flow; we can't say I'm going to stick to this one because this is how I was trained and of the department. So now even if there is something else after CAPS, I still have to familiarise myself with it and go to class and teach my students accordingly.*

> *L5: When we compile the modules, we take notice of what are in the policy documents; in other words, what are specified in the CAPS document and we try to cover those topics.* (See appendices E5 and E7)

Another lecturer, however, felt that there was no difference between OBE, NCS and CAPS as indicated in the response below:

> *L6: Seeing that I have been through all those changes - curriculum changes that have happened since 2001, when I introduce them to that section of the work, to those policies that they need to adhere to but adhere to with an open mind, my conception of all those curricula changes is that I don't see them as changes as such at all. I don't know if I may be incorrect but I see OBE, Curriculum 2005, NCS, and CAPS now I see them as one and processes that tell us to be involved in good teaching; that is my conception of them.* (See appendix E6)

T4 indicated that the misinterpretation of OBE was the main cause of problems with regard to how teachers handled the curriculum.

T4: Policy of OBE. Let me put it well in Sesotho. [When OBE was introduced, people thought OBE cancelled Bantu education you see, but they were making a mistake. OBE did not cancel things that we did long ago; it just came with the strategy that the teacher gives a leaner work and guide them. More work is for the learner not the teacher. Number 2 with OBE it is not bad, but they messed it up by not understanding the meaning of OBE. They thought a teacher would get into class and ask a learner to read without having taught the learner how to read; they take it that these things we used to do, such as recitation, dictation are wrong. They messed it up by taking Bantu education as wrong, but it was right. They cancelled memory verses, recitation, dictations. Many things have disappeared; we don't see them anymore. A child in grade 9 to 10 cannot read. When you do financial mathematics, the child cannot analyse those statements because he just can't read the English in it. (See appendix E11)

Another teacher identified the problems associated with the way OBE was perceived by teachers in the following manner:

T2: The policies, according to my view, they normally are having some form of limitation in terms of how a teacher must teach because they normally give you the idea of you teaching a specific content but not enhancing or looking at some of the responses or the situation in a class per se, because it only gives you an idea. But when you present it in such a way that they tell to do it, when you encounter some of the problems, you fail to answer them because now you have limited your knowledge based on what the policy was saying. Therefore, the policy is just to guide, just to give you a starting point, then whatever that happens after that you ... it has to go with the knowledge of the teacher, as well as how you present the lesson. The policies like I am saying, it's just to give you an *introduction of, you can start this way, but at the end it will be up to the teacher's own what to do at the end.* (See appendix E9)

It emerged from the literature that the National Curriculum Statement Grades R-12 (NCS) represents a policy statement for learning and teaching in the South African schooling sector. To improve implementation, the National Curriculum Statement was amended. A single comprehensive Curriculum and Assessment Policy document was developed for each subject to replace Subject Statements, Learning Programme Guidelines and Subject Assessment Guidelines in Grades R-12. The CAPS is therefore not a new curriculum, but an amendment to the National Curriculum Statement Grades R-12 Subject Statements. It is an adjustment to what we teach (curriculum) and not how we teach (teaching methods). OBE is a method of teaching not a curriculum. It is the curriculum that has changed and not the teaching method. The statement by T4 below indicates the misconception:

There used to be OBE and then there was NCS, and NCS has been removed, now we now have CAPS. So, we are always experimenting on something, new ground. Let's find one thing and let's stick to it, maybe for 10 years and see what happens. (See appendix E12)

Some lecturers argued that what is taught at university is different from what is taught at school; therefore, this was the reason why they have had to align what they teach with the Curriculum and Assessment Policy Statement documents that inform what is taught in the schools. L2 and L1 had this to say about this point:

L2: I think the theory, remember we are talking about theory vs practical. We give them the nice theory that is there and the students have to be faced with reality when they go to schools. That is why I'm saying I'm standing on the issue that here at the university, we are not preparing them enough. We are giving them this theory that is very hard, that is very difficult according to their thoughts, but what they have to face to teach inside the classroom, it's a different story. Therefore, the theory that we are giving them is not enough; it's not enough. We have to be practical; we have to be realistic and look at our market not look at the issue of difficulty and not difficult. (See appendix E2)

L1: *The only thing that we have is the CAPS document actually and we try to align our teaching to the CAPS document.* (See appendix E1)

Contrary to the above, however, one lecturer indicated that lecturers had a tendency not to consider what is contained in the CAPS document in their teaching:

L2: According to my view, as I was a lecturer at the University of [name withheld] *and a lecturer here in this institution and have opportunity to teach mathematics and been a student in the same university, what I have learnt is that lecturers do not take departmental policies very serious. What they do, they think they are autonomous; they don't consider what CAPS is looking for. What is our market? They don't think about the market.* (See appendix E2)

Both lecturers and teachers were concerned about some topics and concepts, which were continually taken out of the school curriculum, only to be included again later. This introduction and removal of some topics from the school syllabus was considered more of a challenge for teachers who might have trained when those topics were not part of the syllabus.

T4: Now actually this is why I said CAPS and NCS is the same to me. I just saw that they add factors or they removed few; otherwise, they are not teaching anything new. Actually NCS had most staff which had to be removed. Like now, I don't teach things like colour; I don't teach lasers. In organic chemistry, we don't teach things like …. They removed such things. So, in a way, the way our syllabus it is changing; to me, they are superficial but there is no real change. I don't believe you can change maths and science because the same maths that I did was taught maybe in the 1960s and it is the same maths that my children are going to do. (See appendix E12)

Some lecturers raised a concern about the prescriptive nature of CAPS. They believe that this deprives teachers of creativity, imagination and originality in their teaching of mathematics and science. It also limits the opportunity for mathematics and science teachers to develop critical thinking skills. L1 had this to say:

> *The only thing that we have is the CAPS document actually, and we try to align our teaching to the CAPS document but the problem is it is too prescribed. I feel that the mathematics students, if you only do the CAPS from A – Z with them, eventually they know the content but they don't have the critical thinking skills. Actually, I know that the department put up on the SA schools website now the whole curriculum with worked- out lessons that teachers just have to follow. They prescribe exactly which question they should do, how to do it, how much to do it and they take away all the creativity of the teacher, all originality from teachers.* (See appendix E1)

The prescriptive nature of CAPS in terms of time spent teaching certain aspects of the curriculum and their consequences was also highlighted by a teacher who stated:

> *T1: The teaching is hampered because we cannot cover everything that is in the work schedule, you see, because if you want to cover that within the certain time that they give us in the work schedule, you can't do that. If you want to do that you have to force learners, you see, like you are rushing, you rush, you rush, you rush then you find that learners did not understand certain aspects; they struggle in the next grade because you were rushing*. (See appendix E8)

Most lecturers maintained that there is a lack of consultation between themselves and the Department of Education (DoE) in as far as determining the curriculum content of both mathematics and science in universities and in schools. In this regard, some lecturers saw the DoE as working in isolation. Thus, lecturers saw themselves as just implementers of policy. This point was articulated by L7 as follows:

> *... it's like the department is working in isolation; we are the ones who are supposed to be implementers of these changes that are taking place. We only work on the final documents that you know*

> *being imposed on us to form the part of our teaching, so we just have to go with the flow.* (See appendix E7)

Some teachers agreed with lecturers that indeed, the DoE did not involve them in decision making and the idea of being just policy implementers was demanding on them and affected them negatively, as the responses below indicate:

> *T4: Erh … now firstly, I do feel that the government is not involving people on the ground who are teachers when they are actually changing these curriculums.* (See appendix E11)

> *T5: It affects us a lot because sometimes that is why we resign, because we know that after each and every year, there is going to be a new thing that is going to be implemented and it's gonna be implemented by who? By us educators! Each and every change come to us and we are the one who must teach learners about that change, so it very strenuous to us.* (See appendix E12)

> *I think for me to be an educator of 11 years, I'm 11 years in this field, I was supposed to know, to be an expertise of my subject, but unfortunately, I'm not because each and every now and then there are changes and into that changes some of the things I don't know them, even though they say there is a workshop. Workshop, you don't gain anything because it is a workshop of 30 minutes, 1 hour; that is all. I cannot be trained in 1 hour, whereas for me to be a qualified one, I have taken that 4 years, 3 years. I think government must change system. I don't know how but they must come up with a way where may be for the whole holidays we can go and practise everything, like for instance in December, during December holidays, let them accommodate us for maybe 3 weeks to discuss, to be work shopped about what is going to happen next year in the classroom.* (See appendix 13)

Teachers were asked how their teaching of mathematics and science was affected by the curriculum transformation. Most teachers indicated that the DoE does not provide adequate orientation upon the introduction of these changes but rather, organises inadequate workshops, which leave them frustrated. One teacher had this to say with regard to a lack of guidance from the DoE:

> *T5: ... they don't provide us with enough orientation. Take for instance, I have trained for three years in college doing teaching, so now they come up with 40 minutes workshop maybe one day, three days. That thing it won't make a different. For me to go three years there it means they know that for you to be a teacher, you need enough time, so these one day, three days thing is not enough. It is not enough for us, and the way I have looked into it, we are all going to resign from teaching because no one can stand for the changes.* (See appendix E12)

> *T2: So the other thing is now this one has to be like probability is in Paper 1, now it's not Paper 1 next year when curriculum changes; Paper 3, now Paper 3 is not there anymore, it's Paper 2 and you have to fit anything in those things like Paper 1, Paper 2, Paper 3 and you have to fit in like, it affect the whole thing now.* (See appendix E9)

Another concern raised by teachers was that learners who were the products of OBE lacked the ability to read. Some teachers had this to say:

> *T4: Problem is they can't read. They don't know how to read even IsiZulu and Sesotho.* (See appendix E11)

> *T3: They can't read with insight, so that's the main problem. And if you give them a long piece of work, they can't extract information … they don't understand basic language.* (See appendix E10)

4.2.3 Theoretical knowledge in the curriculum of BEd (FET)

RESEARCH QUESTION 3

To what extent does the theoretical knowledge in the curriculum of BEd (FET) provided in schools of education adequately prepare students to teach mathematics and science effectively?

This question sought to explore the extent to which the theoretical knowledge of mathematics and science gained from universities is navigated to practice. It emerged that most universities prepare mathematics and science teachers to teach these subjects in high school. Nevertheless, there were those that prepare teachers to teach in both the General Education and Training (GET) and Further Education and Training (FET) bands, concurrently. This is provided for in The Minimum Requirements for Teacher Education Requirements (DHET, 2011) document, which states that:

> *A combined SP and FET programme is appropriate for teaching in secondary schools. The knowledge mix for this phase combination must support teaching in at least three specialisations: Two SP subjects and one FET subject or one SP subject and two FET subjects (where the SP subject should be the same as the FET subjects or the FET subject should be one of the subjects underpinning the SP subject), or one SP subject, one FET subject and one support role.*

It also emerged that in most universities lecturers found it necessary to cover the content that was supposed to have been covered at school level in the first year of study, as alluded to by some lecturers below:

> *L3: ... at first year, we do topics that are at high school.* (See appendix E3)

> *L7: You know, in that case I will still feel that we are re-inventing the wheel; it's like we are doing grade 10-12 over and over again, that is why I say indeed in first year and part of second year it's basically concepts that are done in these grades 10-12 classes.* (See appendix E7)

The reason for this repetition was that students came to these institutions not well prepared for tertiary education, especially when the pass mark at high school is 30 percent but 50 percent at universities. Lecturers regarded the university pass percentage of 50 percent as a challenge to those learners who qualified at 40 percent in high school and suddenly are expected to pass by 50 percent, as L5 said:

… so but yah the ... and that is also a concern of Professor (X); the learners must pass at 30-40 percent at school to obtain a grade 12 certificate but with us it's 50 percent; that is a big gap. (See appendix E5)

The Minimum Requirements for Teacher Education Qualifications document stipulates that at least 40 percent of the total credits for the BEd (FET) degree must be spread across educationally focused disciplinary learning (foundations of education), general pedagogical learning, fundamental learning and situational learning. Indeed, in most universities, the general subject didactics modules were done and they were meant to lay the foundation of teaching in general and the subject specific didactics modules concentrated on how to teach particular subjects as L1 indicated:

…we start to introduce them to different teaching methodologies. (See appendix E1)

... and also, we got the didactics part, that is the 'how to teach' content at school level. So they must be equipped with the content knowledge and the methodology to enable them to teach at school level. (See appendix E3)

In one university though, lecturers indicated that the specific subject modules were not done and lecturers saw this as a problem. L2 had this to say:

… we have the general subject didactics; our argument was that our students at FET mathematics they are taught GSD; they don't have specific subject didactics. That is the challenge that we have as a university as we speak. (See appendix E2)

In most universities, students are engaged in micro-teaching which introduces them to the different skills of teaching. It is through these micro-lesson presentations that they are trained to master individual teaching skills. They are then exposed to classroom teaching where they are taken to real classrooms and have their teaching evaluated. This is also provided for in the MRTEQ document where practical learning is described as an important condition for the development of tacit knowledge, which is an essential component of learning to teach. It is stated further in the MRTEQ document that programmes leading to Initial Teacher Education (ITE) qualifications must take cognisance of the need for students to engage in practical learning, which must be appropriately structured and fully integrated into the overall learning programmes while including structured supervision, mentoring and assessment. In this respect, it is evident from the responses that in all universities, students undergo teaching practice under structured supervision and assessment, but the same cannot be said about mentoring. The school experience component, according to the MRTEQ document, should take place in blocks of varying duration throughout the programme:

> In a full-time contact programme, student teachers should spend a minimum of 20 weeks and a maximum of 32 weeks in formally supervised and assessed school-based practices over the four-year duration of the degree. In any given year a maximum of 12 such weeks could be spend in schools, and *at least* three of these should be consecutive. (DHET, 2011)

As indicated below, student teachers went out for these sessions in their first, second, third and fourth years. L3 elaborated on the process citing problems and challenges in the following way:

> *L3: We take them in six weeks to schools to teach. The first-year students, they do observation, they don't teach. However, you know in schools, they allow them to teach but our purpose is that they must sit and observe how the teachers teach and learn from them. What we give them is journal to fill in, because what they are observing, they start to fill in their journals. In the second year, there are others who drop life sciences or physical sciences but mathematics is the major subject. So, in the second year, they go to school exactly between March and April when the schools re-open and they go there again for six weeks, but there they are expected to teach and there are delegated lecturers who go there and observe how they teach. On the third year, they do the same thing as they do in the first year. In the fourth year they would attend the mathematics for six months and the other six months. What they do,*

they go for teaching practice for six months; that is, from June up until December and they go to teach there and they have files that they have to compile: subject file, the assessment file, and the general file where they come with IQMS and so other things of the content. At the end of the year they don't come back to the university, they are through, what they do. The lecturers go there and evaluate their files and then after evaluating their files, we come up with the marks and then we give them to the teaching practice department and they enter marks. (See appendix E3)

This idea was corroborated by L2 by stating that:

L2: Firstly, in the first year, we register them. They do mathematics, science, as well as life science, and then what we do when the school re-open in March, we take them in six weeks to schools to teach. The first-year students, they do observation, they don't teach. However, you know in schools they allow them to teach but our purpose is that they must sit and observe how the teachers teach and learn from them. What we give them is journal to fill in, because what they are observing, they start to fill in their journals. In the second year, there are others who drop life sciences or physical sciences but mathematics is the major subject. So, in the second year, they go to school exactly between March and April when the school re-open and they go there again for six weeks, but there they are expected to teach and there are delegated lecturers who go there and observe how they teach. On the third year, they do the same thing as they do in the first year. In the fourth year they would attend the mathematics for six months and the other six months, what they do, they go for teaching practice for six months; that is, from June up until December. They go to teach there and they have files that they have to compile: subject file, the assessment file, and the general file where they come with IQMS and so other things of the content. At the end of the year they don't come back to the university; they are through, what they do. The lecturers go there and evaluate their files and then after evaluating *their files, we come up with the marks and then we give them to the teaching practice department and they enter marks. The students don't come in that six months. It means at the fourth year they only attend for six months. And in terms of content subjects like mathematics, science and physical sciences, they do it only for three years; the fourth year, we don't have the content subjects. And the only way they do the fourth year in the mathematics, science and physics is in their Honour's degree. That's where we give them content for the fourth year.* (See appendix E2)

Regarding the extent to which the theoretical knowledge of mathematics and science that students acquire at university prepares them to teach mathematics and science, lecturers were firstly asked to first elaborate on how prepared their students were to teach these subjects after completing their BEd qualification. Secondly, they were asked in what ways the content of mathematics and science shaped their pedagogy in the BEd programme.

Some lecturers indicated that their students were ready to teach upon the completion of their BEd qualification since they had equipped these student teachers with the different theories and methods of teaching mathematics and science to guide them in their teaching of these subjects in their classrooms. They also provided students with important skills, such as problem solving. They further indicated that their students were also provided with enough content to be able to teach these subjects at high school as they dealt with high school content in the first year of study. This was indicated by one lecturer's responses below:

L3: Having different theories that would help him to teach these topics. How, the how part of how to teach, we have different ways of teaching, and if we don't teach them that part, then it means when they go there they just become redundant teachers; that's my view. (See appendix E3)

Even though we can give them knowledge up until grade 12 but we have to give them beyond the grade 12 because they must have knowledge that is beyond grade 12 knowledge. The second thing that I would like them to have is the pedagogical content *knowledge of a specific subject content meaning, that they must not learn only the generic part of methodology but they must have knowledge that is more specific on the issue of mathematics; for example, if they have to do deal with problem solving, how to teach a child in mathematics in terms of problem solving, then those are basically things that a student when he has to leave must have them. Content knowledge, a rich and in-depth content knowledge, as well as a specific pedagogical content knowledge.* (See appendix 2)

L3: ... at first year we do topics that are at high school. (See appendix E3)

Regarding the extent to which theoretical knowledge in the curriculum of BEd that is provided in the faculty/department/school of teacher education to adequately prepare students to teach mathematics and science, teachers were first asked from what they benefited in their university training, in order to survive in the classroom. Secondly, teachers were asked what level of training (for example, Mathematics I, II, or III) they regarded as adequate for teaching mathematics and science at high school.

There was variation in the responses of teachers regarding from what they benefited in their institutions of training. Some teachers indicated that university training enabled them to cope in classrooms and attend to learner questions confidently, as T4 articulated:

T4: Yah, it really plays a part because when teaching something you really need a knowledge that is above, 'cos once I know matric stuff I will not be able to [tackle] certain questions. So my university education really did play a part, otherwise I would have left the profession way back. I wouldn't have survived. So university education really plays a part. For somebody to teach matric you need a degree; you can't do it without a degree. You need a degree to teach matric. Those boys and girls they can now think. They are questioning. (See appendix E11)

T2, however, indicated that while studying at university they did not focus as much on the content as on how to handle the class in terms of discipline and also how to present the content:

> *...so these are the things that I have benefited mostly at university on how to handle, uhm, the class in terms of discipline and how to handle the class in terms of content.* (See appendix E9)

Others indicated that at university they learnt to push themselves and not wait for the lecturer to introduce topics and they were trying to instil the same in their learners. This was articulated by T1 as follows:

> *...whilst at university, I learnt to push myself a lot ... and so I am trying to install that into my learners that they should do the same.* (See *appendix E8)*

There was variation in the teachers' responses regarding the minimum level of specialisation required for a teacher to teach mathematics and science at high school. Some teachers indicated that third-year level was adequate for one to teach these subjects at high school, as alluded to by T2 below:

> *T2: I think Maths 3* (See appendix E9)

Others indicated that it was only after fourth-year level that a teacher would be ready to teach mathematics and science in the high school; that is, after obtaining a degree.

> *T4: I think level 4.*

> *T5: For somebody to teach matric you need a degree; you can't do it without a degree.* (See appendices E11 and E12)

Regarding the extent to which content shaped the pedagogy of mathematics and science in the programme of teacher education, some lecturers indicated that because of the inadequate content knowledge that students possessed after grade 12, teaching first-year content and how to teach it proved to be a problem. Even though the students have passed grade 12, they still do not have a clear understanding of the topics they did from grade 10 to grade 12 because they were drilled to pass matric, regardless of whether they understood what they were doing. These students are also taught by teachers who themselves were taught to memorise. Some of the concepts that were considered to be problematic to learners are indicated by L3 below:

> *The concept of limits, that's the first one; they struggle to understand it. What they are good at is to calculate a limit of a function, but to understand what we mean by limit, they don't understand that, they struggle. And also the concepts of financial maths, the session of compound interest, it's challenging, whereby now let's say interest is compounded, it's annually, quarterly and sometimes they get confused. And also what I have seen is in coordinate geometry, they call it analytical geometry. Or maybe it's because we start it in the school level and then from there we expand it, so when we expand it more, somehow they struggle and also functions. What I can say is it depends, you would find that some students are good at certain topics. The other student is good in other topics and in another one's struggles and another is opposite, good in that. It's like that thing is normal, I don't know.* (See appendix E3)

It also emerged that what made learning in mathematics and science problematic was the under qualification of teachers who were trained at colleges of education who still used old and outdated methods of teaching these subjects, as one teacher commented:

> *L2: Now we have only teachers who are outdated teachers who have learnt in colleges; they have memorised and now they know the whole syllabus, but do they contextualise it, do they make it meaningful to our children?* (See appendix E2)

4.2.4 Teacher training at universities of technology and traditional universities

RESEARCH QUESTION 4

How does the training of teachers at universities of technology differ from similar training in a conventional/traditional university?

This question sought to determine which of the two types of universities is best positioned to train teachers to teach mathematics and science at high school. Lecturers were asked first, how the preparation of mathematics and science teachers at traditional universities differed from that in universities of technology. Some of their responses indicated that the depth at which content was dealt with was the major difference.

It emerged that in traditional universities students tended to be taught specialised mathematics that was required for engineering students and that tuition concentrated more on the application of concepts, whereas in universities of technology (UoTs) students were taught theory.

> *L3: The difference I can mention is that at the traditional university the content is being done at higher level. They were lecturing maths to engineers whoever, everything, and their approach is different. I think their approach is different. So I think it is better for our students who are training to be teachers to be taught by somebody who has got their profession, who understands also what is happening at the school level So my view is, students whom we are training to be teachers, they must be taught by somebody who has got a profession; that is, being a teacher and also who knows what is happening at school level. But if we have got a physical or maybe a maths department there servicing everybody in the university, engineers and then IT and then we combine them and then it won't serve the purpose, I think.* (See appendix E3)

> *L7: Or to my student, I mean how best can I help them understand the concepts much better, what is the best way of dealing with their*

alternative conceptions. So then, how to teach part of science also automatically merges with the content itself, because it also helps me to be in a position to highlight some of the aspects that a pure scientist wouldn't be in a position to do because there is a huge difference to come with your BSc without the aspects of education. You come only in terms of mastering the content of science in a way but if you come with aspects of education at the same time, you would be in a position to know how to deal with learners, knowing their learning behaviours and stuff. (See appendix E7)

Lecturers further indicated that it is a disadvantage for students to have tuition in content in a different faculty from the one from which they learnt their methodologies. These students would have been taught by engineers who do not have professional teaching qualifications, as articulated by one lecturer below:

L2: When I have my students, I know what I'm teaching and I'm able to guide them. You can't explain like this to students or learners at school, this how you must do it, because they cannot understand, but if they are in other department of mathematics, remember those people are the statistician and whatever. They don't have the pedagogical part. And there are ones that teach engineers and other physics, physicians ... On my view is that I think learning in the same department and also learning practical in the same department, not going to the other department, I think it gives advantage to the students. (See appendix E2)

In one institution where students were taught mathematics and science content in the mother faculties, it emerged that lecturers were not content with the arrangement. They rather wished that they taught the students both content knowledge and pedagogical knowledge. The main reason as indicated by L5 below, was that in the mother faculty students passed without understanding the requirements for teaching the subject:

...but the subject knowledge they don't do with us; they get that in the faculty of natural sciences. So, then they come to us and we are only dealing with methodology and lab organisation, lab safety but

we realise that the students don't have necessary subject knowledge from the faculty of physics and chemistry department and zoology. The reason for that is the way they study those four subjects is not to understand them; they want to pass them and then when they get here we try to make sure that they do have some of the relevant knowledge. (See appendix E5)

Some teachers indicated that the level of mathematics and science content knowledge at traditional universities is higher than at universities of technology. One teacher indicated this by saying:

T2: Honestly speaking, according to me, it's like our levels, honestly speaking, it's not the same. I thought that that's how they were trained at university in terms of what they were trained in but I was - we have difference between me and them. (See appendix E9)

However, another teacher indicated that as far as content knowledge was concerned, there was no difference between teachers who were trained at traditional universities and those who were trained at universities of technology, as alluded to by T4:

We are at par. We are the same with them. (See appendix E11)

With regard to whether there are any advantages of offering student teachers content from faculties of mathematics, science and technology, as opposed to offering content in the department/school of education, there were conflicting responses. Some participants indicated that it is more advantageous to have students do content from faculties of mathematics, science and technology than to do content and methodology concurrently in the faculty or school of education. L5 had this to say:

L5: I think they get better subject knowledge because those people are subject specialist. (See appendix E5)

4.3 CONCLUSION

The findings presented above represented the respondents' views and beliefs about what teachers of mathematics and science need to know and be able to do to teach these subjects effectively in high school. The major focus was on the different types of knowledge that student teachers acquire from their initial teacher preparation programmes and the extent to which these knowledges prepare them to cope with the demands of teaching mathematics and science in high school. Most respondents regarded Content Knowledge and Pedagogical Knowledge as the most important types of knowledge that teachers of mathematics and science should possess, but others indicated that Pedagogical Content Knowledge was also critical in teaching these subjects. The results also indicated that the employer's prescriptions in the form of policies affect the curriculum content of mathematics and science, as well as their pedagogy. Theoretical knowledge in the curriculum of BEd (FET) provided in schools of education was regarded by some participants as inadequate in preparing teachers to teach mathematics and science in high school, whereas others regarded it as adequate. There was variation on whether there is a difference in the way mathematics and science teachers are trained in universities of technology and traditional universities. In the final chapter of this study, discussions of the results and the conclusion of the study are provided.

CHAPTER FIVE

DISCUSSIONS AND CONCLUSION

5.1 INTRODUCTION

This chapter is devoted to discussions and a conclusion to the study. The chapter integrates arguments, issues and challenges that emerged from all the chapters. In particular, the chapter presents the researcher's own views and opinions on the different research questions that underpinned the study. This chapter also draws a conclusion to the study.

5.2 SUMMARY

5.2.1 Purpose of the study

The purpose of this study was to examine current teacher knowledge of mathematics and science with reference to how theoretical and propositional knowledge in these subjects is navigated into practice by teachers in South African education.

5.2.2 Restatement of the research questions

The main research question for this research was:

What constitutes teacher knowledge of mathematics and science in BEd programmes; how is this knowledge integrated into the curriculum, and how is the theoretical knowledge acquired at universities navigated into practice to enhance effective teaching and learning?

Subsidiary questions

- What are the different kinds of teacher knowledges; how do they relate and how are they acquired and developed?
- How do employers' prescriptions shape the curriculum content of mathematics and science, and their pedagogy?

- To what extent does the theoretical knowledge in the curriculum of the BEd provided in schools of teacher education adequately prepare students to teach mathematics and science effectively?
- How does the training of teachers to teach mathematics and science in universities of technology differ from similar training in conventional universities?

5.2.3 Restatement of the propositions

The following were the propositions guiding the study:

- An adequate understanding of teacher knowledges is critical to producing teachers who can teach mathematics and science.
- The notion of framing (locus of control over selection, pacing, sequencing, and evaluation of knowledge) might assist in closing the gap between the theory and practice of mathematics and science.
- The current curriculum of the BEd programmes provided in schools of teacher education has not sufficiently integrated theoretical knowledge that teachers need to teach mathematics and science.
- Universities of technology are better placed to train teachers to teach mathematics and science.

5.2.4 Restatement of the research design

Purposive sampling helped the researcher to gather information based on specialist knowledge of the participants. Specific information on the types of knowledge that mathematics and science teachers acquired at universities and how this knowledge is translated into classroom teaching was obtained from both lecturers and teachers. Instruments that were used to collect data for the study in accordance with the interpretive paradigm are interviews, document analysis, and a literature review. Semi-structured interviews with individual informants were conducted (Miles & Huberman, 1994; Denzin & Lincoln, 1994; Patton, 2002). These person-to-person, semi-structured interviews with interview guides allowed for focused, conversational two-way communication. In some instances during these interviews, respondents used their vernacular language which the researcher translated during transcription.

The researcher was careful to transfer meaning from Sesotho and IsiZulu to English, rather than a verbatim translation. The transfer of meaning was more appropriate since there are words in Sesotho and IsiZulu, which do not have equivalents in English. Translation, therefore, relied on the researcher's interpretation.

As a former mathematics and science teacher, the researcher faced the challenge of completely suspending his previous personal experiences in teaching these subjects. This might have influenced what the researcher heard the respondents say.

Five universities with different historical and institutional backgrounds were selected for this study. Lecturers from faculties or schools of education, which offer BEd (FET) programmes for the preparation of teachers to teach mathematics and science participated in this study. Faculties or schools of education were chosen from two formerly English-speaking universities; one from a formerly Afrikaans-speaking university; and two from universities of technology. The above categories were chosen because of historical and cultural tendencies in South Africa regarding the teaching of mathematics and science. Mathematics and science education was not prioritised in traditional universities for Black people.

The policy documents on teacher education that were analysed for this study are: The Norms and Standards for Educators and The Minimum Requirements for Teacher Education Qualifications (DOE, 2011). The Minimum Requirements for Teacher Education Qualifications replaced The Norms and Standards for Educators as a document that provides a basis for the construction of core curricula for initial teacher education, as well as for Continuing Professional Development (CPD) programmes leading to teacher education qualifications. Reviewing the literature helped in establishing the background and context of teacher knowledge in mathematics and science in South Africa.

5.3 DISCUSSIONS

In this section the findings from the participants' responses to individual research questions are explored. Issues relating to the research questions emerging from the literature and teacher education policies, with special reference to The Minimum

Requirements for Teacher Education Qualifications (MRTEQ) document are also discussed.

5.3.1 What mathematics and science teachers should know and do

The first research question sought to establish what teachers should know and be able to do in order to teach mathematics and physical science effectively at school; where teachers acquire this knowledge; and how this knowledge is developed.

5.3.1.1 Entry requirements and levels of achievement

A theme about entry requirements and levels of achievements that prospective teachers needed to meet to be enrolled for a BEd FET degree emerged.

It is argued in this discussion that one of the critical tasks of universities is the production, reproduction and dissemination of knowledge and that students entering university are not expected to be ‘clean slates’ but to bring with them some knowledge that should be expanded by university education. Each student enrolling in any faculty needs to meet the admission requirements for that faculty. It is also argued in this discussion that in theory, students who meet the admission requirements to train to teach mathematics and science are more likely to succeed, but this in reality does not seem to be the case. This could be attributed to the notion that at high school, learners are drilled to pass examinations without a real, in-depth understanding of concepts.

There is a variation on the minimum admission requirements for the BEd (FET) qualification at different universities. Although this variation is admissible under the Minimum Requirements for Teacher Education Qualifications (MRTEQ), it however, means that students can enrol at one university for a BEd (FET) qualification, whereas they may not be allowed to enrol at another university for the same qualification, even if they obtained the same level of achievement in grade 12. Universities prescribe different Admission Point (AP) scores to enrol students for BEd (FET) qualification to teach mathematics and science. It is proposed in this study, that there has to be some uniformity in the minimum requirements for admission to the BEd (FET) qualification that prepares students to teach mathematics and science, for all institutions. An agreed-upon AP score combined with a minimum percentage in mathematics and physical sciences would ensure that prospective students have the same level of reasoning about mathematical and scientific ideas and the ability to evaluate arguments and evidence.

5.3.1.2 Knowledge base for teaching and pedagogical content knowledge

Even though content knowledge and pedagogical knowledge were the most common types of knowledge that lecturers wanted their students to master in order to be able to teach mathematics and science effectively, the researcher argues that this thinking undermined the existence of other varieties of teacher knowledges and learning as proposed by Shulman (1987). The researcher agrees with Shulman's (1987) assertion that supporters of teaching professionalism base their arguments on the belief that there exists a knowledge base for teaching (a codified or codifiable aggregation of knowledge, skill, understanding and technology, of ethics and dispositions, of collective responsibility), as well as a means of representing and communicating it. In as much as knowing subject matter is imperative for a teacher trainee before he/she can teach it, and knowing what teaching and learning styles to apply for a particular topic and ways of conveying them are equally important, the researcher is of the view that pedagogical content knowledge (PCK), which entails knowing how subject matter is transformed for teaching is critical to the teaching of mathematics and science, since it advances the theory of teacher knowledges and learning that emphasise rules of content. In the case of the MRTEQ policy, PCK is the disciplinary learning aspect of the policy.

It is argued that PCK has not been given enough recognition in the curriculum of BEd (FET) for mathematics and science teachers. Participants generally, did not raise the issue of PCK. The researcher supports the implementation of PCK in mathematics and science teachers' programmes. It is further asserted that the three facets of PCK identified by the Mathematics and Science Partnership (MSP) programme, the overall goal of which is to improve classroom instruction and student achievement in mathematics and science through professional development in the USA, are critical for effective mathematics and science instruction. The first facet is the knowledge of students' thinking in mathematics and science. This knowledge comprises three general and related aspects that are of significance in the teaching of mathematics and science. The researcher argues that since mathematics and science have a hierarchical knowledge structure (Bernstein, 2000), it is important for teachers' knowledge to include understanding which ideas are prerequisites or foundations for more sophisticated concepts. It is contended in this discussion that teachers who possess knowledge of students' thinking are better placed to understand ways that students typically think about ideas and that there are informal or intuitive ways in which students commonly approach problems involving specific content ideas. It is also argued that for some ideas, students' informal or intuitive thinking may be very close to correct understandings; for other ideas, students' prior experiences may result in initial conceptions that counter established disciplinary understandings. Teachers who understand the cognitive development of ideas are also in a better position to teach mathematics and science effectively, since this knowledge offers teachers frameworks for guiding students' growing understanding of specific concepts.

The second facet is the knowledge of implications for instruction. This study argues that teachers who possess this knowledge are able to assess correctly how their representations signify concepts and how comprehensible these representations are to learners. Being able to assess how comprehensible concepts are to one's students helps the teacher in the selection, sequencing and pacing of mathematical and scientific concepts. Possession of this knowledge also empowers teachers to understand how particular instructional experiences can build on students' thinking to provide opportunities to learn specific mathematical or scientific ideas. When teachers understand the representations of mathematics or science concepts and how they might be used in instruction, they then become better assessors. Teachers without this understanding tend to use examples from the textbook, such as those prescribed by the CAPs document, without being original and creative.

It is the researcher's view that generally, teachers who possess content-specific knowledge of activities understand which aspects of the content are highlighted in a given activity and those which might be obscured. Content specific knowledge supports an understanding of what aspects of a targeted concept can and cannot be addressed well, with a particular activity (MSP, 2010). It is argued in this discussion that this knowledge of content-specific activities also helps to enhance inquiry teaching and learning in mathematics and science classrooms where the teacher selects activities that provide opportunities for the construction of the knowledge of mathematical and scientific concepts and ideas.

The third is knowledge of the curriculum**.** Wheelahan (2010) states that theoretical knowledge must be at the centre of all qualifications. The researcher agrees with Wheelahan's (2010) argument that there are two ways in which knowledge is structured in the curriculum. The first is that students who possess theoretical knowledge become part of society's considerations and shape their field of practice and the relationship between knowledge and practice. The second is that the pursuit of truth should be the normative goal of the curriculum, but tempered by an awareness of the fallibility of knowledge and thus, should be revised in the light of new evidence.

5.3.1.3 Structure of knowledge in the curriculum

The researcher contends that the seeming disregard for the structure of knowledge in the curriculum of the BEd (FET) programme is generally problematic because in essence, the nature and structure of the knowledge of mathematics and science shapes their pedagogy. Furthermore, and related to the structure of knowledge, the researcher takes issue with the tendency to underplay the role of knowledge in the curriculum. The MRTEQ document is silent about knowledge structures and their significance in the teaching and learning of mathematics and science. According to the MRTEQ document, one of the basic competencies of beginner teachers is that they should know how to teach their subject(s) and how to select and determine the sequence and pace content with both subject and learner needs. The argument in this study is that teachers can select, sequence and pace content if they know the structure of the knowledge of their discipline. The researcher agrees with Wheelahan (2010) that theoretical knowledge is increasingly marginalised in the curriculum in all sectors of education, particularly in competency-based training, such as the one advocated by the MRTEQ document which has a set of minimum competencies required by a newly qualified teacher.

Bernstein (2000) points out that a teacher needs to understand the structure of the knowledge of the discipline to be able to teach it. It is argued in this study that teachers who understand the structure of the knowledge of mathematics and science are able to distinguish between the distinct structures of what should be taught in mathematics and science classes and how it should be taught. This includes knowing how the instructional materials that teachers use, help to organise the mathematics or science content for classroom teaching. It is the researcher's view that teachers who understand the structure of the knowledge of mathematics and science are better placed to understand how content ideas are sequenced; that is, which ideas are introduced earlier on and are used as the foundation for learning and other ideas later; how connections are made; that is, which ideas are tied together and in which ways; and how the various activities and their sequencing in the instructional materials are intended to contribute to mathematics and science learning goals. Based on this discussion it is maintained therefore, that Bernstein's social realist; Wheelahan's formulation of the critical realist; and Shulman's practical rationalist approaches are complementary because together they provide insights into the structures of knowledge; the content of knowledge; the relationship between knowers and knowledge; and the manner in which subject matter is transformed into teaching mathematics and science.

5.3.2 Curriculum reform and the pedagogy of mathematics and science

The second research question was pursued to explore how curriculum reform and transformation at school level from the introduction of Curriculum 2005, to the most recent attempt – the Curriculum and Assessment Policy Statements (CAPS) − has affected both lecturers and teachers in the manner in which they teach. The researcher agrees with Parker's (2006) contention that school curriculum documents usually project symbolic images of what the state considers worthwhile knowledge and pedagogical practices for schooling that would advance these new transformation ideals.

In this discussion it is argued that teachers of mathematics and science have been negatively affected by the curriculum transformation. A key principle of the new curriculum according to the Department of Education (2003:2) is social transformation aimed at "ensuring that the educational imbalances of the past are redressed and that equal educational opportunities are provided for all sectors of our population."

It is reasoned that the prescriptive nature of CAPS, for instance, has forced teachers to focus on the preparation of learners for standardised and official examinations.

This undermines the teachers' responsibility to select, sequence and pace knowledge.

These reforms, it is argued, have not had an adequate impact on transforming classroom practices, since they were not well assimilated into current practice as a result of the inadequate training of those involved and the poor management of change by the Department of Education. The Department of Education did not provide a distinction between innovation (the policy for change), and change itself (the transformation of social practices that might result from the engagement with the CAPS policy).

Responses to the implementation of curriculum reform and transformation in schools varied between individuals, as reflected in the interviews. This study avers that some teachers have accepted the transformation process and have acted in accordance with the new roles of educators, while others have rejected transformation and have continued with their old classroom practices; these teachers seeing themselves as passive implementers of externally initiated innovation. This perspective has lowered teachers' morale and motivation levels. Their response was thus to adapt superficially (for instance in terms of paperwork), while continuing with more established practices. There are also instances where teachers have merged the old with the new by selecting aspects that they feel are more suitable to them, considering their circumstances, such as availability and adequacy of learner support materials; text books in particular; class size; and infrastructure.

The responses of teachers to the implementation of the curriculum and the transformation process described above, resonate with Priestley's (2011) outcomes to a process of transformation. These outcomes are: (a) morphogenesis, where the new ideas supplant the old; (b) morphostasis, where the old ideas are maintained and the new are rejected; and more commonly (c) where elements of the new merge with elements of the old, leading to a form of morphogenesis, particularly where there are points of consensus, as well as contradictions between the old and the new, or where the dissonance between them is not significant enough to merit conflict.

It is argued in this research that in order to embrace transformation, teachers of mathematics and science need to undergo a deep change which requires new ways of thinking and behaving. Some teachers however still apply their conventional teaching styles to teach mathematics and science, such as ‘watch and do’ (Cuoco, 2001: 169), where learners watch teachers solve problems on the board and then learners are required to emulate the teacher by following the same procedures that he/she used in solving the problem. This is then followed by lots of practice on nearly identical problems; the cycle repeats until the class ends. Thereafter, learners are given homework that requires even more practice. The problems given to learners often involve substituting numbers in formulas or applying the procedure over and over. Learners therefore apply rules that they do not understand. Another traditional instructional practice that mathematics and science teachers still adhere to amidst curriculum transformation is the ‘show and tell’ style (Handal, 2003: 50), where working in small groups is not common, learners do not participate actively, teacher questioning emphasises wrong or right answers, and learners often experience passive learning. Another defining characteristic of this traditional style of teaching is that too much emphasis is given to rote learning, procedures and facts. Excess teacher talk dominates the communication in the classroom and learners’ desks are arranged to face the teacher’s desk. It is argued in this discussion that instead of these traditional/conventional practices, teachers may adopt research-based ‘best practices’ in teaching mathematics and science (Zelmelman, Daniels & Hyde, 2005: 116). This entails using the following as part of instruction, namely: a manipulative/hands-on approach (making learning concrete and active); cooperative group work; discussion and inquiry; questioning and making conjectures; the justification of thinking; a problem-solving approach to instruction, making content integration a part of instruction; using technologies, such as calculators and personal computers; assessment as a part of instruction; and promoting the role of the teacher beyond that of transmitter of knowledge to facilitator of learning. It is further opined that the use of problem-based learning might be a successful instructional strategy where mathematics and science are integrated to make them relevant and meaningful to the learner. Integrating mathematics and science provides the opportunity for learners to apply the disciplines to real situations that are relevant to the learner’s world and presented from the learner’s own perspective.

The discussions in this chapter suggest that the way in which curriculum transformation was handled by the National Department of Education as the employer, particularly the orientation stage and monitoring implementation, has been inadequate. It is argued that the lack of involvement of lecturers and teachers, as practitioners of education by the National Department of Education is the major barrier to reform implementation. This lack of involvement has denied the practitioners an opportunity to play their roles of being real active participants in decision making; of conveyors of curriculum philosophy; of motivated and effective implementers and designers of curricular materials and teaching approaches; and lifelong learners for constant improvement (Nan-Zhau, 2006). It is further argued that the National Department of Education has not provided quality programmes of professional development needed to support teachers to reinvent themselves professionally, so as to cope with the demands of transformation. Instead, short training workshops have been organised for teachers who are then expected to train other teachers.

5.3.3 Theoretical knowledge in the curriculum of the BEd (FET)

The third research question explored the extent to which theoretical knowledge in the curriculum of the BEd FET provided in faculties or schools of teacher education prepares students to teach mathematics and science effectively.

5.3.3.1 Theoretical knowledge and curriculum

The researcher concurs with Priestley's (2011) point that there is some validity in the argument that curriculum theory and practice are faced with new uncertainties, and that such uncertainties require fresh approaches to practice and new ways of thinking. It is argued in this study that this argument reflects the situation in South Africa. Priestly's (2011) suggested facets to this situation are: firstly, the recent emergence in curriculum policy around the world of the new models of the national curriculum which are characterised by various common features, such as a structural basis in outcomes sequenced into linear levels. Secondly, there is a focus on generic skills or capacities instead of a detailed specification of knowledge/content. Wheelahan's (2010) point too has credence in the context of this study in that he maintains that there is a crisis in the curriculum and that it arises as a consequence of the displacement of knowledge from the centre of the curriculum by the dominant models of the curriculum, such as OBE and its competence-based approach. The researcher supports Wheelahan (2007: 1) in her argument that "the competency-based vocational education and training qualifications in Australia has had the potential of denying students access to the theoretical knowledge that underpins vocational practice and that competence and outcomes in training packages tend to be erroneously used to substitute what should be curricula and pedagogical issues in the vocational training". The researcher posits that the above argument works in teacher education programmes where teachers must teach competently to attain certain standards and that assessment must be conducted of these standards. The researcher agrees with Wheelahan (2007: 5) who warns that "training packages shape the curricula because they stipulate the nature of assessment and this means that there are limits on the how of learning", because, as Bernstein (2000: 36) explains "content is transformed into evaluation and context is transformed into transmission". In OBE in South Africa, each module or qualification should state the desired outcomes and assessment criteria, so that students know in advance what they need to do to achieve the outcomes. Moreover, the teacher is seen as a facilitator who is an authority to the learners in terms of the content that must be transmitted. The teacher has ceased to be a repository of knowledge and wisdom, but facilitates the learning experience. In this model, emphasis is on competency-based approaches to pedagogical practice that equip students with a tool-box of work-ready skills; therefore, denying teachers the opportunity to be original and creative in their thinking. This study argues that this model has stripped knowledge from the curriculum (Young, 2008; c.f. Priestley, 2010; c.f. Wheelahan, 2010). OBE has resulted in the under-preparedness of learners for tertiary education.

5.3.3.2 Learner under-preparedness for higher education

It is the researcher's view that learner under-preparedness poses a significant challenge for the higher education landscape in South Africa. The researcher supports the argument by Maree, Alduous, Hattingh, Swanepoel and Van der Linde (2006) that many learners in South African schools do not master the knowledge and skills underlying learning and problem solving sufficiently. Thus, learners often acquire deficient, superficial and rote knowledge of basic concepts at the expense of well-founded theoretical/conceptual knowledge. This argument was also supported by the teachers and lecturers who participated in this study. This means that learners are taught to pass grade 12 without necessarily preparing them for tertiary education. The researcher also supports the view that the recurring poor performance in mathematics and science calls for a concerted effort to put in place measures that will help improve the status quo. To tackle the under-preparedness of higher education students, some universities have opted to roll out extended curriculum programmes where the main focus is on re-teaching high school mathematics and science.

It is argued in this study that the inability of mathematics and science education programmes to attract learners who perform well in these subjects at high school is problematic. Learners who obtain good grades in mathematics and science are not attracted to do education but rather opt for more lucrative professions, such as medicine and engineering. In order for universities to be able to produce quality mathematics and science teachers, they need to be able to motivate students with good marks to choose teaching as a career. This idea supports Brunner's (1977: 31) reasoning that:

> …the best way to create interest in a subject is to render it worth knowing, which means to make the knowledge gained usable in one's thinking beyond the situation in which the learning has occurred. Third, knowledge one has acquired without sufficient structure to tie it together is knowledge that is likely to be forgotten. An unconnected set of facts has a pitiably short half-life in memory.

It is argued in this study that for universities to serve as creative pathfinders in terms of the improvement of the overall quality of mathematics and science education, lecturers of mathematics and science education should be involved in the strategies to address inadequate learner performance in mathematics and science. It is the researcher's view that understanding the relationship between what one learns at university and what one would encounter in one's professional practice is crucial in the teaching and learning of mathematics and science.

It is the researcher's view that lecturers who train mathematics and science teachers are far removed from the school environment. There is little communication between these lecturers and the teachers in the high school. This creates a problem for the teaching and learning of mathematics and science, since these lecturers do not understand the complexities and the challenges of teaching these subjects at high school, where these subjects are mostly presented as sets of facts, techniques and procedures.

The researcher acknowledges that the mathematics and science education curricula should provide knowledge that prospective teachers can internalise. The following knowledge, skills and understanding as suggested by Hollins (2011) should be embraced by a curriculum that intends to provide knowledge that the prospective mathematics and science teacher can internalise: i) knowledge of human growth and development and individual and group differences that when combined with specific knowledge of particular learners, such as their background experiences; ii) what they know and how they make sense of what they know and what they value. How and why, inform the design of learning experiences and the specific ways in which learning is facilitated; iii) a deep understanding of the learning process that combines findings from the new learning sciences, with a clearly delineated theoretical perspective on learning as a framework for classroom practices and the assessment of learning; iv) a deep understanding of the organising ideas for a discipline; v) domain-specific reasoning and practices; vi) the processes for participating in a disciplinary-based discourse community; and vii) how to connect disciplinary knowledge and practices to the everyday experiences of learners from diverse cultural, linguistic and experiential backgrounds; viii) an understanding of pedagogy as a clearly designed and interrelated pattern of learning experiences embedded within a particular theoretical perspective and guided by a clearly articulated philosophical stance that provides vision and purpose for long- and short-term learning outcomes; ix) an understanding of how to identify and develop appropriate classroom assessment approaches for evaluating learners' progress in relationship to discipline-specific knowledge and practice and how to manage the demands of a standards-based curriculum and assessment; and x) an ability to maintain a strong professional identity, engage in self-directed professional growth and development, recognise characteristics and qualities of professional communities in different contexts and work collaboratively with colleagues within a professional community to improve learning outcomes.

The researcher supports the suggestion by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1985 on the programme of study and the percentage of time to be spent on each component to be taught to science student teachers. UNESCO suggests that the science content should: constitute 50 percent of the total time and should cover the history and philosophy of science; science taught as a human science; technology and society; science activity; include environmental concepts and principles; and laboratory topics (selection depends on work major). Professional education should constitute 35 percent of the total time and should cover: the psychology of learning science (25% to include recent developments); content and teaching methods (for skills and rational thinking); laboratory techniques (including computer instruction); educational technology; evaluation in science education; curriculum and instruction; science education research; science teaching/internship; foundations/other education courses (10% made relevant to teaching and learning). Liberal education should constitute 15 percent of the total time covering the humanities and communication. From the above, it is clear that the bulk of the instructional time should be dedicated to disciplinary knowledge (UNESCO, 1985).

5.3.4 Mathematics and science teacher training in universities of technology and traditional universities

In South Africa, initial mathematics and science teacher training can be done at universities of technology or traditional/conventional universities. The fourth research question of this study sought to establish if there are any differences between the training of mathematics and science teachers in universities of technology and training in conventional universities and if so, which one of the two types of universities is better placed to train these teachers.

The researcher contends that teacher training is a continuous process that begins with initial training at an institution and then throughout the teacher's professional life. It is argued that initial teacher training generally, should include four components, namely: improving the general educational background of the trainee teacher; increasing his/her knowledge and understanding of the subjects he/she is to teach; the pedagogy and understanding of children and learning; and the development of practical skills and competencies (Perraton, 2010). This argument is corroborated by Ware (1992: 13) when he says that:

> Whatever route a teacher takes to subject matter knowledge and professional competence, the actual content of the teacher's tertiary education is split between course work in science [and mathematics] content, pedagogical instruction including supervised teaching and general education courses. The balance of these three components varies considerably from country to country, and even sometimes from institution to institution of the same type within a country.

It is further argued in this study that curricula and pedagogical practices and learning in universities of technology and traditional universities are driven by competence and outcomes. These competencies and outcomes inform curricula and are used to determine what should be taught, learnt and assessed. Teaching and learning practices in both types of universities are guided by critical course outcomes and individual institutional graduate attributes. In reality, there is no significant difference in the curricula of mathematics and science teacher education in universities of technology and traditional universities.

The researcher further avers that there are similarities in the way that mathematics and science teachers are trained in both universities of technology and traditional universities to obtain a BEd (FET) qualification. These similarities demonstrate that it is insignificant where mathematics and science teachers are trained. First, is the development of professional competence. In both types of universities, student teachers undergo pedagogical instruction, which includes supervised teaching and some general education courses. Supervised teaching begins with micro-teaching, where student teachers present to a small group in 5 to 20 minutes a selected and specific aspect of teaching. The participants are the student teachers' peers, who are taught like learners. The presentations are recorded and played back during the evaluation phase of peer assessment and reflection. When they are not out in the schools, students engage in micro-lesson presentations, using different teaching-learning media (such as the use of chalkboard, chalkboard and poster, chalkboard and 3D models, or using transparencies, overhead projectors, PowerPoint presentations).

Another component of supervised teaching that students in both universities of technology and traditional universities engage in is teaching practice. The researcher contends that this is a crucial aspect of the teacher preparatory programmes in teacher training institutions. It is the period when student teachers are assisted in putting into practice the theories and principles of education, which they have learnt in the classroom as they teach learners in the partnership schools. It is also during teaching practice sessions that student teachers experience a supported transition from study to work; from a trainee to a competent teacher, through mentoring and they receive this support at the time they need it most. It is a cardinal and indispensable aspect in the preparation of teachers.

Different universities in South Africa use different terms for this period, such as practice teaching, student teaching, teaching practice, field studies, infield experience, school-based experience or internships but the way it is conducted is generally similar in both types of universities. The amount of time spent on these sessions is the same, even though universities spread it differently. It is argued in this discussion that this ongoing engagement with schools gives the universities an opportunity to actualise their commitment to supporting students and partner stakeholders, in turn, leading to the enhancement of the institution's reputation/standing (see Pans, 2010).

Second, is the acquisition of subject matter knowledge. The researcher argues that mathematics and science subject matter knowledge is a central component of what teachers need to know at both universities of technology and traditional universities. It is further argued that the variation of where students are taught mathematics and science content as shown below, is insignificant. In some universities, regardless of type, students obtain their subject matter instruction for both mathematics and science from their schools/faculties of teacher education, whereas in others, students get their content from the faculties of mathematics, science and technology and they go to the education faculty for only pedagogical learning; fundamental learning; situated learning; and practical learning, while in others, students get all types of learning from the faculty/department of education.

It is postulated in this thesis that teachers need to be properly educated and trained for professional efficiency and inculcated with a positive attitude that will enable them to go through the training properly equipped for the responsibility ahead (Nwanekazi, Okoli & Mezieobi, 2011). The curriculum of teacher education is generally similar in universities of technology and traditional/conventional universities, which therefore negates the proposition that universities of technology are better placed to train mathematics and science teachers than traditional/conventional universities.

5.4 CONCLUSIONS

Insights that emerged from the analysis were clarified in respect of each research question. The researcher arrived at the following conclusions for each of the research questions. First, the researcher concluded that teachers lack an adequate understanding of the different types of teacher knowledges, which are critical to produce teachers who can teach mathematics and science. It was concluded that the current BEd (FET) curriculum for mathematics and science education concentrates mostly on subject matter knowledge and pedagogical knowledge, at the expense of pedagogical content knowledge (which is necessary for the practice of effective teaching) and other forms of knowledge. It was concluded further, that despite research showing that the relationship between teachers' mathematical knowledge and student achievement is such that teachers with strong mathematical knowledge at a greater depth are more likely to foster students' ability to reason, conjecture, and solve problems, the curriculum of the BEd (FET) was found not to provide prospective teachers with the requisite subject-matter knowledge to implement high quality instruction. Teachers, therefore, lack the ability to diagnose and address students' (mis)conceptions and computational (dys)fluencies.

Second, the researcher concluded that curriculum reform and transformation at school level from the introduction of Curriculum 2005 up to the most recent attempt – the Curriculum and Assessment Policy Statements (CAPS) − have impacted negatively on both lecturers and teachers of mathematics and science. This is mainly because of little or no consultation with stakeholders on the part of the policymakers. The prescriptions on the curriculum based on curriculum reform were implemented hastily and, therefore, have been detrimental to the teaching of mathematics and science. The removal and addition of some topics to the curriculum have been most confusing to teachers. This is because some teachers had not done such topics at either high school or university. Some topics were done at university, while these teachers were already teaching. This led to more confusion and frustration on the part of teachers who, out of fear of embarrassment, then opted not to teach such topics. It was concluded further that there was poor monitoring of innovation on the part of the Department of Education. This resulted in some teachers resisting transformation resiliently, by superficially adhering to the prescribed changes (especially with paperwork and conformity to set time frames), whereas in class, they continued with their traditional instructional practices. Others, however, have conformed to the demands of the Department of Education.

It is concluded that mathematics and science method courses remain highly fragmented and disparite; thus, there is a need for the integration of method courses of mathematics and science. This will help close the gap that exists between the theory and practice of these subjects and improve science education as a whole. Physical science involves mathematics, and both subjects involve process skills. Integration will equip teachers of these subjects with the knowledge and skills to teach them meaningfully to learners. Efforts should be made to eliminate the presentation of science and mathematics lessons from the traditional methods, where they were treated separately and studied for their own sakes. The emphasis should be on inquiry learning rather than on traditional methods, which emphasise rote learning of facts and procedures. The integration of mathematics and science method courses will benefit students in that more focus will be placed on the explanation of concepts. Thus, more learners' scientific and mathematical conceptual learning, and an enhanced ability to think critically and apply information, motivation and interest will be achieved.

Third, the researcher concludes that the proposition that theoretical knowledge in the curriculum of the BEd (FET) provided in schools of teacher education does not adequately prepare students to teach mathematics and science effectively, holds. This is attributed to the displacement of knowledge from the centre of the curriculum. Teachers do not simply need to be proficient in solving any problem in the topics they teach but should also be able to select and sequence mathematical and scientific concepts so that they are usable in the classroom. Theoretical knowledge provided to prospective teachers does not help them to interpret curriculum materials and explain these to learners. Teachers need to be exposed to specialised knowledge that they need to know, and to know how to use in their teaching of mathematics and science. They should know in detail the topics that are fundamental to the school curriculum and beyond. Teachers with theoretical knowledge are aware that in teaching, it is much easier to start from cognitive roots; that is, starting with a concept that learners comprehend which forms the basis of a more complex theory; for example, when teaching the Pythagoras theorem, learners need to know how to calculate the area of rectangles. Thereafter, learners will develop a conceptual understanding of why and how “the sum of the squares of adjacent sides in a right-angled triangle equals the square of the hypotenuse”. In this way, teachers are able to unpack or deconstruct ideas so that they are accessible to learners.

Fourth, the researcher concludes that contrary to the proposition that universities of technology are better placed to train teachers to teach mathematics and science than traditional universities, both are equally placed to train teachers to teach mathematics and science. The faculties of education in both types of universities operate in much the same way for training prospective teachers; therefore, there is no significant difference in the provision of knowledge for students in both types of universities.

Lastly, it is concluded that the curricula of teacher education in South African universities should be such that it provides opportunities for the development of not only content knowledge and pedagogical knowledge but also PCK for mathematics and science.

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APPENDIX A: Letter seeking permission to collect data

ACADEMIC AND PROFESSIONAL PEDAGOGY

2015/10/26

TO WHOM IT MAY CONCERN

This letter serves to advise that Mr Ratokelo Thabane, student number 21155668, is registered student for Phd at Central University of Technology (CUT).

Mr Thabane is requesting permission to collect data from:

I also have to indicate that the data required will be used for education purposes only.

Yours Sincerely

PROFESSOR IM NTSHOE
HEAD OF DEPARTMENT

ACADEMIC DEVELOPMENT AND SUPPORT

APPENDIX B: Letter to universities' registrars

TO: THE REGISTRAR
TSHWANE UNIVERSITY OF TECHNOLOGY
PRIVATE BAG X680
PRETORIA
0001

Dear Sir

Re: Permission to interview lecturers

My name is Ratokelo Willie Thabane. I am a student at the Central University of Technology, Free State. I am currently doing PhD in Education. My supervisor is Prof M.I. Ntshoe. The title of my thesis is:

Deconstructing teacher content and pedagogical knowledge in mathematics and science curricula in teacher education in South Africa.

The main research question of this study is:

What is the teacher knowledge of mathematics and science in BEd programs, how is this knowledge integrated in the curricula, and how is theoretical knowledge acquired at universities navigated into practice to enhance effective teaching and learning in the FET band?

I hereby request permission to conduct interviews with lecturers giving instruction in mathematics and science education in your institution.

Yours Sincerely

Thabane RW (Mr)

APPENDIX C: Schedule of questions

Lecturers' questions

Research question	**Interview questions**
What are the different kinds of 'teacher knowledges', how do they relate, and how are they acquired and developed	(i) What are the selection criteria for prospective student teachers of mathematics and science in this institution? (ii) What would you like your students to accomplish at the end of their training? (iii) What are the specific types of teacher knowledge that you would like your students to master?
How does the employer (DoE) shape the curriculum content of mathematics/science and their pedagogy?	(i) In what ways does the Department of Education, through its policies

Research question	**Interview questions**
	influence the curriculum content and pedagogy of mathematics and science in universities?
To what extent does theoretical knowledge in the curriculum of BEd provided in the faculty/department/schools of teacher education adequately prepare students to teach mathematics/ science effectively?	(i) To what extent are your students ready to teach once they have completed the Bachelor of Education qualification? (ii) To what extent does theoretical knowledge of mathematics and science that students acquire at university prepare them to teach these subjects? (iii) In what ways does content shape pedagogy of mathematics and science in the programme of teacher education?
How does the training of teachers to teach mathematics/science in universities of technology differ from a similar training in conventional universities	(i) How does the preparation of mathematics and science teachers at conventional universities differ with the one in universities of technology? (ii) What are the advantages of offering student teachers content from mother faculties as opposed to offering

Research question	**Interview questions**
	content in the department/ school of education?
Conclusion	Is there anything you would like to add? Thank you for your time

Teachers' questions

Research question	Interview questions
What are the different kinds of 'teacher knowledges', how do they relate, and how are they acquired and developed	(i) What in your view should a teacher of mathematics and science know and be able to do after completing their qualification? (ii) How do you develop your knowledge of content in this subject and how to teach it?
How does the employer (DoE) shape the curriculum content of mathematics/science and their pedagogy?	(i) How do National Policies such as NCS and CAPS determine content of what you teach and how to teach it? (ii) How is your teaching affected by the changing approaches to learner

	assessment?
To what extent does theoretical knowledge in the curriculum of Bed provided in the faculty/department/schools of teacher education adequately prepare students to teach mathematics/ science effectively?	(i) In what ways did you benefit from what you learnt at university for your survival in the classroom? (ii) What level of training (e.g. Maths/science I, II, and/or III) do you think is adequate for one to be able to teach this subject at high school?
How does the training of teachers to teach mathematics/science in universities of technology differ from a similar training in conventional universities	(i) What is the difference between preparing to become a teacher at a university of technology and conventional university? (ii) How do you compare yourself with your counterparts who trained from a different institutional type than the one you trained at? (iii) How is your teaching different from the way someone trained at a different institutional types teach
Conclusion	What other challenges are you experiencing regarding content knowledge of mathematics and Sciences and how they are taught

	in teacher training and in schools? Thank you for your time

APPENDIX D: Consent form for interviewees

FACULTY OF HUMANITIES

Consent form for interviewees

This informed consent form is for lecturers at Tshwane University of Technology whom I am inviting to participate in a qualitative research.

Name of researcher: Ratokelo Willie Thabane

Name of Institution: Central University of Technology

Name of Supervisor: Prof, M.I Ntsoe.

Title of Dissertation: **Deconstructing teacher content and pedagogical knowledge in mathematics and science curricula in teacher education in South Africa**

This Informed Consent Form has two parts:

• Information Sheet (to share information about the study with you)

• Certificate of Consent (for signatures if you choose to participate)

You will be given a copy of the full Informed Consent Form.

Part I: Information Sheet

INTRODUCTION

I am **Ratokelo Willie Thabane**. I am a student at the Central University of Technology. I wish to invite you to participate in the research which I am doing. You may talk to anyone you feel comfortable talking with about the research and you can take time to reflect on whether you want to participate or not.

Purpose of the research

The purpose of this study is to strengthen the existing BEd (FET) programmes for students who are preparing to teach mathematics and science at FET phase with a view to improving the standard and quality of the content and pedagogical knowledge of students, thus helping them to integrate it in their effective teaching and learning of mathematics and science in the classroom.

Type of Research Intervention

This research will involve your participation in an interview that will take about 30 to

45 minutes. Audio recordings of the interviews will be made.

Use of Research Recordings for Educational Purposes or Presentation Purposes

The segments from the audio recordings may be used for educational or presentation purposes. You therefore have the option of whether or not you consent to such uses of the recordings.

Mark the appropriate section with an X.

______I agree that segments of the recordings made of my participation in this research may be used for conference presentations.

______I do not want segments of the recordings made of my participation in this research to be used for conference presentations.

______I agree that segments of the recordings made of my participation in this research may be used for education and training of future researchers/practitioners.

______I do not want segments of the recordings made of my participation in this research to be used for education and training of future researchers/practitioners.

Once segments have been chosen, the remainder of the recordings will be destroyed (unless approved for archiving).

Segments cannot be used for purposes beyond those detailed and consented to in the informed consent form.

Participant Selection

You are being invited to take part in this research because we feel that your experience as a lecturer can contribute much to our understanding of what knowledge is needed for mathematics and science teachers in the FET phase.

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not.

Procedures

We are asking you to help us learn more about teacher content and pedagogical knowledge in mathematics and science curricula in your Institution. I am inviting you to take part in this research project. If you accept, you will be asked to:

Participate in an interview with myself. During the interview, I will sit down with you in a comfortable place at the Institution. If it is better for you, the interview can take place in your home or a friend's home. If you do not wish to answer any of the questions during the interview, you may say so and I will move on to the next question. No one else but me will be present unless you would like someone else to be there. The information recorded is confidential, and no one else except **R.W Thabane, Prof M.I Ntshoe, Members of the FRC and the external reviewer**, will have access to the information documented during your interview. The entire interview will be recorded using a digital audio- recorder, but no-one will be identified by name on the recording. The recording will be kept electronically on a computer.

Duration

The research takes place over 24 months in total. During that time, we will visit you once for interviewing you.

Risks

There is a risk that you may share some personal or confidential information by chance, or that you may feel uncomfortable talking about some of the topics. However, we do not wish for this to happen. You do not have to answer any question or take part in the discussion or interview if you feel the question(s) are too personal or if talking about them makes you uncomfortable.

Benefits

There will be no direct benefit to you, but your participation is likely to help us understand better what needs to be done to improve the quality of instruction in mathematics and science.

Reimbursements

You will not be provided any incentive to take part in the research. However, you will be given acknowledgement for your time, and participation.

Confidentiality

The research being done in the institution may draw attention and if you participate you may be asked questions by other people in the institution. I will not be sharing information about you to anyone outside of the research team. The information that I collect from this research project will be kept private. Any information about you will have a number on it instead of your name. Only the researchers will know what your number is. It will not be shared with or given to anyone except **R.W. Thabane, Prof M.I. Ntshoe, Members of the FRC and the external reviewer.**

Sharing the Results

Nothing that you tell us today will be shared with anybody outside the research team, and nothing will be attributed to you by name. The knowledge that we get from this research will be shared with you and your institution before it is made widely available to the public. Each participant will receive a summary of the results. The results will be published so that other interested people may learn from the research.

Who to Contact

If you wish to ask questions late, you may contact any of the following:

Mr R.W. Thabane
Central University of Technology
1 Park Road Bloemfontein
051 507 3423
rthabane@cut.ac.za

OR

Prof M.I Ntshoe
Central University of Technology
1 Park Road Bloemfontein
051 507 3825
intshoe@cut.ac.za

This proposal has been reviewed and approved by Faculty Research committee of Central University of Technology, which is a committee whose task it is to make sure that research participants are protected from harm. If you wish to find more about the FRC, contact Prof S.N Matoti, Central University of Technology, 1 park Road Bloemfontein 051 507 3371.

Part II: Certificate of Consent

I have been invited to participate in research about teacher content and pedagogical knowledge in mathematics and science curricula in teacher education.

(This section is mandatory)

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study

Print Name of Participant: ____________________________

Signature of Participant: ____________________________

Date: ____________________________

Day/month/year

Statement by the researcher/person taking consent

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily. A copy of this Informed Consent Form has been provided to the participant.

Print Name of Researcher/person taking the consent: THABANE

Signature of Researcher /person taking the consent:

Date: 18/02/2014

RATOKELO WILLIE THABANE