Examining the Development of Topic Specific Pedagogical Content Knowledge in Stoichiometry in Pre-service Teachers

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Declaration

I declare that that this research report is my own unaided work and has not been copied from another source.

I further declare that the text used is my own, except where duly referenced and no part of it has been copied from another source (unless indicated as a quote). All phrases, sentences and paragraphs taken directly from other works have been cited and the reference recorded in full in the reference list.

I make this declaration on my honour as a postgraduate student at Wits University and recognise that by maintaining the declaration, I maintain both my own integrity and that of the University of which I am a member.

Bongani Prince Ndlovu

Signature

Abstract

Over the past three years, National Senior Certificate diagnostic reports reported that learner performance in key chemistry topics remains an aspect for concern. In these reports, poor understanding of stoichiometry is identified as an underlying factor. On the other hand, the status of mathematics and science teaching has been under critique by several education researchers, pointing to poor teacher training in the subjects. One possible way to respond to the challenge in science education is to introduce and emphasize the development of Topic Specific Pedagogical Content Knowledge (TSPCK) as the professional knowledge for teaching science topics in Initial Teacher Education (ITE) programme. TSPCK is renowned for enabling teachers to pedagogically transform difficult content of specific science topics into forms best understandable by learners. This study examined the impact on the quality of TSPCK following an intervention that explicitly targeted the development of the competence to transform content knowledge using stoichiometry as a topic of learning. This examination happened as teacher plan to teach the topic.

The study followed a Mixed Method research design and a case study as a research strategy. It was located in the methodology class of physical science IV. The participants were 10 pre-service teachers who were in their final year of Bachelor study in education (B. Ed). They were bound by the requirements of the course and their common choice of physical science as their major subject. These pre-service teachers were exposed to a TSPCK based intervention that explicitly targeted the development of TSPCK component interaction. More evidence of component interactions was comprehended as developing quality of TSPCK. Quantitative data was collected as a set of pre- and post-intervention TSPCK tests using existing, specially designed tools that were developed and validated in a separate study. Five (5) of the then pre-service were followed a year later after the intervention to measure the quality of TSPCK in the topic of intervention in order to determine the extent of retention of the quality of TSPCK since the intervention. Qualitative data was collected through face to face interviews to confirm observed patterns of retention.

The findings in this study indicated that pre-service teachers experienced a visible improvement in the quality of their TSPCK in stoichiometry as a direct result of the intervention. Pre-service teachers showed more evidence of component interactions post the intervention. The results further indicated that pre-service teachers experienced the components of TSPCK to have different levels of difficulty when using them to transform the content in stoichiometry during planning. The component of “conceptual teaching strategies” was found to be the most difficult. A year later, the quality of TSPCK in planning to teach the topic of the intervention was found to have been retained by the then pre-service teachers. Recommendations about the implementation of TSPCK in core topics in ITE are made. Firstly, for initial teacher education, it is recommended that courses such as methodology for teaching chemistry be structured as TSPCK based intervention.

Secondly, more work need to be done in the examination of retention span of TSPCK. Thus, similar studies must be conducted in an effort to increase empirical evidence about the extent at which TSPCK is retained by beginning teachers.

Dedications

I dedicate this work to three people important in my life. Firstly, I devote this work to my mother Thokozile “Magadalina” Thwala, whose prayers have kept me this far in my academic endeavours. Secondly, this is dedicated to my one and the only daughter Luyanda. May the good Lord grant you serenity to grow wiser, and above all may He grant you divine protection. Lastly, my heartfelt dedication goes to my partner, “BK” for always standing by me through difficult times. Your continued support and encouragement has kept me this far. You are highly appreciated.

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Secondly, I want to acknowledge Steven Malcom for your input and availability when I needed some resources. Ms Denise Van der Merwe, thank you so much for your continued encouragements when I felt like giving up sometimes. To Ms Ezra Sadiki, thank you for assistance during the validation of the scoring purpose.

Thirdly, I would like to acknowledge the financial aid from the NRF through Prof. Marrisa Rollnick for funding this project. Without your financial support as anchor, it was going to be difficult to reach finality of this project.

Lastly, I would like to thank the pre-service teachers, who were at the time of data collection furthering their studies in science education, Thabo, Kgomotso, Sharon, Michael, Tsepo (pseudonyms) for availing themselves also for the second set of data collection.

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List of Acronyms and Abbreviation

PCK	Pedagogical Content Knowledge
TSPCK	Topic-Specific Pedagogical Content Knowledge
PTC	Pedagogical Transformation Competence
TPKB	Teacher Professional Knowledge Bases
TSPK	Topic Specific Professional Knowledge
PCK&S	Pedagogical Content Knowledge and Skills
CK	Content Knowledge
DoBE.	Department of Basic Education
ITE	Initial Teacher Education
MM.	Mixed Methods
B. Ed.	Bachelor of Education
LPK	Learner Prior Knowledge
CS	Curriculum Saliency
WiD	What is difficult to teach?
Rep	Representations
CTS	Conceptual Teaching Strategies

CHAPTER 1: BACKGROUND OF THE STUDY

This chapter begins by giving a preamble, this aims to situate the study by outlining the statement of the problem with evidence drawn extensively from literature and national diagnostic reports on learner performances. A rationale for conducting such a research project is provided. Two research questions have been formulated to steer this study and are indicated in this chapter; additionally, an account of the researcher's positionality is outlined. This aspect of the write up is critical as it assists the reader to understand the worldview of my position in terms of the claims made in this research report.

1.1. Preamble

The goal of teacher education is not to prepare teachers to teach in prescribed ways but to develop them to reason thoroughly about their practice in transforming abstract content into forms that are accessible to learners (Shulman, 1987). In light of this assertion, this study focuses on examining how potential teachers could be prepared competently for their practice. There is evidence that pre-service teacher's competence can be improved through focused interventions. For example, Aydin, Demirdogen, Nur-Akin, Uzuntiryaki-Kondakci, and Tarkin (2015) have shown that pre-service teachers' knowledge of teaching has potential to develop through interaction of content-specific components, such as those contained in the prompts of a Content Representation (CoRe) (Loughran, Mulhall, & Berry 2004). This tool captures and exposes teacher's knowledge about the subject or topic of focus.

Sub-Saharan countries such as South Africa have documented a various number of challenges that hamper the effective teaching of mathematics and science. Furthermore, Spaull (2013) has stated comparatively that the standard of mathematics and science teaching in South African is lower than that of other developing countries. This status can be attributed to few specific factors such as. historical segregation in the pre-democratic era (Mji & Makgato, 2006); secondly, poor teacher preparation mainly due to former Bantustan colleges of education, and lastly a focus on generic pedagogical transformation methods (Park & Oliver, 2008) instead of topic focused preparation of teachers (Mavhunga, 2016). Hence, in this study, I examined the development of pre-service teachers' professional knowledge for teaching science situated at the topic level.

I have chosen to focus on pre-service teachers in this research since in-service teachers are generally understood to have a great deal of burden in their experience. Thus it is difficult to reverse some of the inadequacies in their knowledge of teaching. In addition, it is important to study pre-service teachers since they have insufficient and incoherent knowledge for teaching (Cochran, King, & DeRuiter, 1993). Hence, exposing them to educative programmes within science topics in ITE programmes can develop and expand their pedagogical knowledge and reasoning (Aydin, *et al.* 2015).

1.2. Problem Statement

The results from the examination for the national senior certificate (NSC), particularly physical sciences paper 2 have not been satisfactory over the past 4 years. This concerning observation is often attributed to poor learner understanding in quantitative aspects of chemical change (DoBE, 2014, 2016). This branch of chemistry is known as stoichiometry; it deals with quantities in chemical reactions, providing quantitative relationships between reactants and products (Broster, Horn, James, & Solomons, 2012). It is best regarded as mathematics behind chemistry (Kolb, 1978). Given this analogy, stoichiometry is largely a core topic to other chemistry topics (Potgieter, Rogan, & Howie, 2005) such as reaction rates, chemical equilibrium, acids and bases. Thus, poor understanding of this topic negatively impacts the understanding chemistry.

The recent diagnostic report, DoBE (2016) on physical sciences paper 2 reveals that all topics that had stoichiometry aspects were poorly answered during the final examination. Table 1.1 below shows the poor trend observed in the past four years in selected questions:

Table 1.1: **Percentage performance in NSC Physical Sciences Papers 2 over a period of 4 years**

Annual Performance in Percentages	**2013**	**2014**	**2015**	**2016**
Organic Compounds &**Stoichiometry**	**44.5**	**47**	**36**	
Reaction Rates &**Stoichiometry**	**33.2**	**36**	**35**	**39**
Acid and Bases &**Stoichiometry**	**44.4**	**48**	**37**	**29**

From Table 1.1, I deduce that almost all topics or questions that had stoichiometry aspects seem to have achieved below 37% in 2015, below 48% in 2014 and below 44.5% in 2013. Most dismal, is the last column in the table. Topics with stoichiometry achieved between 29% and 39%. Note that in 2016, organic compounds was not combined with stoichiometry, hence the blank space. Generally, over the 4 years the trend continues to avow that learner performance in chemistry decrease on an overall. From the previous reports, there has been explicit mention of stoichiometry as being a root course of this observation for an example:

> "The stoichiometric calculation in Q5.5 was a challenge to most candidates. Very few obtained full marks. Those who attempted the calculation made one or more of the following errors... [*The list of errors is contained in the full diagnostic report*] " (DoBE, 2014 p. 25)

This assertion validates the claim that stoichiometry is the difficult topic to most Grade 12 candidates sitting for chemistry examination.

Furthermore, in the 2016 diagnostic report, it is reported that, generally, learners could not use the correct mole ratios. This affirmation confirms poor understanding of stoichiometry. Previously, the 2013 the diagnostic report also affirmed that, "In Question 6.6, many candidates did not know how to approach this question; learners had a poor understanding of stoichiometry" (DoBE, 2012, p. 191). Therefore, these reports confirm that there is a problem with this topic in the senior certificate examination. Therefore, the responsibility of the science education community is to get to the fundamentals of how the knowledge for teaching develops from the perspective of teacher education. Failure to respond to this problem might have dire consequences on the general learner performance in chemistry as stoichiometry is regarded as a core topic in chemistry (Potgieter et al., 2005)

1.3. Research questions

The current study will examine the impact of an intervention on the development of pre-service teachers' knowledge to transform abstract concepts in stoichiometry, thereby developing their Pedagogical Content Knowledge (PCK) exclusively located in the topic. We call this form of PCK, Topic-Specific Pedagogical Content Knowledge (TSPCK). Furthermore, it will investigate the retention of the developed TSPCK in stoichiometry. These intentions will be examined through the following research questions:

I. What is the impact of an explicit intervention on developing the competence to transform content knowledge on the quality of pre-service teachers' TSPCK in planning to teach stoichiometry?

II. To what extent is the quality of the TSPCK in planning to teach stoichiometry retained by pre-service teachers a year later after the intervention.

1.4. Rationale

Teachers are the most important element in the learning process, Feiman-Nemser (2001) argues that for effective learning to take place, teachers must have been developed competently. The author argued for a direct relationship between teacher competence and the academic performance of learners. Thus, it is reasonable to attribute the observed poor learner performance in stoichiometry and related topics to the reported poor preparation of teachers in science. On the other hand, Shulman (1987) asserts that when developing teachers' professional knowledge, emphasis should be placed on the development of pedagogical reasoning, as it is equally important as the act of teaching itself. He specifically advocates for the development of pedagogical transformation of content knowledge as the essence of process of pedagogical reasoning (Shulman, 1987). Thus, in this study, it is posited that an early exposure of pre-service teachers to the process of pedagogical transformation of content knowledge in stoichiometry, will increase the quality of their knowledge of planning to teach the topic. This in turn will enable them to draw on a rich foundation for teaching it in the immediate future. A number of education researchers, including science education, attest o the desirable need that the actions in class are explained and influenced by reasons related to pedagogical reasoning during planning (Loughran, Keast, & Cooper, 2016). Hence there is a genuine argument for exposing pre-service teachers to the kind of knowledge that develops their teaching competence in specific topics. It is acknowledged that such an exposure alone is not '*a one solution bullet'*, as the intervention where learning happens, is limited to a focus on the planning of teaching rather than on classroom practices or the combination of both. Nevertheless, it is a good starting point in establishing the foundation for effective teaching as pointed out by Shulman (1987) and other science education researchers (Nilsson & Loughran, 2012).

Few empirical studies on TSPCK with pre-service teachers have been reported such as Aydin et al. (2015), however, none have of these studies were conducted in the topic of stoichiometry, particularly in the planning aspects. Furthermore, little is known in the literature about the retention of neither the bigger construct of PCK nor the topic specific construct of TSPCK, once acquired from an intentional intervention. This study is thus perceived to add to literature on PCK in three ways: Firstly, it models the implementation of refined construct of TSPCK, in stoichiometry therefore adding to the pool of studies that demonstrate the topic specificity of PCK, and the modelling of this nature as knowledge for learning to teach science topics. Secondly, it shares insight about the possible retention of acquired TSPCK. Lastly, it provides an empirical response to the recommendation in the 2012 diagnostic report that asserts:

> "*Stoichiometry should form part of future teacher development programs for Grade 10, 11 and 12 teachers*" (DoBE, 2012, p. 191),

In the next section I profile my positionality. This section arguably is crucial as it assist the reader with an account of the worldview of the researcher, how it shapes the perspectives and thought processes that will emanate in this research work.

1.5. The Researcher and Positionality

I regard myself as a pragmatist, I have a strong belief that God has created humankind to be as different as possible, this belief allows me as a researcher to accept that there is multiple realities out there that is waiting for humankind to establish. Furthermore, this alignment with pragmatism engenders that as the researcher I will not be "asking questions about reality and the laws of nature" (Cresswell, 2013) instead I will focus on the problem and the manner in which it can be addressed.

On a spiritual dimension, I am an African male grounded in a strong Christian dogma. I grew up in a Christian family and believed that *Jehovah,* the God of ancient times has greater plans for men and their endeavours in life. The following passage is extracted from the holy bible. I always meditate about it:

> *"Before I formed thee in the belly I knew thee; and before that camest forth out of the womb I sanctified thee, and ordained thee a prophet unto the nations" (Jeremiah 1 verse 5, KJV)*

Academic, I have derived my passion on education in my early years of schooling. In 2007, I enrolled for B.Ed. and completed my undergraduate studies at the University of Pretoria. In the beginning of 2011, I furthered my post-graduate studies and completed a BSc honour with the University of the Witwatersrand of which I completed it in 2013. During the completion of my honours study, I was introduced to PCK (Shulman, 1987) using self-studies. From that point, my research interest in PCK grew.

Professionally, I started teaching at Dr. B.W Vilakazi high school in 2011. By that year, I have been involved with secondary school improvement program and tutoring grade 12 physical sciences. In 2013, I joined Kutlwanong centre for mathematics, sciences and technology education where I have been tutoring grade 10, 11 and 12. In 2015, I was appointed as a mathematics, sciences and technology head of department at Siyabusa secondary school. This appointment afforded me a window to view and inquire whilst monitoring how teachers plan and enact their lesson in our subjects.

1.6. Overview of the report chapters

This research has six chapters. Chapter 1 has preamble this thesis by outline background information concerning this research.

Chapter 2 is dedicated to the literature review. This is also accompanied by the theoretical framework employed for this research work.

Chapter 3 outlines the research design. This chapter further deliberates on the intervention located in methodology course, its structure and specific contents treated for 4^{th} year chemistry students.

In chapter 4, the analysis of the impact of the intervention on the quality of TSPCK is discussed; briefly, chapter 5 is aimed at answering the first research question on shift in the quality of TSPCK.

Chapter 5 is the response on the second research question that focused on the retention of TSPCK in stoichiometry.

The last chapter discusses and concludes findings presented in chapter 4 and 5. This discussion contributes theoretically to the PCK literature and paves a way forward for prospective studies in the examination of the development of TSPCK in chemistry topics.

CHAPTER 2: LITERATURE REVIEW

This chapter presents literature that was reviewed for this research work. In the first section I review studies on preparation of pre-service teachers since this study focuses on examination of the development of TSPCK in pre-service teachers. In the second sub-section-I provide a discussion on learning of stoichiometry and associated areas of difficulty. Thirdly, focus is to give to the re-conceptualisation of PCK at a topic level in view of initial teacher preparation. Lastly, I close by a brief review on the retention of PCK, especially pre-service teachers.

2.1. Preamble

This chapter begins by a premise that teachers have a direct bearing in the learning process of their learners, thus teachers' insufficient ability to transform content knowledge impacts negatively in the learner's learning process. As a result, there is an unquestionable need to explore ways in which pre-service teachers are generally prepared. Within this examination, pre-service teachers should be afforded opportunities to realise the type of sophisticated knowledge needed to attain coherent connections in their knowledge bases (Mavhunga, Ibrahim, Qhobela, & Rollnick, 2016). As indicated in chapter 1, this study focuses on the topic of stoichiometry, generally it is perceived as the most difficult and a fundamental topic in chemistry (Potgieteret al., 2005). Thus, this chapter will engage deeply with the learning and teaching of stoichiometry.

Lastly, a large focus in the re-conceptualisation of PCK, pre- and post 2012 summit is discussed relating to its topic specificity. There is an argument from empirical research that preparation of pre-service teachers should be topic-specific based (Nilsson & Loughran, 2012) and therefore this chapter will reflect of studies that avows for topic-specific PCK within ITE. TSPCK is fairly a recent construct, and as such, the literature has gaps. The last section of this chapter is attempt of this study to pinpoint existing gaps, especially with the retention of TSPCK after a certain time interval.

2.2. Preparation of science pre-service teachers

Effective initial teacher education (ITE) remains the panacea to challenges experienced with poor learner performance in South African schools, particularly in science classes. This argument is derived strongly from what Feiman-Nemser (2001) articulated, she claims that "*if we want schools to produce more powerful learning on the part of students, we have to offer more powerful learning opportunities to teachers*" (p. 1014–1015). Thus according to the author effective preparation of teachers will translate to acceptable learner performance. And as such, this study is anchored around this premise with the aim to explore nature and development of TSPCK when pre-service teachers plan to teach a specific chemistry topic.

A number of empirical research studies have reported success in improving the quality of PCK in a topic with science pre-service teachers. A number of different strategies and actions have been used. For example, Nilsson (2008) reported improvements through increasing opportunities for reflections in pre-service programmes. In Bertram and Loughran's report, (2014) through exposure and participation in classroom teaching experience using the content specific components of a CoRe. In the latter study, pre-service teachers' knowledge for teaching improved as the participants were allowed to complete CoRes, which they actively used in their teaching (Bertram & Loughran, 2014). However, of interest to this study is the success registered by Mavhunga & Rollnick (2013) who exposed pre-service teachers to an intervention that explicitly taught them how to transform content knowledge of a topic (Chemical Equilibrium) by thinking through the components of TSPCK (discussion to follow later on this construct) individually and interactively. The resulting effect was evidence of transformed understanding of chemical equilibrium enabling a discussion about the teaching of the topic in sophisticated ways. The treatment used was grounded in the pedagogy of transformation of content knowledge as found in the pedagogical reasoning process by Shulman (1987). According to Shulman, the act of reasoning through concepts of a topic for teaching is more important over and above the knowledge of conceptual facts. It encompasses knowledge about the make-up, the most important aspects of the topic, the links between concepts and ways of representations of concepts among other things.

In the study by Mavhunga and Rollnick (2013) the development of PCK in a specific topic was achieved through the introduction of the competence of transforming content knowledge. A similar finding is shown in Aydin, et al. (2015), where the development was achieved through the interaction of content-specific component of PCK in a topic. Hence, both these findings explicitly attest to the importance of the value of focussing at the topic level when developing core practices and knowledge such as PCK with clear focus on topics in Initial Teacher Education (ITE).

The next discussion expands on the learning and teaching of this topic - stoichiometry as the topic in which the development of PCK is explored in this study.

2.3. Stoichiometry and the associated Learning and Teaching Difficulties

2.3.1. Defining Stoichiometry

Stoichiometry is the branch of chemistry or physical sciences (in the South African curriculum) that deals with quantitative aspects of chemical change (Broster, Horn, James, & Solomons, 2012). It is best simplified by Kolb (1978) as arithmetic behind chemistry. Malcolm, Mavhunga, & Rollnick, (2015) have identified three Big Ideas associated with this topic. These are the *mole concept*, *concentration of solutions* and the *limiting reagent; reaction stoichiometry* is also an accepted Big idea amongst the concepts that makes up the topic. On the other hand, concepts such as dilution, volumetric analysis, and law of conservation of mass, balanced equations, and others were regarded as subordinate ideas embodied in the respective listed Big Ideas (Malcolm, Mavhunga, & Rollnick, 2015).

Stoichiometry is regarded as fundamental to other chemistry topics (Potgieter et al., 2005). Thus, its fundamental nature has a direct impact on other chemistry topics such reaction rates, electrochemistry, acids and bases, etc. Generally, poor understanding of stoichiometry results in a dismal learner performance in chemistry as a whole. Literature has documented a list of areas of difficulty with this topic; some of these difficulties pertain to teaching and other to learning processes.

2.3.2. The Learning Difficulties in Stoichiometry

Generally, the understanding of chemistry depends on making connections between invisible and intangible particles (Davidowitz & Chittleborough, 1999). Therefore, this hypothesis makes the study of the Big Ideas mentioned above such as a mole concept, concentration and reaction stoichiometry difficult to understand given that the mole is made up of a large number of sub-atomic particles (Kolb D. , 1978).

Furthermore, the notion that stoichiometry is chemistry arithmetic (Kolb, 1978) means that calculations are involved. Malcolm et al. (2015) have argued that some of the difficulties learners have, stem from their inability to perform calculations that require the mole concept; secondly, in constructing and balancing chemical equations, thirdly, algebraic skills, and in the interpretation of a word problem into procedural steps that lead to the correct answer. Thus, these shortcomings in learner ability to handle mathematical skills engender difficulty in the learning and teaching of stoichiometry. Additionally, these authors have argued that learners are found to solve problems relating to reaction stoichiometry by relying on algorithmic methods without necessarily acquiring conceptual understanding. This reliance on algorithm is an indication of the lack of conceptual understanding.

The mole set comprise of an abstruse number of particles, learners are required to develop mental pictures in order to represent these particles in a set, which they cannot see, or touch (Kolb, 1978). Thus it becomes difficult for learners to learn this topic because of how teachers teach it without taking into cognisance the conceptual understanding that learners must acquire.

A review by Kolb (1978) further asserts that the complexity of teaching the mole concept is attributed to mole definitions; she states that the mole has taken a more generalised meaning ranging from “weight of the substance”, “volume of substance for an example, 22.4 litres of a gas taken at STP”, “... the mass in grams of Avogadro’s number of molecules of any substance and etc. In averting this large quantity of definitions, the 20th century meeting held in Paris on weights and measures designated the mole as one of the seven basic units and both the United States Bureau of Standards (USBS) and the International Union of Pure and Applied Chemistry (IUPAC) endorsed the mole as the SI-unit for measuring the amount of substance. By definition, it is then regarded as an amount of substance that contains as many elementary particles as there are in 12g of carbon.

The knowledge of the full implications of the SI definition of 1 mole is a necessary condition for teaching the concept of a mole in accordance with SI (Tullberg, Stromdahl, & Lybeck, 1994). In addition, teaching this concept has been found to be difficult because of its complex and abstract nature from other counting units. Literature has documented *inter alia* the following parts as attributing difficulty in the teaching of the mole concept; (i) items that make up the set are invisible (Kolb, 1978), and (ii) the set is quiet abstruse. Furio, Azcona, &Guisasola (2002) are in agreement and point out that the complexity of teaching this idea "*the mole*" is based on the fact that the huge amount of particle that are involved in the mole are incomprehensible by learners. It is therefore hard to imagine the learning of how to teach stoichiometry without reference to these specific issues on what is difficult to understand in a topic.

Another aspect found that contribute to the complexity of teaching the mole, are common misconceptions held by students. Students assume that the mole exists in gases only (Novic & Mensis, 1976) and if there is a mole in the solid state it consists of molecules not atoms; thus moles exist only with two or more atoms. Secondly the common error committed by students is not restricting the molar volume of 22, 4 dm^3 to gases only (Novic & Mensis, 1976). In other words, they tend to apply it even in liquids and solids. I therefore argue that approaches to prepare pre-service teachers to teach science need to have reference to these specific learning difficulties and common misconceptions experienced within a specific topic, such as offered by the construct of TSPCK (PCK in a specific topic) in order for them to design their instructions around the learner prior knowledge.

2.4. Theoretical Framework

2.4.1. Pedagogical Content Knowledge as knowledge for teaching science

PCK came into existence during the late 1980s when Lee Shulman and his co-researchers at the University of Stanford proposed the seven professional knowledge bases for teachers (Shulman, 1987; Bishop & Denley, 2007). These knowledge bases were:

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

PCK was featured amongst the seven knowledge bases identified by these scholars for teacher professional knowledge (Bishop & Denley, 2007). However, Shulman (1987) argued that an overlap of content and pedagogy pointing to exclusive teacher's zone and their special type of professional knowledge was indispensable.

Following this argument, PCK has been widely conceived as that zone where a merger of content and pedagogy results in ways of representing and formulating the subject that makes it comprehensible for others (Loughran, Mulhall, & Berry, 2004), particularly learners. Conversely, Hassard & Dias (2009) defined this PCK construct as a teachers knowledge of how to assist learners comprehend specific content and how to create environment in which such comprehension of new content can occur.

As much as PCK has been defined as this type of special knowledge, it is more than just an overlap of pedagogy connected to specific content. Inextricably, it blends consistent and generative understandings of big ideas that make up the curriculum or a topic, depending on its specificity. Therefore, there is a significant need for teachers to master their subject matter (content knowledge), a wide range of teaching strategies and contextual aspects of their learners in order to execute their teaching responsibility efficiently. The synthesis of all these professional knowledge is regarded as PCK (Hassard & Dias, 2009).

Most interestingly, this construct (PCK) has been widely perceived as tacit (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008) and this means that it is difficult to measure empirically. However with its tacit nature, it continues to be widely employed by the science education community as a theoretical and an analytical framework in which an examination of teacher knowledge development can be understood. This has happened with in-service teachers (Aydin, Friedrichen, Boz, & Hanuscin, 2014) as well as with pre-service teachers (Mavhunga & Rollnick, 2013).

Since its inception, PCK has been reconceptualised to be defined from different levels of generality. Veal & MacKinster (1999) assert that PCK may be situated at disciplinary as well as topic level, thus introduced the PCK taxonomies without any experimental work done. They argued that, an acute difference between these two taxonomies lies in the centre of reasoning, especially when preparing for teaching. In the section below, I expand only on the topic specific PCK.

2.4.2. Topic specific nature of PCK

Magnusson et al. (1999) have argued that *'effective teachers need to develop knowledge with respect to … all of the topics they teach"* (p. 115). Inevitably, there has been a general agreement emerging form empirical research that supports the notion of PCK within specific topics. This idea was also suggested by Veal and Mackinster (1999) who introduced taxonomies of PCK. According to them PCK exist at a domain level, however it is best conceptualised at a topic level. Previous models in PCK such as Magnusson, et al., (1999) have components that are content – specific such as knowledge of learners, representation and instructional strategies and these components explicitly reveal the topic-specific PCK. The study by Aydin et al., (2015) employed these components amongst others such as knowledge of assessment and orientation to explicitly unravel topic-specific PCK with pre-service teachers. Findings of this study will be discussed on the section below. However, prior that discussion, a refined construct of TSPCK was coined by

Mavhunga in her Doctoral Thesis in 2012, thus I will begin the next section by defining and describing how TSPCK looks like.

2.4.3. Defining TSPCK

TSPCK has been generally conceived as ‘a theoretical construct referring to the capability needed to transform teachers’ own comprehension of a given topic into formats that are suitable for teaching” (Mavhunga, 2012). In a separate paper, TSPCK was further described as the competence to transform knowledge of a given topic for purposes of teaching (Mavhunga & Rollnick, 2013). The transformation of abstract knowledge – to be discussed later, happens through the content specific-components (Aydin et al, 2015).

According to Malcom et al., (2015) TSPCK is distinct from other PCKs (General PCK or Domain Specific PCK) since it focuses on the transformation of specific concepts (subject matter) at the topic level. Thus, this assertion implies that TSPCK differs from one topic to another.

2.4.4. TSPCK Model

Figure 2.1 below shows the model developed by Mavhunga (2012) with an aim of refining and locating the concept of TSPCK within the PCK fraternity. On the right hand side of the model, content-specific component are shown. These components are drawn from the work of Geddis & Wood (1997) within which the transformation of abstract content to formats readily available for learners to comprehend occurs. These components (shown on the right side of the model) will further be deliberated in the subsequent sections. The five components that make up TSPCK are *learner prior knowledge*, *curriculum saliency*, *what is difficult to teach*, *representation*s and *conceptual teaching strategies* taken from the work of Geddis & Wood (1997).

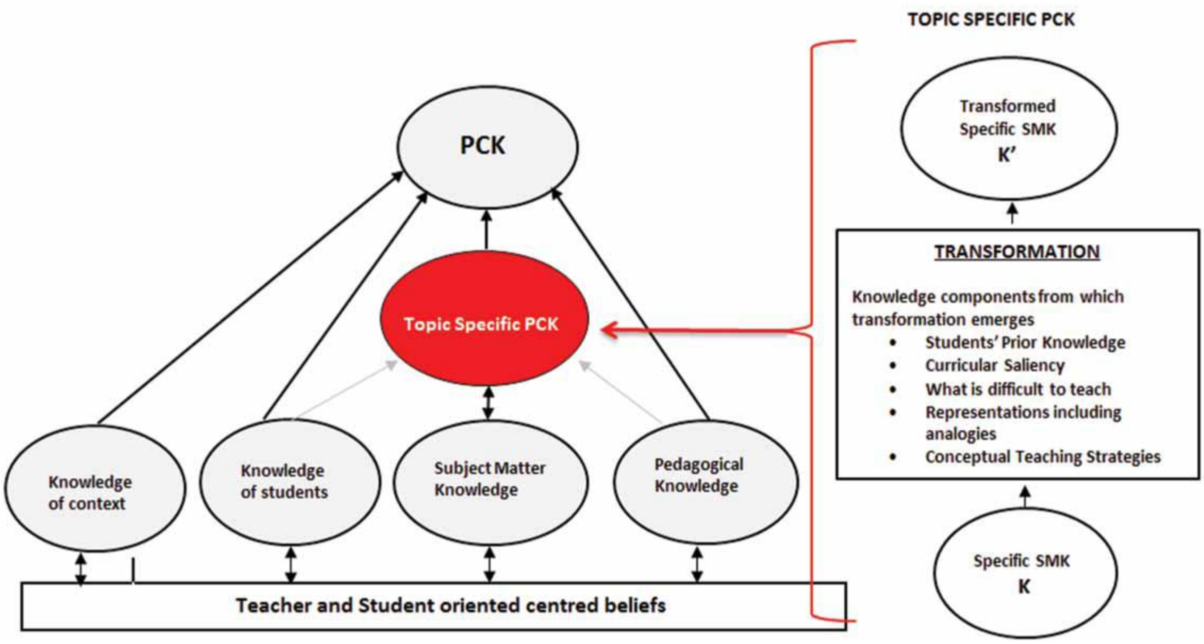


Figure 2.1**: TSPCK Model (Mavhunga, 2012)**

This model extrapolates strongly from Davidowitz and Rollnick (2011) PCK model. There are four knowledge components taken from Cochran et al., (1993) model that informs generic PCK, *see the bottom part of the model*. However, three of these, *viz*.: knowledge of students, subject matter knowledge and pedagogical knowledge informs TSPCK, see Figure 2.1. Within the TSPCK model there is a direct link between of subject matter knowledge (content knowledge) and TSPCK. Conversely, a strong TSPCK has been argued to impact on the specific content knowledge (Mavhunga, 2012). Conversley, previous studies such as Rollnick et al., (2008) posited that adequate SMK develops PCK. Then again this model attest that sufficient content knowledge and TSPCK are proportional.

The work discussed above was a great contribution in PCK literature. From the empirical point of view, it informed some aspects of the consensus model of PCK generated post the 2012 summit in the University of Colorado. Below, I preview this model in the next section:

2.4.5. Results of the 2012 PCK Summit – Consensus model

In October 2012 about 24 PCK scholars from across the globe, with different ideas about PCK were called to a summit in order to foster a unified conception of PCK. In Figure 2.2 below this model is shown taken from (Gess-Newsome, 2015).

The top part of the model portrays teacher professional knowledge bases (TPKB). Embedded in TPKB, are the various teacher knowledge domains: the assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students and curricular knowledge (Gess-Newsome, 2015). The second feature is locating professional knowledge at the topic level, i.e. TSPK (topic-specific professional knowledge) included in this feature is knowledge of instructional strategies, representations, learner understanding, science practices and habits of mind, the first three are more relevant in this study as explores PCK using content-specific components. This facet of PCK began to acknowledge the topic specific nature of PCK which was greatly informed by the TSPCK model.

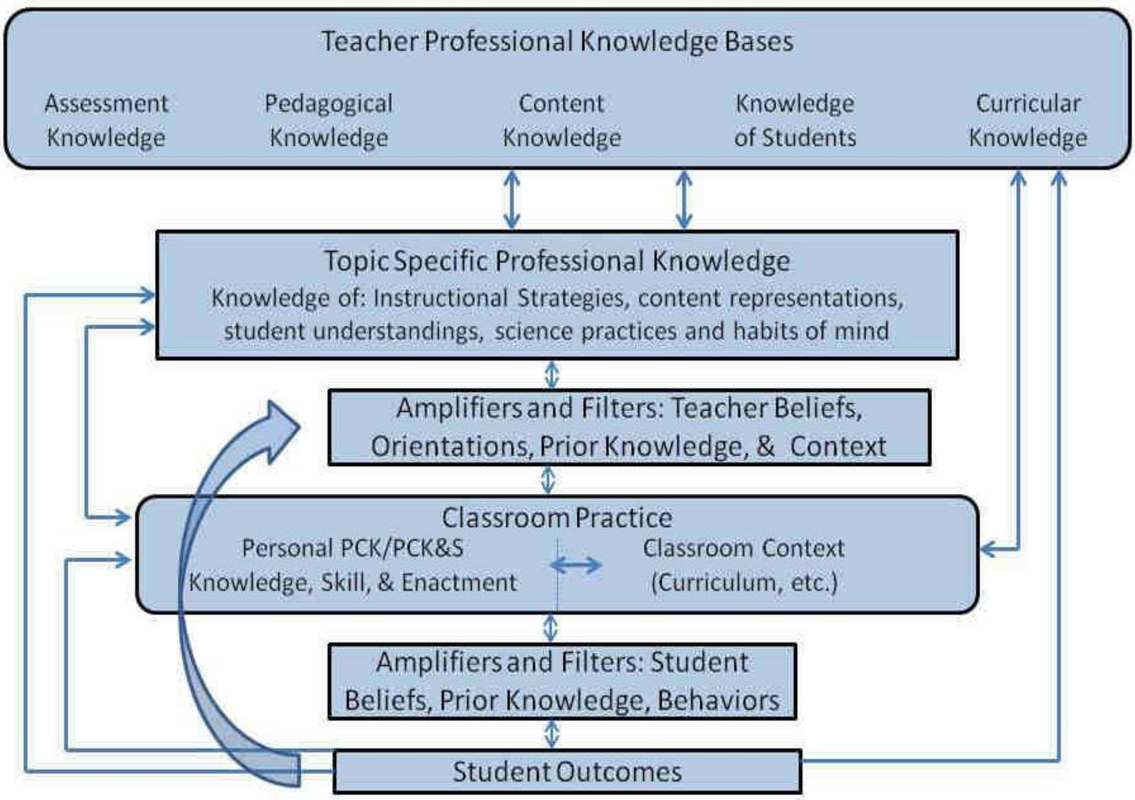


Figure 2.2**: PCK consensus model (Gess-Newsome, 2015)**

Unique in this model, PCK is viewed in two ways, i.e. a knowledge base used in espousing and delivering topic-specific instruction in a specific context, secondly as a skill involved during enactment of lessons (Gess-Newsome, 2015). In summary, it provides lenses of examining PCK at both planning stage as well as actual act of teaching stage.

Secondly, this model introduces the idea of PCK&S (pedagogical content knowledge and skill). Unlike the previous PCK models, this model shows a part on student outcomes and Gess-Newsome (2015) asserts that student outcomes are not an automatic product of teaching. They are a direct result of teachers engaging with content and simplifying it for learner comprehension. In addition to student outcomes, factors such as beliefs, prior knowledge and behaviours affect student learning such and are regarded as student amplifiers and filters.

2.4.6. Transformation of Content Knowledge within TSPCK Components

According to Shulman (1987) teaching is an act of transformation of subject matter to forms that are readily available to be comprehended by learners. In addition to this conception, Bishop & Denley (2007) alluded that transformation is part of the process referred to as "pedagogical reasoning". This pedagogical reasoning is used to give a description of how teachers pull from the pool of their professional knowledge about ideas to be taught and how to present them (Bishop & Denley, 2007). This transformation is best understood to occur as a direct result from the interaction of five content-specific knowledge components (Aydin et al., 2015). These components will be discussed later on in this section.

Before Bishop and the colleague further unpacked the notion of transformation of subject matter (or abstract content knowledge), it was discussed by Geddis et al., (1993) as well as Geddis & Wood (1997). They argue that transformation of subject matter into forms that are accessible to learners is important for teachers to master for learner comprehension of scientific ideas and should occur within specific components. In their expansion of this notion, Geddis & Wood (1997) proposed that the value of focussing on transformation of abstract content knowledge is that it draws attention to content, learners, as well as educational goals. According to Geddis et al., (1993) abstract content knowledge easily available to learners, needs to be transformed by being represented in an authentic manner as possible, that is, it should not lose the scientific value as argued above. The components that are mention will be discussed subsequently.

2.4.6.1. Leaner Prior Knowledge

The idea of prior knowledge has long existed in the field of PCK formerly referred to as knowledge and beliefs about students' understanding of specific scientific concepts (Hassard& Dias, 2009). This component of TSPCK also includes misconceptions (Rollnick & Mavhunga, 2015) that learners bring in class about the topic under discussion. However, the work done by Geddis et al., (1993) has placed this component as central to transformation of subject matter.

2.4.6.2. Curriculum Saliency

This aspect of teacher knowledge in which transformation occurs relates to the ways in which teachers learn to deal with the demands to complete the syllabus, by the virtue of this demand they prioritise an important topic in order to cover the curriculum. Furthermore Vokwana (2013) in her thesis clarified that this component encapsulate the knowledge of “which topics are fundamental and which are peripheral (p. 32)”.

2.4.6.3. What is difficult to teach?

One of the critical components of TSPCK is – what makes the topic difficult to teach. This component pertains to gate-keeping concepts in a particular topic as well as concepts that may not be easy for learners to understand. According to Vokwana (2013) this component “helps teachers in developing conceptual representations and instructional strategies which might be useful in confronting the difficulty of the concepts (p. 32)”. There are several reasons why students find learning difficult in some science concepts, some concepts are abstract such as the mole, quantum mechanics, protein synthesis (Magnusson, Krajcik, & Borko, Nature, Sources, and Development of Pedagogical Content Knowledge for Science Teaching, 1999), and thus teachers should be knowledgeable about each type of complexity and aspects of this complexity that makes it inaccessible to learners. This familiarity in turns would make it easier for the teacher to engage meaningfully with the next component of TSPCK, i.e. representations.

2.4.6.4. Representations

This component of TSPCK includes powerful examples, metaphors, analogies, models, simulations, diagrams and illustrations (Geddis & Wood, 1997) of learners’ familiar preconceptions or alternative conceptions. This component according to these authors is the result of pedagogical transformation of subject matter and the next component that is instructional strategies endorsing precise instructional encounters. Additionally, in this component, there are three levels of representation, as argued by Johnstone (1991) that must be taken into account for efficient or conceptual teaching of chemistry topics; these are macroscopic, microscopic and symbolic levels.

2.4.6.5. Conceptual teaching strategies

The last TSPCK component is conceptual teaching strategies. This component as mentioned above is the product of all the other four components (Mavhunga, 2012). The conceptual teaching strategies component needs teachers to go beyond the use of pedagogical strategies that requires the use of a mixture of conceptual values and is therefore the most perceived as the most complex when it is compared to the other TSPCK components (Malcolm et al., 2015). Firstly, a teacher must be familiar with learner prior conceptions (misconceptions or alternative conception) so that they can be in a better position to select appropriate representation(s) to be used in their conceptual teaching strategies. This component of PCK consigns to teachers' knowledge of specific strategies that are valuable in helping learners to grasp specific scientific concepts (Magnusson, Krajcik, & Borko, Nature, Sources, and Development of Pedagogical Content Knowledge for Science Teaching, 1999).

2.4.7. Reflecting on the value of TSPCK in pre-service programme

It is posited that pre-service teachers have incoherent PCK (Cochran, King, & DeRuiter, 1993), and PCK is generally understood to develop through practice (Mulholand & Wallace, 2005). However the inception of TSCPK has empirically proven that it can be taught or developed prior to practice. A number of experimental studies with pre-service teachers have shown that when pre-service teachers are exposed to an intervention that overtly targets the development of pedagogical transformation competence (PTC), pre-service were found to develop the quality of their PCK. A study by Mavhunga (2016) showed that the TSPCK based intervention directly impacts on the pre-service teachers pedagogical transformation competent (PTC) in the topic of chemical equilibrium. On average pre-service quality of TSPCK was found to have improved from basic to developing component interaction. In another study, Aydin et al., (2015) also showed that pre-service teachers in the topic of reaction rates, moved from fragmented to a more integrated and coherent PCK at the end of the practicum course.

In both studies, the quality of TSPCK is measured and understood to have developed when pre-service teachers intergrate TSPCK components as they plan to teach. This intergration of components is seen during TSPCK episodes (Park & Chen, 2012) which offered opportunities for evaluating the quality of TSPCK from different pedagogical context, such as planning and, or teaching.

Implications of such studies thus supported the view that initial science teacher professional development should be anchored greatly on developing PCK in specific topics within a certain science discipline. As argued above, this can be achieved through the use of the components of PCK that expose its topic specificity. Furthermore the development of PTC as a possible competence need for continual development of TSPCK across a wide range of topics. In addition, Mavhunga (2016) has pointed that focusing on a single topic during the intervention in order to placeprominence on the expansion of PTC makes the methodologycourses more suitable in a context and the time spent is meaningful. In a seperate study pre-service teachers have been found to expand their PTC in a topic of transference (Mavhunga, Ibrahim, Qhobela, & Rollnick, 2016), thus offering a possible pathway to empower pre-service teachers to continuously grow their TSPCK across a spectrum of science topics without depending on the engagement that explicitly develop their topic-specific teaching withing the methodology courses.

I therefore put forward that there is a need to further conceptualise this theory of TSPCK with pre-service and inservice teacher in order to develop effective knolwdge topic-by-topic in order to assist science teacher.

2.5. Retention of knowledge for teaching acquired by pre-service teachers

One of the of the fields within teacher education that has indicated paucity of empirical studies is the extent at which knowledge for teaching acquired during pre-service programme is retained. A recent study on in-service teachers reported that a positive retention of elements of PCK discussed in an intervention (professional development programme) were linked to the teacher's classroom practice a year later after the programme (Rozenszajn & Yarden, 2014)

Rozenszajn & Yarden (2014) have examined the expansion of two components of PCK of three practicing teachers in the course of a professional development aimed at designing new teaching and learning materials. In their study, the notion of retention of major parts of the expanded PCK after one year of professional development provided an influential way for PCK expansion (Rozenszajn & Yarden, 2014).

From personal teaching experience, I claim that it is thus important for science research such as this one to explore the retention span of TSPCK acquired in ITE programs. This examination will therefore inform teacher educators about how TSPCK outside the methodology course is shaped and developed, if not retracted.

2.6. Gaps in literature

As indicated in section 2.6.1 above, there is lack of studies in retention. There is another gap in terms of retention span of pre-service teachers who completed interventions that develops the quality of TSPCK and continuing with their post-graduate studies in contrast to those shoots straight to practice. This comparison will directly inform the role of class room exposure to the quality of TSPCK, especially for novice teachers.

CHAPTER 3: THE RESEARCH DESIGN

In this chapter, I unpack the research design of this study. I provide an account of how my worldview has shaped the choice of research methods employed in this study will be given. As this study explores the impact of an intervention, I therefore provide a description of the structure of the intervention followed. I also provide a description of the size of the sample for the two research questions. Data collection process as well as the tools use is also described with the help of the flow diagram. I close by highlighting actions taken to contribute towards validity and reliability.

3.1. Preamble

> *"Research may be seen as an activity that leads to the answering of questions or creating that which does not currently exist. It should be clear that research is not just about gathering information. Information has to be analysed and interpreted, and this should lead to answering questions about the problem" (White, 2004 p. 9).*

The assertion by White (2004) must be taken into thought with the notion that different researchers have different philosophical postulations. They have different beliefs and approaches of interacting with their surroundings as well as data at their disposal. This supposition makes it important that a paradigm at which a researcher conforms too is outlined. This in turns assist a reader to assume a close perspective as the author intends. In addition, the choice of research methodology and methods is indisputably influenced by this philosophical conformation of the researcher (Creswell, 2013). In Chapter 1, I have outlined that I regard myself as a pragmatist. This worldview has shaped my ontological and epistemological beliefs in many ways. In the following sections, I will unpack the research design, and show how it is aligned to pragmatic school of thought.

3.2. Methodology

Methods are described as techniques or processes we use to conduct our research; conversely, methodology is the discipline that employs these methods

(Kinash, Wood, & Mathews, 2010). So, in this study a mixed method design is employed. This methodology uses both qualitative and quantitative methods (Creswell, 2013) situated within the pragmatic paradigm. Pragmatism as a philosophy is known for not committing to one system of reality but aims for a more holistic view (Creswell, 2013). MM type of research has commonly been used in social studies and is common in studies of individual behaviour, such as this one. Opie (2004) defined MM as affording researcher(s) with multiple perspectives and interpretations, i.e. quantitative and qualitative. I therefore employed this methodology because of its compatibility with pragmatism.

Creswell (2013) argues that a clear rationale that accounts for using MM design must be given. In this research, I employed PCK as a theoretical framework, more precisely PCK at a topic level, i.e. TSPCK. PCK has been largely defined as tacit (Rollnick et al., 2008), by inference, so is TSPCK (Mavhunga and Rollnick, 2015) and its development at a topic level has been found to be idiosyncratic (Aydin et al., 2015). This means that, a researcher must be able to use multiple perspectives in order to examine the development of such knowledge per pre-service teacher.

Quantitative studies have their specific limitations; this involves its positivist approach to reality and a focus on manipulation of variables (Creswell, 2013). This methodology thus absolves the study from rich data that can be gathered qualitatively and offer the researcher(s) an in-depth understanding of phenomena. Contrary to quantitative studies, pure qualitative research generates findings that cannot be generalised (Opie, 2004) hence a paradigm shift that combines both methods is inevitably useful for studies in the social science.

During the 20th century, social sciences research has seen a paradigm shift from both ends of the two approaches. There is a convergence into a mixed method approach. Thus, most social sciences research studies are now situated in the continuum between the extreme ends. MM, thus have aspects of quantitative data with evidence drawn from qualitative data and, or vice versa. In clarity, "...*investigators use both quantitative and qualitative data because they work to provide the best understanding of a research problem*" (Creswell, 2003 p. 12), particularly when a complex construct such as PCK in a topic is explored.

3.3. Research Strategy

This study employs a case study as research strategy According to Yin (1994) a case study is understood as an empirical inquiry in which a focus is on a contemporary phenomenon within its real-life context; however, boundaries between phenomenon and its context are not evident. On the other hand, Opie (2004) defined a case study as an "in-depth study of interactions in a single instance in an enclosed system" with boundaries. According to this author, case study focuses tightly on a particular instance with the objective of revealing ways in which events come together to create certain outcomes. This view is supported by Cohen, Manion, & Morrison (2011) who proposed that a case study afford a distinctive example of “real people in real situations” and therefore serves to enable a reader to understand ideas clearly when presenting them with theoretical principles. This study followed the definition by Opie (2004) as it offers strategy to focus on a particular group of people such as chemistry pre-service teachers in this study.

The following criteria to qualify a study as a case study are outlined in Opie (2004):

> (i) ... frequently designed to illustrate a more general principle, (ii) —the focus is one unit of analysis (iii) — concentration upon a particular instance in order to reveal the ways in which events come together to create particular kinds of outcomes and lastly — an opportunity for one aspect of a problem to be studied in some depth within limited time scale (p. 74).

Based on the latter criterion my study can be considered to be a case study because it focused on the development of chemistry teachers’ knowledge for teaching a specific topic – stoichiometry, for a group that stayed together in a given period of time. Consequently, I have considered this method due to the contextual reality it brings to my research work. Although this is commonly regarded by many researchers as difficult to systematize and analyze, it is based upon a real happening and is strongly linked to my own experience as a teacher.

3.4. Sample

The sample of this study consist of the 2015 cohort of 4th year students herein referred to as pre-service teachers majoring in physical sciences and graduated in 2016. Sampling was done conveniently and purposefully, purposive sampling is applicable in special instances where a researcher selects cases with a specific purpose in mind (White, 2004). In this case, the class was selected because the methodology course had an explicit goal of developing TSPCK in selected core topics, including Stoichiometry. The participants had been exposed to an intervention of TSPCK for a specific period. These participants are within the age range of 20-25 years.

The first question examines the shifts observed in TSPCK because of direct exposure to the intervention. Participants were required to complete TSPCK tools in stoichiometry as a set of pre and post-intervention test in order examine the impact of the intervention. Only 10 pre-service teachers were able to complete both tools. So the analysis of data for the first question is based on 10 pre-service teachers.

The second research question involves the examination of retention of TSPCK; sampling for this task was done conveniently for the feasibility of the project. Convenient sampling is defined by Opie (2004) as a technique where a researcher(s) choose nearest individuals and continue until they have the required number. In this case, only five participants from the cohort who were followed since they were still in the University furthering their BSc in science education Honours programme. The Honours programme by being in the Faculty of Science has a very strong content knowledge emphasis as opposed to a focus on education theories. Thus, the exploration of retention of the quality of TSPCK was on interest as the construct is not discussed explicitly.

3.5. Explaining the TSPCK based Intervention in Stoichiometry

The sciences methodology courses in third and fourth years of the B.Ed. degree undergraduate programme has an explicit focus on developing specialization for professional knowledge in teaching core topics (Mavhunga & Rollnick, 2017). TSPCK as construct has been found useful; it facilitates discussions and attainment in one topic at a time. In this methodology course, pre-service teachers are prepared explicitly using this construct to develop required knowledge for teaching physical sciences in South African context. This part of the course is called an intervention and not an instruction because of its specific aim that deliberately exposes pre-service teachers to the components of TSPCK. The intervention runs over a period of six weeks, where each contact session consisted of a three-hour period. The components of TSPCK are introduced one at a time in a form of both a formal lecture and a tutorial. Table 3.1 below shows a breakdown of the focus of the intervention when discussing each TSPCK component and the sequence of discussions:

Table 3.1**: Description of the TSPCK intervention in stoichiometry**

TSPCK Component (week)	**Intervention**	**Specific Content**
Learners' prior knowledge (1)	Discussions were on widely researched common misconceptions of the topic found in the literature.	The Mole, understanding molar mass, gases at STP, converting between units, concentration and dillusion
Curricular saliency (2)	Discussions were geared towards identifying the 'Big Ideas' and the corresponding subordinate concepts in a topic; sequencing big ideas; awareness of the foregrounding concepts, and knowing what is most important to understand in a big idea.	Chemical change, balancing chemical equations, reaction stoichiometry, ions in solution, concentration and solution stoichiometry, application in industries and other field and chemical literacy
What is difficult to teach (3)	Exploration of concepts considered difficult to learn, and identifying the actual issues that make understanding difficult. This focused on the pinpointing the actual difficulty.	Molar volume, stoichiometric calculations, volume in gas reactions, stoichiometry for gas reactions, gas laws, conservation of mass, stoichiometric calculations, limiting reagents, reaction stoichiometry, actual yield
Knowledge of representations (4)	Introduction of the three levels of explanations in chemistry at macroscopic, symbolic and sub-microscopic levels. Emphasis was placed on the power of using all three representations side by side in explaining a phenomenon.	Limiting reagent, practical demonstration, chemical equations, reaction of hydrogen gas and nitrogen gas

Conceptual Teaching strategies (5)	Conceptual teaching strategy would consider the generated knowledge from the other four components.	Volume of gases, amount of the substance, periodic table, percentage composition, guided experiments, concentration
Pulling it together (6)	Introduction of Content Representations (CoRe) as a tool to capture thoughts as one thinks about content knowledge of a topic through the knowledge components of TSPCK.	

3.6. Data Collection Instruments

In this study, data was mainly collected using a TSPCK stoichiometry tool; see Appendix II. The data for the second research question, exploring retention of TSPCK in stoichiometry was collected with the same tool and corroborated by follow up interviews to confirm the patterns observed from the TSPCK responses. These interviews were conducted using the interview schedule with semi-structured questions; see Appendix V. In the next section, I provide expansion on the structure of the TSPCK tool in stoichiometry.

3.6.1. TSPCK in stoichiometry tool

Kind (2009) argues that developing valid instrument(s) to measure teachers' PCK is an integral part in teacher education. Additionally, amongst other contributions, measuring PCK facilitates science teachers in developing their teaching practice and identifying areas for teacher support and growth. In stoichiometry this tool firstly assist science community, particularly chemistry teachers to develop and advance their instructional practice, and afford the teacher educators with understanding of the type of knowledge needed to develop pre-service teachers.

The TSPCK tool in Appendix II, was developed and validated in a separate study, with the purpose to provide tools for the measurement of the baseline PCK of South African teachers for a specific topic in chemistry, i.e. stoichiometry (Malcolm et al., 2015). The tool is structured per the five components of TSPCK. Items in each category are structured as teacher tasks seeking responses to classroom learning and teaching contexts.

The tool has categories of TSPCK arranged from difficult to easy, and curricular saliency was found to be difficult, in order to understand the impact of the intervention program, the tool by Malcolm et al. (2015) was used to elicit pre-service teachers' knowledge before they undergo the intervention.

The first TSPCK component engaged in the tool is the "Learner Prior Knowledge". In a tool, a scenario begins by outlining a known area of learner misconception; the extract below is taken from the tool on the first component:

1. Before starting the section on reaction stoichiometry you give the learners a diagnostic test. One of the questions in the diagnostic test is reproduced below.

Each cube represents a volume of 22,4 dm³ at STP. In which of the three pairs of cubes, Set A, Set B or Set C, is there 1 mole in each cube and in which of the three pairs cannot contain 1 mole in each cube?

Set A Cubes		Set B Cubes		Set C cubes	
N_2 (g)	H_2 (g)	O_2 (g)	Hg (ℓ)	SO_2 (g)	S (s)

How would you respond verbally to learners who state that all the cubes contain one mole?

Figure 3.1: **Extract for the component of Learner Prior Knowledge in the TSPCK Tool**

Pre-service teachers are given a set of four choices, each of which are correct to chose the one that can best address the misconception. They are then required to explain their choice and support their choice. The next category in the tool is based on the component of curricular saliency. In this category pre-service teachers are given a list of concepts in stoichiometry. They are required to choose a set of three big ideas and choose and place them in a sequence that depicts the best order of teaching. Additionally they are to provide reasons for both your choice and suggested sequence.

The third category focuses on the component of "What is difficult to teach". In this category, the list of concepts taught is stoichiometry is given and pre-service teaches are asked to tick those which are difficult to teach and cite with reasons why do they regard them as difficult.

The fourth category focuses on the component of "Representation". Three different representations, with different level of representations (particulate, symbolic and macroscopic) are shown. Respondents are asked to critiques each representation. Secondly, they are required to choose the most suitable representation that which they can use to teach. After choosing, they should indicate how they are going to use it.

Lastly all these four components inform the choice of an appropriate teaching strategy. The next extract is a sample response from the learners when dealing with the concept of limiting reagent:

About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:

$$TiC\ell_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgC\ell_2(\ell)$$

In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.

Titanium (IV) chloride Limiting reagent is the reactant with the least number of moles in the equation	Magnesium This is the reactant present in the least amount according to mass.

Figure 3.2: **An extract of a scenario from the TSPCK tool for the component of Conceptual Teaching Strategy**

In this category, pre-service teachers were supposed to design a conceptual teaching strategy that will confront this misconception.

Will all these components studied together, we can begin to measure the quality of TSPCK in a topic of focus. Thus, at the end of the intervention, the same tool was used to evaluate the influence of the program. In order to examine if there was any development, category difference as outlined in the TSPCK rubric – see Appendix IV, will be analysed.

3.7. Data collection process between 2015 and 2016

This study is part of the larger PCK study within the science education division, in the University of Witwatersrand. It has elements of a longitudinal study, as it entails looking at data collected a year ago and comparing it to new data collected in 2016. I therefore accessed the archived, completed TSPCK tests, done at the beginning of the intervention as pre-test and at the end the intervention in 2015 as post-test. These TSPCK tests were completed in 2015 and stored in the archives of the course without being analyzed. They then became my data for analysis of the shifts in the quality of TSPCK in stoichiometry as the result of the intervention. They were then analysed, discussed below, to measure qualitative shifts between the pre and the post intervention ability of the pre-service teachers to transform content knowledge in stoichiometry. This set of pre and post TSPCK test was analysed to respond to the first research question about the impact of the intervention on the quality of TSPCK.

Similarly, in 2016, after one year the intervention ended, five former pre-service teachers were followed. These followed former pre-service teachers were enrolled in the in the year to fulfil their BSc in science education honours studies. The same TSPCK tool was re-administered with the then pre-service teachers to measure the degree of retention of the quality of TSPCK. This data was further corroborated with face to face interviews. In Appendix V, the interview schedule was followed. The sample of questions that were asked shown below:

i. What is your understanding of TSPCK?
ii. What are you currently engaged with?
iii. To what extent have you found this concept/theory useful in your current engagement?
iv. Which component of TSPCK you have found to be difficult?
v. Which component of TSPCK you have found to be easier?

In summarizing an account of data collection process, Figure 3.3 provides a schematic representation of the process followed

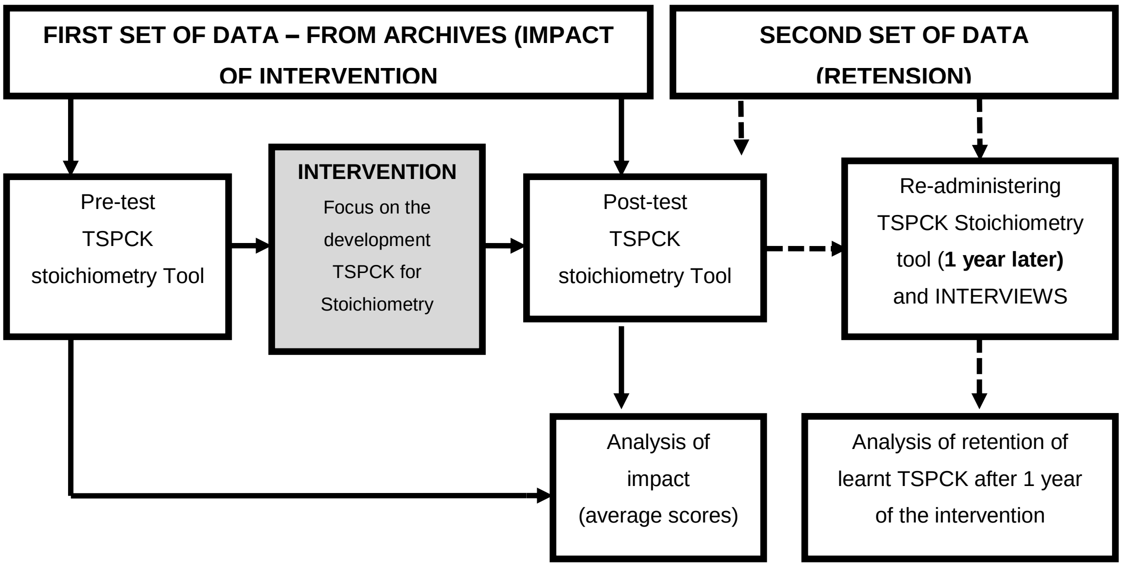


Figure 3.3**: Process for data collection and analysis**

The first question is answered by the first set of data, shown by solid arrows on the left hand side of Figure 3.3. This question explores the impact of an intervention that explicitly discussed TSPCK components during the development of teacher knowledge for teaching stoichiometry. After one year of the intervention as mentioned above, TSPCK tool in stoichiometry was re-administered with five former pre-service teachers. This data was collected for comparison between a post intervention and a period of one year, shown with broken arrows on the left hand side of Figure 3.3.

3.8. Data Analysis

This study employed a mixed method analysis method. This approach to data analysis strongly conforms to pragmatism (Driscoll, Appiah-Yeboah, Salib, & Rupert, 2011). This data analysis method is conceived by Onwuegbuzie & Combs (2011) as involving the analysis of one or both data type which occurs either concurrently or sequentially.

The rationale behind the choice of this approach to analysis is grounded on the basis that PCK is tacit (Rollnick, 2008) and so is TSPCK. This tacit nature of TSPCK requires that multiple views should be used to analyse data in order to enhance the value of the claim generated in the study. In addition, as I have indicated above a researcher, I have aligned myself with pragmatic worldview, thus a pluralistic approach to data analysis is required to unfold an in-depth understanding of the development of TSPCK. Lastly, this study has elements of longitudinal program of inquiry, thus Cresswell (2013) argues for the need of mixed method analysis in such studies to enhance the quality of the findings.

During data analysis in this study the sequential mixed method was followed. In this approach to data analysis, "*qualitative analysis phase precedes the quantitative analysis phase or vice versa, and findings from the initial analysis phase inform the subsequent phase (Onwuegbuzie & Combs, 2011, 3)*".

Thus, firstly, data was analysed from the quantitative point of view and average scores per TSPCK components calculated from pre and post-test responses. Secondly, they were compared to indicate the shifts in the quality of TSPCK described in the TSPCK rubric, see Appendix IV. This rubric was used to score individual tests written by the pre service teachers during the pre- and post- TSPCK test responses. The rubric is structured into the five components of TSPCK. Each component has criteria describing possible increasing understanding and extent of interaction with other components across four categories of performance. There four response categories in the rubric are, "Limited", "Basic", "Developing" and "Exemplary"; describing the degree of TSPCK component interaction. The first description as illustrated in the TSPCK rubric indicate lack of component interaction whereas, "Exemplary" describe evidence of TSPCK component interactions. These descriptors from "Limited" to "Exemplary" illustrated progression from one response category to another and were marked using a Likert scale of 1 to 4. An example of the extract of the rubric describing the four categories of performance for the component of learner prior knowledge is shown below in Figure 3.4

	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
Learner Prior Knowledge	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • No attempt to address the misconception.	• Identifies misconception or prior knowledge • Provides standardized definition as a means to counteract the misconception • No evidence of drawing on other TSPCK components.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using one other component of TSPCK interactively.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on two or more other components of TSPCK interactively.

Figure 3.4: **An Example of an extract from the rubric describing the four categories**

In order to convert qualitative responses to data that can be interpreted quantitatively, the Rasch statistical model (Ministep Winstep Rasch version 3.92.1) was used. According to Bond and Fox (2001) this model converts raw scores for each item, in this instance scores generated from the TSPCK components responses to probability measures that are now placed on a linear scale of equal intervals (Bond & Fox, 2001). This means that the scale of Limited to Exemplary (or 1-4) used in the TSPCK rubric gets converted to a linear scale where the interval between 'Limited' and 'Basic' is equal to that of 'Basic' and 'Developing' and so on. The advantage of such a scale is that it provides a rank order displaying the order of the extent of difficulty of TSPCK components as experienced by the participants. Furthermore, Bond and Fox (2001) indicate that the Rasch model has an added benefit of calculating two sets of values to help the researcher determine the validity of a set of measures, i.e. person measure and item measure. This is seen as important for a researcher since it evaluates if all the items have internal coherency and the same for the persons' responses. In addition the model has a way of calculating validity by measuring whether the items and persons' responses work together to measure a single construct. Thus, the use of the Rasch model in this study provided a sense of validity and reliability from the quantitative aspect of the study. This method was used to determine the validity and reliability of the pre and post-intervention scores – in response to the first research question.

The pre- and post test scores were compared the scores in two ways firstly I used the qualitative scores generated in the TSPCK rubric – to established overview of the pattern per group and per TSPCK component. Subsequently, I provided examples of qualitative evidence of difference in the responses of sample individual in the pre and post to map the quality of shift in the categories of the TSPCK quality.

The data for examining the retention of quality of TSPCK was analysed through in-depth qualitative methods. In this case I analysed the responses in the TSPCK tool using the TSPCK rubric and show how the responses reflected TSPCK episodes. Average scores per TSPCK components were calculated to measure the degree, of growth, retention or retraction in the quality of TSPCK. Furthermore, TSPCK episode are defined as evidence of moments where two or more TSPCK components are used interactively in an explanation or in a response. Subsequently, interviews were used to confirm the observed overall patterns of the group and individuals.

3.9. Validity and Trustworthiness

MM design requires that reliability and validity be established using traditional methods of each research strand. Firstly this section will mainly focus on the two aspects of rigour, i.e. validity and reliability on behalf of quantitative methods. Secondly, it will focus on trustworthiness and credibility of qualitative methods employed in this study on behalf of qualitative methods.

3.9.1. Validity and Reliability

Different scholars have viewed the concepts of validity and reliability differently. For the sake of this study, I have aligned with the view provided by (Maxwell, 1992). His view is that validity is the extent at which a tool, method or tests measures what it supposes to measure. Furthermore Kane (2012) adds that all validity is construct validity. He aligns himself with Newton's notion that takes validity to be a property of proposed interpretations and uses of test scores. Conversely, this study adopts the same notion of validity, i.e. the test measures exactly what it supposed to measure, in this case, the quality of TSPCK. Thus, in this study, the validity data interpreted was established using the fit statistics calculated by this Rasch statistical model. According to Boone & Rogan (2005), a construct is valid if all the items or components that make up that theory (construct) fall within the conventional statistical range of -2:2. Thus for this examination, the Rasch fit statistics were used to determine the construct validity, these were calculated for both the pre and post test scores.

On the other hand reliability refers to dependability, consistency and replicability of results, over time, over researchers and over groups of respondents (Cohen, Manion, & Morrison, 2011). In this study a TSPCK rubric was employed to mark qualitative responses from the TSPCK tool. Prior the marking process, three responses were selected and marked independently by raters in order to improve reliability through inter-rater reliability.

Furthermore, both persons and item reliability indices which are equivalent to the traditional Cronbach value were calculated and analysed to establish quantitative reliability.

3.9.2. Trustworthiness and Credibility

The first aspect relates to trustworthy. Opie (2004) asserts that trustworthy has to do with confirmability. This aspect of qualitative rigour means that data collected form one instrument can be confirmed with another data collected from another instrument. Thus in this study, trustworthiness is established through qualitative means of collaborating different data sets called methodical triangulation. The data collected from interviews, was collaborated with data from written responses in the TSPCK tool for establishing retention. Secondly, prior the analysis of data, inter-rater reliability was achieved with the two other raters

On behalf of credibility, Opie (2004) outlines criterion that can be followed to insure that the study is credible. Firstly data-gathering procedures are explained as done in section 3.7. Secondly, data presented in findings chapter is transparent, and it is ready re-analysis. Negative instances ere explicitly reported, this involves instances where data did not fit the beliefs of the researcher.

3.10. Ethical considerations

Prior the process of engaging existing data, an application was sent to the ethic committee earlier in the year 2016 for clearance. Subsequently, the study was granted clearance with the protocol number: *2016ECE022M;* see Appendix I. This study has longitudinal elements, thus consent forms were already signed by students (4^{th} year pre-service teachers) in 2015.

Pertaining to the protection of research participants, Howe & Moses (1999) distinguishes between two ways of maintaining the privacy of participants. These issues are confidentiality and anonymity. To cater for confidentiality, pre-service teachers were given pseudonyms. Secondly, to cater for anonymity, in this study the data analysed and presented in chapter 4 and 5 is identity specific. Secondly the pseudonyms used in the study were not based on the actual gender of the participants. Thirdly, the name of the institution at which data was collected was not explicitly mentioned.

Interviewing in qualitative research is progressively more of a moral inquiry (Kvale, 2006). This according to the author is true for mixed method design, consequently the researcher must take into account if how will the research improve human situation and adding to the body of knowledge. To cater for this issue, the researcher in this study makes considerations that the interaction between researcher and respondents may be stressful for respondents. In this ethical issue, Creswell (2013) then suggests that Interviews should begin from the premise that a power imbalance exists between the data collector and the participants. Thus in this study interviews were actively involved. This approach to interview creates the likelihood of public conversation between the two parties. Active interviews does not automatically endeavour for agreement between interviewer and interviewee (Kvale, 2006).Thus in this approach power imbalance is addressed.

CHAPTER 4: THE IMPACT OF THE INTERVENTION ON TSPCK IN STOICHIOMETRY

In this chapter, I begin by recalling the research question on the impact of the specific intervention on quality of TSPCK acquired by pre-service teachers. I outline the analysis by first establishing the reliability of the qualitative values obtained, and then confirm validity and reliability from quantitative means. Once validity and reliability has been established I then present the findings on the impact of the intervention on the quality of TSPCK in Stoichiometry close the chapter with a brief summary of findings and their link to the literature on TSPCK.

4.1. Preamble

The purpose of this study was the examination of the development of pre-service teachers' TSPCK in stoichiometry following an intervention that targeted the pedagogical transformation of content knowledge. In this chapter I therefore analysed data for the measurement of the extent of development of TSPCK as a direct result of the TSPCK based intervention. For analysis, data from completed pre and post TSPCK tools were retrieved in the archives of the chemistry methodology course, in which the intervention was done. The class consisted of 24 participants, however, data from only 10 participants could be organized into pairs of pre and post-TSPCK completed sets. In caring out this task both, qualitative and quantitative methods were employed. As mentioned in the Methodology chapter, chapter 3, the employability of qualitative data analysis in this project is justified by the notion that PCK is tacit (Rollnick, et al. 2008); by inference so is TSPCK (Rollnick and Mavhunga, 2015). Given the tacit nature, it can best be explored from both qualitative and quantitative approaches, i.e. mixed method analysis

As mentioned in the Chapter 3, for each completed test, participants' responses where scored against criteria contained in the TSPCK rubric, see Appendix C. Values generated from the rubric were then averaged and compared visually for category score difference between the pre and post TSPCK tests. Care for improving reliability of the generated values was assured by two raters whose agreement was found to be 89% and 78% in the pre and post-test respectively.

Where there was disagreement, the raters discussed with convincing evidence until consensus was reached. The values generated from pairs of pre/post test with 10 pre-service teachers from this process are presented in Table 4.1below.

Table 4.1**: TSPCK values for Pre vs. Post Test in Stoichiometry**

Pre-service teachers	LPK	CS	WiD	Rep	CTS	Person Mean
Moosa	1 (3)	2 (3)	1 (4)	1 (4)	1 (1)	1 (3)
Mandla	2 (3)	1 (3)	2 (2)	1 (3)	2 (4)	1 (3)
Precious	1 (1)	2 (2)	2 (3)	1 (1)	1 (2)	1 (2)
Itumeleng	1 (2)	1 (3)	1 (4)	1 (2)	1 (1)	1 (2)
Henry	1 (2)	2 (3)	2 (4)	1 (3)	2 (4)	2 (3)
Jacob	3 (3)	2 (3)	3 (3)	2 (3)	1 (2)	2 (3)
Hlengiwe	1 (2)	2 (3)	2 (4)	2 (3)	1 (1)	2 (3)
Lexy	2 (4)	3 (4)	3 (4)	3 (4)	3 (4)	3 (4)
Lucas	2 (4)	2 (2)	3 (3)	1 (2)	1 (1)	2 (2)
Mandisa	2 (3)	2 (2)	3 (3)	1 (1)	1 (1)	2 (2)
TSPCK Component average	**2(3)**	**2(3)**	**2(3)**	**1(3)**	**1(2)**	**2(3)**

Note that pseudonyms In the Table 4.1 have been used for anonymity reasons, the abbreviations shown in the top row of the table represents the TSPCK components, viz.: LPK represents “Learner Prior Knowledge”, CS represents “Curriculum Saliency”, WiD represents “What is Difficult to teach”, Rep represents “Representation” and CTS represents “Conceptual Teaching Strategies”. The values written in the bracket were generated post the intervention, wherein those outside the bracket were pre-test values. These values were then averaged in order to describe the shifts indicating improvement of TSPCK in terms of category differences. These shifts observed were based on the average values calculated mathematically across each TSPCK component. These averages were then analysed to signify the overall score of the group (Mavhunga, 2016). The overall values for pre and post-tests were interpreted against corresponding response category mapping the quality of TSPCK outlined in the rubric. It is important to recall that the criteria for each quality of TSPCK represented in the TSPCK rubric, calls for a determination of the extent of interaction of the components as argued by Mavhunga (2016). Thus the calculated average values stand as a proxy for measurement of the probable overall and summative outcome of the component interactions (Mavhunga, 2016). Furthermore, average values were generated as decimals during analysis; Mavhunga (2016) draws attention to the limitation in the sensitivity of the scale of the TSPCK rubric. She stresses that calculated averages are generated as fractional values; hence, they have to be rounded off in this analysis in order for them to be located suitably in the corresponding category, hence the average values shown in the Table 4.1 have been rounded off for locating them in an appropriate category.

Subsequent to that, raw scores from Table 4.1 were subjected to a Rasch analysis to ensure equal level of difficulty between the categories that grade the quality of TSPCK in the TSPCK rubric. Boone and Rogan (2005) outlined the importance of Rasch analysis. According to them, raw scores at either ends of the scale (linkert) have the greatest margin of error, so the use of Rasch person measures would additionally provide a precise picture of performance in a test. Furthermore, the Rasch statistical model allows calculation of validity and reliability of both items and persons (Bond & Fox, 2001). The Rasch model lets a researcher create person-item maps, provides indices of person separation reliability and item separation reliability (Boone & Rogan, 2005). These maps and indices statistically assist to evaluate the construct validity of an instrument, and the person-item maps may be used to explicate construct validity by evaluating the distribution of items along the latent scale (Boone & Rogan, 2005).

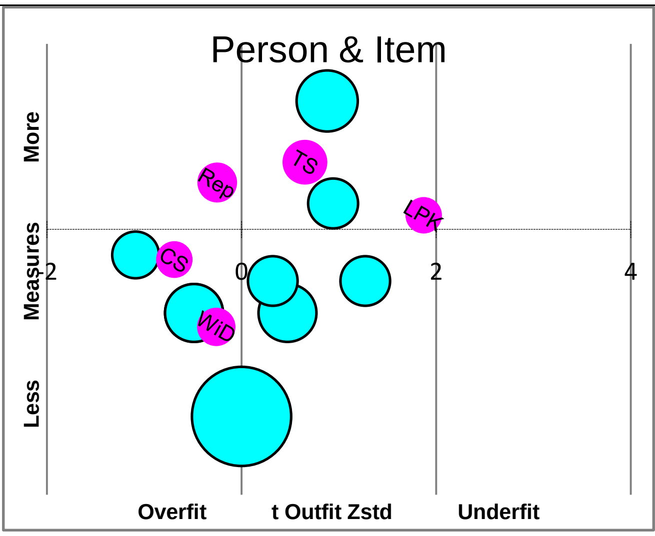
The calculated person reliability complemented that which was established through qualitative means by raters. The Rasch statistical model was used even though the sample was small because it ensures a better match between measure and the target sample (Wirth, Houts, & Deal, 2015). Moreover, the TSPCK tool in stoichiometry have been previously validated and used in separate studies (Malcolm et al., 2015). The use of Rasch with small samples has been argued in (Gruijter, 1986). He asserts that Rasch is usually applicable in larger sample, however small sample studies could benefit from the calculations offered by Rasch in order to determine patterns rather than to focus on accuracy of single values. Hence, the values from both pre- and post-TSPCK tests were converted into probability measures and standardized through this statistical model (Boone and Rogan, 2005) as argued above. These probability measures are presented in Table

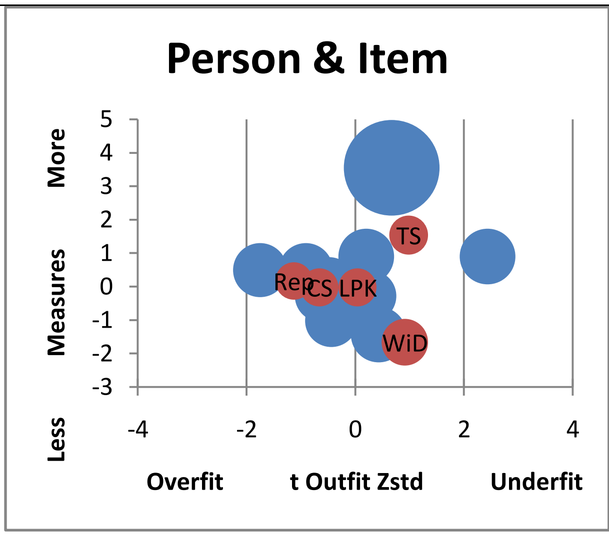
4.2 below for further determination of patterns. In the following section, I will show how validity and reliability was established.

(i) Establishing validity

The Rasch model provides many tools that let one consider a subject of validity in details (Boone & Rogan, 2005). It does this measure by generating a bubble chart that shows a distribution of items. According to these authors, these maps are for showing the distribution of the difficulty of the test items of the instrument vs. the ability of the participants. A good validity is established when both the ability of the participants and the item difficulty is spread across the latent scale of the instrument. Meaning, the instrument has a combination of easy, difficult item, and that equally the participants could do easy and difficult test items. Table 4.2 below shows the comparison of pre and post person and item maps:

Table 4.2**: Bubble plots for item measures**

<table>
<tr><th>Bubble plot (Pre TSPCK)</th><th>Bubble plot (Post TSPCK)</th></tr>
<tr><td>


</td><td>


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

In both cases, the distribution of persons and items is across the latent scale and then the instrument is valid because there were no persons who found the test too easy or too difficult. In the Table above, TSPCK items (components) in each test fell within the conventional fit statistical range of (-2; +2). This acceptable fit of items was analysed to indicate that a single construct was being measured as intended (Bond & Fox, 2001). Thus, both the pre and the post-TSPCK tests were found to be valid. However pots the intervention, one pre-service teacher, Henry was found to be a misfit. This was misfit is attributed to the fact that Henry had scored high on difficult item and low on easy items.

(ii) Establishing reliability

Traditionally, when test reliability is established, a Cronbach alpha is calculated to express the reliability of a test (Boone & Rogan, 2005). However, the Rasch model provides us with two reliability estimates, one for items and one for persons (Bond & Fox, 2001), as compared to the standard procedure of only reporting an internal consistency index (such as Cronbach alpha, K-R 20) that only considers people (Boone & Rogan, 2005). Table 4.3 below contains Rasch measures that assisted in establishing the reliability of the scores.

Table 4.3**: Rasch values comparing Pre and Post TSPCK values in stoichiometry**

	Pre-test	**Post-test**
Mean Rash Values(person measure)	-1.65	0.34
Validity measures as fit statistics	all values fell within 2;+2	all values fell within 2;+2
Reliability indices (persons)	0.79	0.63
Reliability indices (items)	0.83	0.75

In the table above, person reliability index of 0.79 and the item reliability index of 0.83 prior the intervention are shown. Post intervention, the person reliability index was 0.63 and item reliability index was 0.75. All these reliability indices have values ≥0.6, hence reasoned to be acceptable.

The discussion above has shown both qualitatively and quantitatively the reliability and validity of the values generated from the tools. The following discussion will therefore unpack on findings drawn from this analysis.

4.2. The development of TSPCK in stoichiometry post the intervention

The impact of the TSPCK intervention on the quality of pre-service teachers' planned TSPCK

Two main results were drawn from the analysis of the data with respect to the research question on the impact of the intervention on the quality of TSPCK. Firstly, based on the quality categories in the TSPCK rubric, pre-service teachers overall, experienced one category positive shift indicating improvement in the quality of their TSPCK in stoichiometry. Secondly, there is evidence suggesting that pre-service teachers experienced the engagement with the components of TSPCK at different levels of difficulty. This means that while they drew on the different TSPCK components to formulate their responses to teacher tasks, they found some components easier to use than others did. These findings are discussed one at a time in details below.

4.2.1. A positive shift in the quality of TSPCK as a results of the intervention

4.2.1.2. The overview of quantitative values

I present again, Table 4.1 below to demonstrate the nature of the shifts in the values of the pre-and post-tests. Remember that, values outside the parenthesis represent pre-TSPCK scores and those inside the parenthesis represent post-TSPCK scores.

Table 4.1**: TSPCK values for Pre vs. Post Test in Stoichiometry**

Respondent	LPK	CS	WiD	Rep	TS	Person Mean
Moosa	1 (3)	2 (3)	1 (4)	1 (4)	1 (1)	1 (3)
Mandla	2 (3)	1 (3)	2 (2)	1 (3)	2 (4)	1 (3)
Precious	1 (1)	2 (2)	2 (3)	1 (1)	1 (2)	1 (2)
Itumeleng	1 (2)	1 (3)	1 (4)	1 (2)	1 (1)	1 (2)
Henry	1 (2)	2 (3)	2 (4)	1 (3)	2 (4)	2 (3)
Jacob	3 (3)	2 (3)	3 (3)	2 (3)	1 (2)	2 (3)
Hlengiwe	1 (2)	2 (3)	2 (4)	2 (3)	1 (1)	2 (3)
Lexy	2 (4)	3 (4)	3 (4)	3 (4)	3 (4)	3 (4)
Lucas	2 (4)	2 (2)	3 (3)	1 (2)	1 (1)	2 (2)
Mandisa	2 (3)	2 (2)	3 (3)	1 (1)	1 (1)	2 (2)
TSPCK Component average	**2(3)**	**2(3)**	**2(3)**	**1(3)**	**1(2)**	**2(3)**

The focus in the table is on the last row (bottom of the table). This represents aggregated values per TSPCK components. The last column represents aggregated person scores for each pre-service teacher across the five TSPCK components investigated. From Table 4.1, the pattern observed from the comparison of pre and post-test average values contrasting the performance of the pre-service teachers as a group, reveals that they shifted from a score of 2 to that of 3 (see brown shaded cell in the last row of the table). The same pattern is noticed across the average values per components (in the last row of the table), in exception for the component of Representation which registered a noticeable shift of two categories quality shift. The pattern of quality shifts across the TSPCK components, described above is summarized and represented best by Figure 4.1 below.

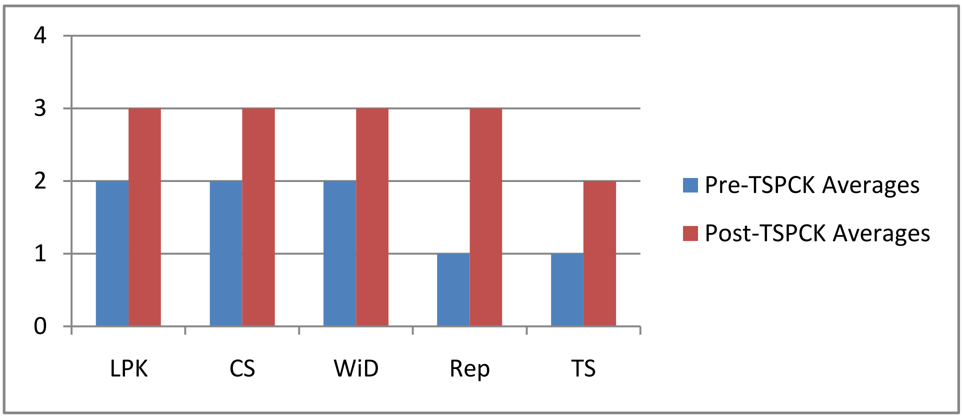


Figure 4.1: **Comparison of pre/post values across the TSPCK components**

Similarly, the last column (far right) in Table 4.1 shows overall person scores. These indicate the performance profile of each pre-service teacher across the five TSPCK components. The pattern observed shows that 2 participants registered a shift of 2 quality categories; these are teacher Moosa and Mandla shaded in green colour. 6pre-service teachers registered an improvement of one qualitycategory shift. These are pre-service teacher Precious, Itumeleng, Henry, Jacob, Hlengiwe and Lexy, shaded in blue colour and

2 pre-service teachers registered no shift, these are in the last two rows of Table 4.1, and they are Lucas and Mandisa. The pattern described herein is summarized and represented by Figure 4.2 below

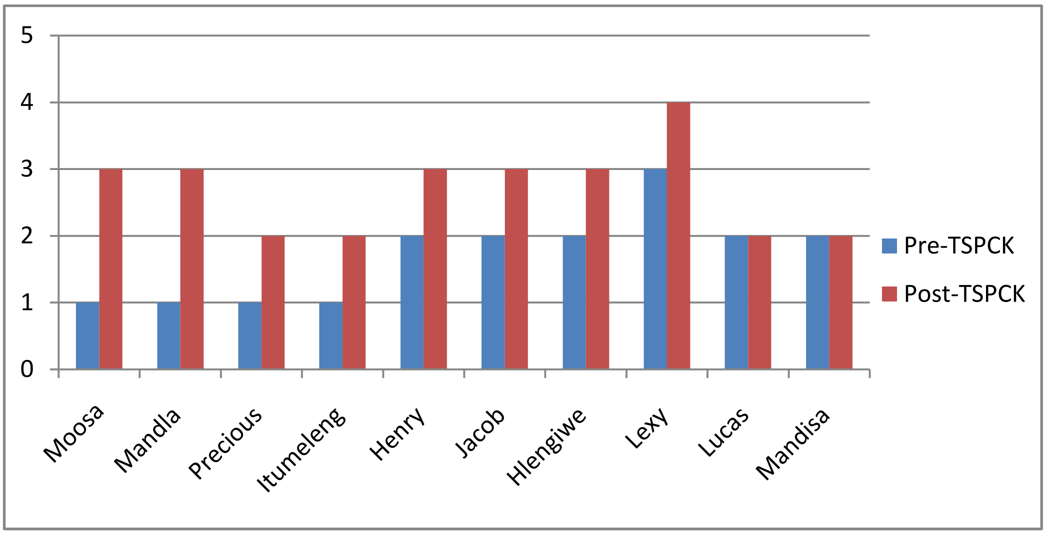


Figure 4.2**: Comparison of TSPCK pre/post values across each pre-service teacher**

On average, this was interpreted to represent an overall positive shift of 1 response category. However, the calculation of average values must not be understood to be a means to interact the respective TSPCK component interaction as argued in the introduction section of this chapter.

While the quantitative values in Table 4.1 assisted us to quickly establish the overview pattern of the impact of the intervention, they are however limited in demonstrating the depth of the shift experienced by the pre-service teachers. In the discussion here below, I present cases demonstrating a single (one) and a double (two) quality category shifts. For each case, I first refer to the criteria in the TSPCK rubric then show evidence from pre-service teachers' extracts of their responses. For ease of reference, I have, for each case inserted an extract of the relevant TSPCK component rubric criteria.

4.2.1.2. Overview of qualitative data

Following below, are examples of qualitative extracts displaying the 1 and the 2 categories shifts.

Example of 1 category positive shift: Extract from Leaner Prior Knowledge

The first component showing an improvement of 1 category shift is for the component of "Learner Prior Knowledge", denoted by the abbreviation LPK. In this category, pre-service teachers were presented with two case scenarios where they were to formulate a response to correct a misconception. One scenario was on the molar volume at STP and one on concentration of solutions; see TSPCK tool in stoichiometry in Appendix A. Below is an extract showing the criteria from the TSPCK rubric used to evaluate the responses from the pre-service teachers.

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
Learner Prior Knowledge	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • No attempt to address the misconception.	• Identifies misconception or prior knowledge • Provides standardized definition as a means to counteract the misconception • No evidence of drawing on other TSPCK components.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using one other component of TSPCK interactively.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on two or more other component of TSPCK interactively.

Figure 4.3**: An extract of the TSPCK rubric for the component of LPK**

According to the rubric, a score of 2 implies that a respondent is able to identify a misconception but fail to show evidence of drawing from other TSPCK components in addressing the misconception. However, there is a provision of a standard textbook definition. A score of three implies that in addition to identifying the misconception, there is an effort to correct the misconception by drawing from other TSPCK components. The extract below is taken from both pre and post-test responses of Mandisa.

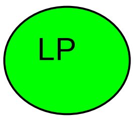
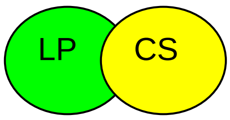
Extract from pre-test tool	**Extract from the post-tool**
"This response contains important information which can help the learner to see that the concept of occupying the same volume at Standard Temperature and Pressure (STP), does not apply to any substances".	*"In our everyday experiences we expect things with equal masses to have the same number of particles. Therefore, the learner needs to understand that equal mass of substances does not mean that the number of particles is also equal. This response can help the learner to clearly understand the concept of **concentration**, since it provides detailed information explaining the relationship between **molar mass**, , **volume** and the **amount** of substances"*
	

Figure 4.4: **Extracts from Mandisa on the component of Learner Prior Knowledge**

The response from the pre-test reveals that the Mandisa was aware of the misconception that occupying same volume at STP does not apply to all substances, but gases. However, at this stage there is no evidence of confrontation of this misconception by drawing on other TSPCK components, the respondent was therefore scored a 2. Post intervention, the Mandisa was scored a 3 for "Developing" TSPCK. Mandisa identified a misconception – addressing learner prior knowledge and drawing on other components to address the misconception.

For an example, Mandisa begins by identifying a misconception that:

> *"...in our everyday experiences we expect things with equal masses to have the same number of particles".*

To advance it further, Mandisa asserts that equal mass of substances does not mean that the number of particles is also equal. The pre-service teacher confronts the misconception by offering a correct statement using a standardised explanation. In addition, addresses this misconception by drawing on aspects of curriculum saliency (CS), shown by the articulation of the concepts which related to number of particles, mentioned as concentration and the relationship it represents between quantities such as molar mass, amount of substance (mole) and volume seen in the extract below:

> *"..to understand concentration, the relationship between molar mass, volume and the amount of substances must be explained".*

In this extract, there is evidence of two TSPCK component interaction (LPK and CS) which was lacking in the pre-test response, hence Manias was scored 3 post the intervention. Another example of a 1-category improvement in the quality of TSPCK between the pre and the post-test, from Jacob on the component of curriculum saliency is given below.

Example of 1 category positive shift: Extracts from the component of Curriculum Saliency

The notion of curriculum saliency in the TSPCK tool relates to planning and sequencing of ideas in the topic (Malcolm et al., 2015). The crucial part of this task was the selection of the "Big ideas" as argued by Lough ran et al., (2004). Secondly, pre-service teachers were supposed to show how the Big ideas relate to each other and how each Big idea relates to its corresponding subordinate ideas. Lastly, it also embodies pre-concepts that must be understood before stoichiometry is taught and the importance of the topic in other fields in science.

Generally, pre-service teachers were scored two for “Basic” TSPCK. A one response category shift to 3 for “Developing” TSPCK was registered from the analysis in Table 4.1 above. In the TSPCK rubric, this component has the following criteria outlining the extent of component(s) interactions

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
Curricular Saliency	• Identified concepts are a mix of Big Ideas and subordinate ideas • Identified pre-concepts are far from topic • Sequencing no value due to mixed concepts • Reasons given are generic - benefit of education.	• Identifies at least 3 Big Ideas • Not all 3 Big ideas subordinate concepts identified • Suggested sequencing has one or two illogical placing of Big Ideas. • Identified pre-concepts are far from the current topic • Reasons exclude conceptual considerations and show no evidence of drawing on other TSPCK components.	• Identifies at least 3 Big Ideas • Subordinate concepts correctly identified for all Big Ideas • Provides logical sequence • Identifies pre-concepts relevant to the topic • Reasons given for importance of topic include reference to conceptual scaffolding/sequential development draw on one other TSPCK components e.g. what makes topic difficult.	• Identifies at least 3 Big Ideas • Subordinate concepts correctly identified for all Big Ideas with explanatory notes • Provides logical sequence of all three Big Ideas and with logical reasons • Identifies pre-concepts relevant to the current topic and explanatory notes given • Reasons include conceptual scaffolding with reference to other TSPCK components

Figure 4.5**: An extract of the TSPCK rubric for the component of CS**

In this TSPCK component, pre-service teachers were given a list of concepts that makes up the topic of stoichiometry, see TSPCK tool in appendix A. They were asked to select concepts that they regarded as Big Ideas, and justify their choices. Subsequently, they were asked to draw a mind map showing how the Big Ideas relate to each other and to subordinate ideas. The last aspect dealt with pre-concepts that must be acquired before stoichiometry is taught and the importance of the topic.

In order to explain this shift, extracts from Jacob’s pre- and post intervention responses were compared as shown below. Firstly, the comparison was made between the choices of the “Big ideas”.

Chosen big ideas (Pre)	Chosen big ideas (Post)
1. Conservation of mass 2. Balancing chemical equation 3. Limiting reagent	1. Mole concepts 2. Limiting reagent 3. Concentration

Figure 4.6**: Comparison of Big Ideas from Jacob’s responses in the pre TSPCK tools**

Big ideas are regarded as concepts that are being commonly viewed as important for students to acquire in order to understand a specific topic (Loughran, Mulhall, & Berry, 2004). In stoichiometry, the mole concept, limiting reagent, concentration, reaction stoichiometry and quantitative analysis method are regarded as Big ideas (Malcolm, Mavhunga, & Rollnick, 2015).

From the comparison above, Jacob in the pre-test did not identify the correct Big ideas. Subordinate ideas such as conservation of mass and balancing chemical equations were regarded as big ideas; see the list of chosen ideas in the extracts above. Post the intervention at least 3 Big ideas were correctly chosen. This was analysed to represent a category shift.

Secondly, the participants were asked to draw a mind maps to show how they regard the nature of the relationship between big ideas and subordinate ideas. The following extracts (mind maps) are taken from Jacob and are shown below to represent their initial response versus post intervention responses:

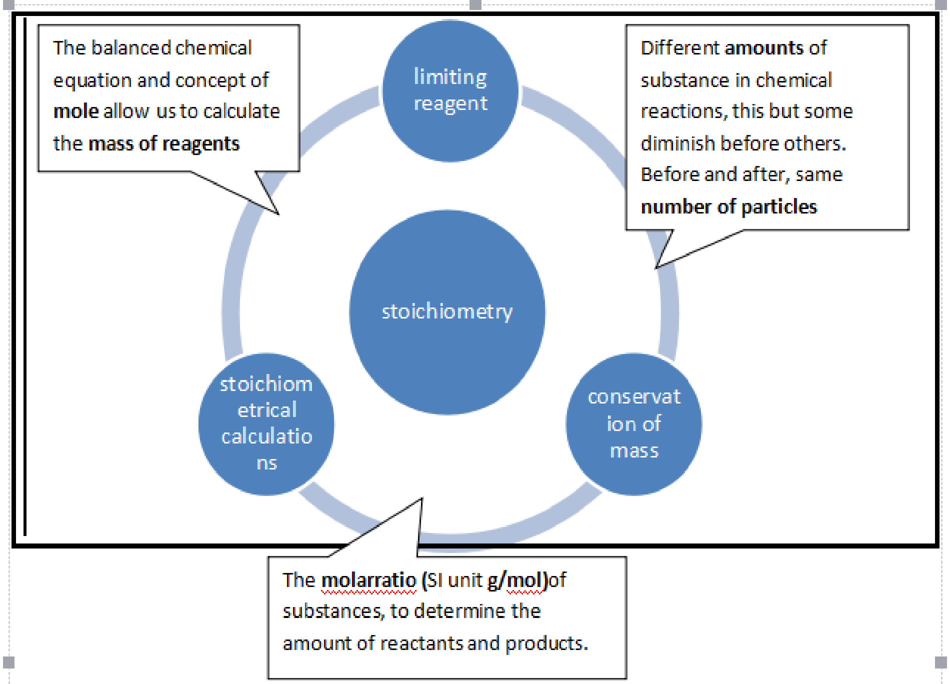


Figure 4.7**: Mind map of Jacob extracted from pre-TSPCK tool**

In this mind map, Jacob does not identify at least 3 big ideas, subordinate ideas were also regarded as Big ideas; this is why the pre-service teacher was scored a 2 for "Basic" TSPCK. Post the intervention, the mind-map produced differs from the pre-mind map in the sense that at least three "Big ideas" are identified. Furthermore, in the post TSPCK map, all the subordinate ideas are logically placed and provide logical sequencing. Below is the mind map taken from the post TSPCK response?

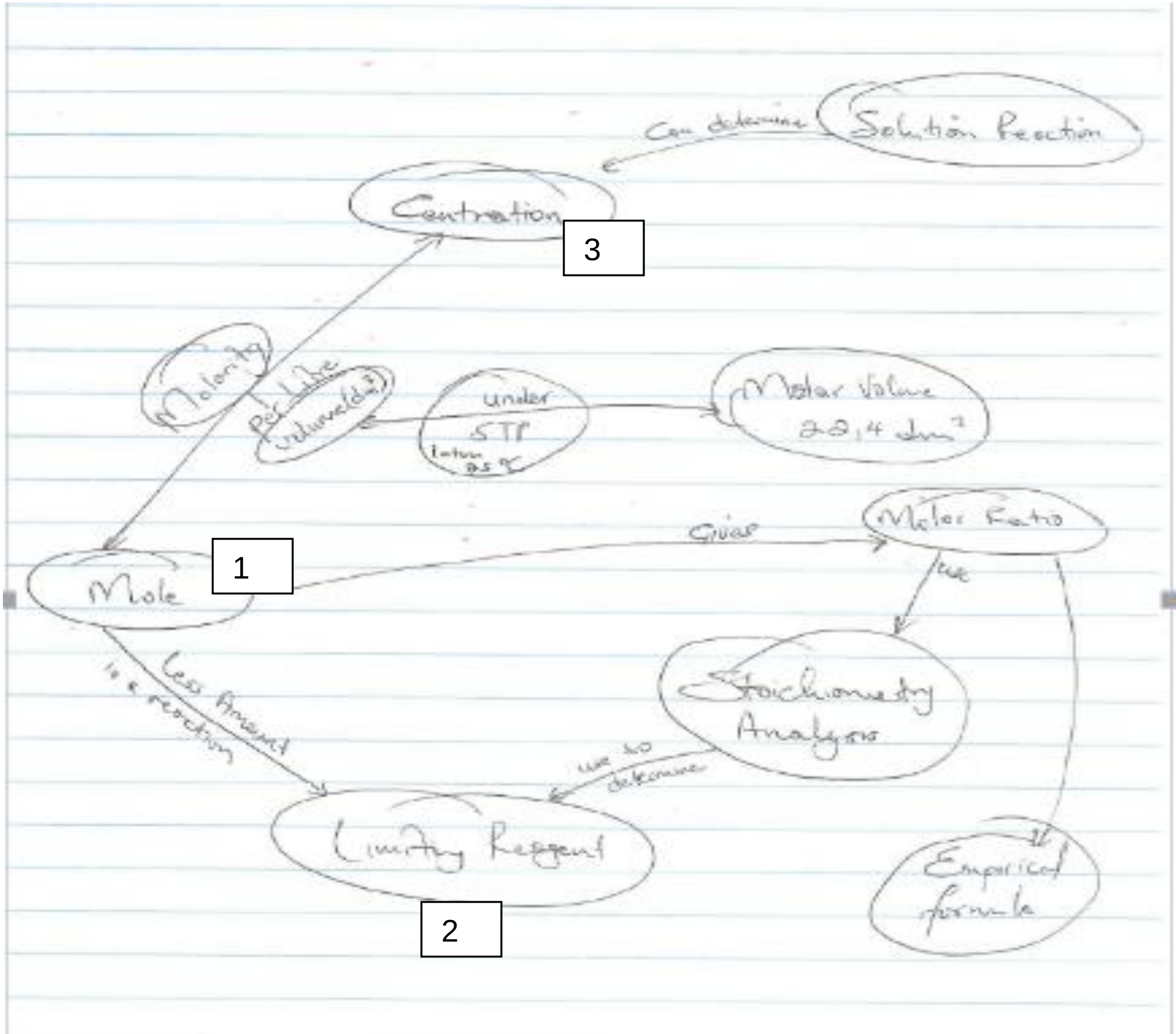


Figure 4.8**: Mind map of Jacob extracted from the post-TSPCK tool**

Post the intervention, the pre-service teacher has identified correctly that the mole is linked to limiting reagent as it represents the “amount” in the reaction (see the connecting arrow in the mind map). Secondly, concentration is also linked to the mole by molarities per litre. The mind map post the intervention also has arrows that serve as sign posts; pointing to the nature of relationship. For an example, there is a link from the mole to molar ratios, stoichiometric analysis and the determination of the limiting reagents. That order shows that the pre-service teacher begins to be able to sequence ideas for teaching. Thus for this component, Jacob was able to register a category shift from 2 to 3 in the TSPCK rubric descriptor.

Another aspect that was given attention in this component was the importance of the topic. The abstract below is taken from the post intervention response; note that the pre test was blank:

> *"Stoichiometry forms the basis of most BIG topics in chemistry such as K_C; K_P; K_a; K_b , Haber process, Oswald process (industry fertilizer productions), limiting reagents and Gas Laws."*

In this case, the pre-service teacher was scored a3 because he provided reasons that involve conceptual scaffolding. Stoichiometry is a topic dealt in details at grade 11; however, it forms basis for grade 12 topics such as reaction rates, chemical equilibrium, and acids & bases. The third component that was discussed for one category positive shift was "What is difficult to teach".

An example of 1 category positive shift: the component of "What is difficult to teach"

In this category, pre-service teachers were given a list of concepts that have been found to be difficult to teach in stoichiometry (Malcolm, Mavhunga, & Rollnick, 2015). Pre-service teachers were then asked to select by providing reason(s) why they regarded those concepts as difficult. The TSPCK rubric for this component had the following criteria for TSPCK component interaction. Scoring was therefore based on this criterion:

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
What makes topic difficult	• Identifies broad topics without reasons and specifying the actual sub-concepts that are problematic.	• Identifies specific concepts but provides broad generic reasons such as 'abstract'.	• Identifies specific concepts leading to learner difficulty • Reasons given relate to one other TSPCK components.	• Identifies specific concepts with reasons linking to specific gate keeping concepts and to TSPCK components such as prior knowledge and aspects of curricular saliency.

Figure 4.9: An extract of the TSPCK rubric for the component of WiD

On average, the entire sample registered a positive shift of 1 response category from basic to developing TSPCK component interaction. Given below are extract responses on the component of "What is difficult" from Hlengiwe.

Pre response	Post response
They are far too long and the learners often find to calculate them impossible because they are procedural	This involves more of algebra, so learners who struggle with algebra normally find this concept difficult. Balancing chemical equations is one of the pre-requisites in understanding Molar ratios, so for learners who have a problem with balancing chemical equations, molar ratios become very hard to understand

Figure 4.10**: Extract of the components of WiD from Hlengiwe's responses in post TSPCK tool**

This response reveals that the pre-service teacher prior to the intervention considered algorithmic calculations as difficult. This response registered a score of 2 "Basic" component interactions, because it tends to lean more on generic procedures with no specific concepts identified. This justification lacks in terms of relating to other TSPCK components.

Post the intervention, the same pre-service teacher for the same concepts provided a justification that identifies specific concepts that lead to difficulty. Such ability corresponds to the criteria on developing quality of TSPCK, according to the rubric; see the extracts above for comparison. For an example, the pre-service teacher highlights the importance of algebra in performing stoichiometric calculation.

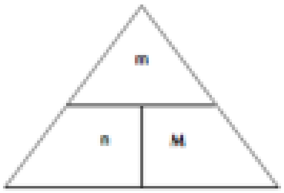
Example of a 2 category positive shift: Extract from component of Representation

In this category, the TSPCK tool in stoichiometry shows three different teaching representations. These are carefully chosen to be used as teaching analogies and, or illustrations in stoichiometry (Malcolm, Mavhunga, & Rollnick, 2015). The first representation deals with macroscopic level, the second one shows a mathematical relationship between the number of moles, the actual mass of a substance and the molar mass of that substance. The third representation is the three levels of representation in chemistry, i.e. microscopic, macroscopic and symbolic. In the next Figure 4.11, I demonstrate these representations below as they appear in the TSPCK tool:

Representation 1: Based on macroscopic representation

Items	Kind of Set	Number in Set
Socks, dice	Pair	2
Eggs, oranges	Dozen	12
Bottles, cans	Case	24
Brushes, pencils	Gross	144
Sheets of paper	Ream	500
Atoms, molecules	Mole	$6,02 \times 10^{23}$

Representation 2: Base on mathematical representation



Representation 3: Base on all three levels of representation

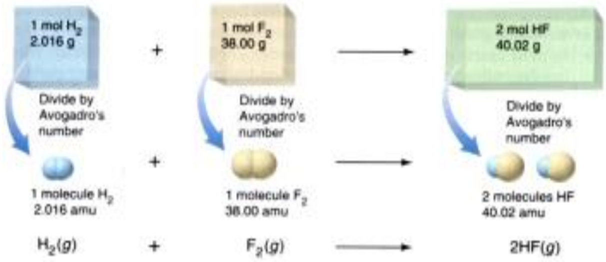


Figure 4.11**: Three representations used in the TSPCK stoichiometry tool**

Two aspects were considered in the TSPCK tool. Firstly, pre-service teachers were supposed to comment on the representations by mentioning what they like and, or what they do not like about the representation. Secondly, they were required to select the one they prefer to use and justify their choice. During analysis, the following criterion from the TSPCK rubric was used to score pre-service teachers, see extract below indicating descriptors for TSPCK component interaction:

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
Representa-tions	• Limited to use of only macroscopic analogies, demos, etc.) representation with no explanation of specific links to the concepts represented	• Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.	• Use of macroscopic representation and use of scientific symbolic representation with explanatory notes linking the two representation to the aspect(s) of the concept being explained • Use of above representations combination with reference to one other TSPCK components e.g. learner prior knowledge	• Use of macroscopic representation or symbolic representation with sub-microscopic representation to enforce a specific aspect • Explicit link to other components of TSPCK e.g./emphasis of core aspect of CK demonstrated in the representations and learner prior knowledge

Figure 4.12**: Descriptors from the rubric corresponding to the component-Representation**

On average, the group registered a shift of 2 categories from score of 1indicating a 'Limited' quality of TSPCK to a score of 3 indicating 'Developing' TSPCK. Raw scores in Table 4.1 above also reveals that 7 out the 10 responses in the component registered a score of 1. This was the case as not all these pre-service teachers produced satisfactory responses and in some cases, there were no responses at all. Given that this was the only component where such a pattern was noted, also that it was not the last item in the tool, it was therefore assumed that participants were not confident in this TSPCK component. A typical example is shown from extract of Moosa. This pre-service teacher had written nothing in the pre-TSPCK test, I have analysed the blank space to mean an inability to respond in this component. However, post the intervention, he chose representation 3 the most suitable for teaching and citing that:

[Rep 3]...covers three levels of representation, Symbolic (chemical equation), Macroscopic and Microscopic. The combination of these three representations will enhance students' conceptual understanding

Figure 4.13**: Extract taken from Moosa's post TSPCK tool on the component of Representation**

This participant appreciates that to understand chemistry; all the three levels of representation must be taken into account. Furthermore, the pre-service teacher begins to provide explanatory notes linking the concept to be taught with the representation. See extract below where Moosa was explaining how he is going to use the representation to teach.

I will let learners measure out the given masses using a scale and measure their amounts also. From there they can write down the chemical equation and fully balance it. This will make them question the same amount of substance in the two elements and the difference in their mass.
I then would show the learners how the amount of substance, mass and elementary particles differ. For example the equation shows that for one mole of hydrogen we need one mole of Fluorine. This molar ratio tells us that the amount of the two substances is equal, but their mass is different when we inspect or use the equation that relates the three concepts.

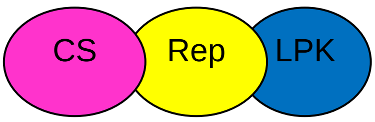


Figure 4.13**: Extract taken from Moosa's post TSPCK tool on the component of Representation**

In order to score a 3 for developing TSPCK component interaction a response must contain explanatory notes. This is an important criterion in this component because it serves to indicate how the teacher will incorporate these levels in teaching. The response shown in extract 5 above indicated that the macroscopic representation will be addressed through weighing mass using the scale see the (bluish shading). Secondly, symbolic representations will be given attention with equation (see the yellow shading). Lastly, the teacher attempts to drive the idea that the number of elementary particles, mass of the substance and the amount of the substance (measured in moles) differs. This notion can best be understood from the microscopic level (see purple shading).

Lastly, this response was scored a 3 for "Developing" TSPCK component interaction given that Moosa attempted to draw the component of "What is Difficult", see the text that is highlighted in green. It has been found in earlier analysis that learners find it difficult to comprehend that moles of different elements have different masses. The pre-service teacher asserts that:

> *"This will make them question the same amount of substance in the two elements and the difference in their mass. I then would show the learners how the amount of substance, mass and elementary particles differ"*

This statement confirms that Moosa is aware of the area of difficulty, and he will attempt to correct it by using the representation. The last discussion from these extracts is based on the component of conceptual teaching strategies.

Example of 1 category shift but remaining in the lower quality categories of the TSPCK rubric: Extracts from Conceptual Teaching Strategies

In the TSPCK stoichiometry tool, the pre-service teachers were given the following scenario.

About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:

$$TiC\ell_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgC\ell_2(\ell)$$

In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.

Titanium (IV) Chloride
Limiting reagent is the reactant with the least number of moles in the equation

Magnesium
This is the reactant present in the least amount according to mass.

Figure 4.14**: Scenario extracted from the TSPCK tool on conceptual teaching strategies**

Pre-service teachers were asked to design a conceptual teaching strategy that would help learners develop conceptual understanding about the limiting reactant. Scoring with the rubric was based on the following criterion as shown from the extract taken from the rubric:

	(1)Limited	(2) Basic	(3) Developing	(4)Exemplary
Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions • Lacks aspects of curriculum saliency • Use of representations limited to macroscopic or symbolic scientific symbolic representation	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy • Lacks aspects of curriculum saliency • Use of macroscopic and symbolic representations with no linking explanatory notes	• Considers confirmation/confrontation of student prior knowledge and/or misconceptions • Considers at least one aspect related to curriculum saliency e.g. sequencing or what not to discuss yet or emphasis of important concepts • Uses at least two different levels of representations to enforce understanding.	• Considers student prior knowledge and evidence of confrontation of misconceptions. • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding

Figure 4.15**: Extract from the rubric-showing criterion for conceptual teaching strategies**

Analysis of raw scores revealed that a shift of 1 response category was registered from “Limited” to “Basic” TSPCK component interactions. A sample response of a conceptual teaching strategy from Jacob is shown below as evidence of this qualitative shift observed:

Learners seem to confuse the concept of theoretical and actual amount of the compounds, because the equation only delineates when there is theoretical amount of the two compounds, whereas the amounts of the compounds is reliant on the calculation of the *n* which is the amount present from this formula $n = m/M$ from which we divide the sample mass with the Molecular Mass from the periodic table

Figure 4.16**: An extract taken from Jacob's responses in the component CTS in the pre-TSPCK tool**

The response above was generated in the pre-TSPCK test. In this response, it is not clear what the teaching strategy was. Jacob was scored a 1 even though; he had acknowledged student prior knowledge. From this response, the pre-service teacher seemed to be aware about learner prior knowledge about the confusion between theoretical and actual amount of the substance. Furthermore this response was scored a 1 because it only considered one level of representation, i.e. $n = m/M$ which is almost symbolic and algorithmic in its approach. Lastly this strategy as a result of all the shortcomings mentioned above lacked the strength of drawing from other TSPCK components to address the learner misconception. This strategy was therefore considered evidence that pre-service teachers recorded an average score of 1 in the component of conceptual teaching strategy.

Post the intervention, an average score of 2 for "Basic" TSPCK was generated from the post -TSPCK responses. The sample of the response shown below is the extract for the same pre-service teacher, Jacob.

I would challenge learners' thinking would be to give them two reagents from which one has been given in less sample and I will ask them which of the two would be a limiting reagent. Learners are tempted to say one with the less sample mass has to be one that limits the reaction. The chemical reaction would be as follows:

Activity was adopted from:
https://www.chem.tamu.edu/class/majors/tutorialnotefiles/limiting.htm

$$4\,NH_{3(g)} + 5\,O_{2(g)} \longrightarrow 4\,NO_{(g)} + 6\,H_2O_{(g)}$$

A 2.00 g sample of ammonia is mixed with 4.00 g of oxygen. Which is the limiting reactant and how much excess reactant remains after the reaction has stopped?

Learners would think since the oxygen is given in more mass, it is one in excess and ammonia is the limiting reagent.

Figure. 1

$$2.00\ \cancel{g\ NH_3} \times \frac{1\ \cancel{mol\ NH_3}}{17.0\ \cancel{g\ NH_3}} \times \frac{4\ \cancel{mol\ NO}}{4\ \cancel{mol\ NH_3}} \times \frac{30.0\ g\ NO}{1\ \cancel{mol\ NO}} = 3.53\ g\ NO$$

$$4.00\ \cancel{g\ O_2} \times \frac{1\ \cancel{mol\ O_2}}{32.0\ \cancel{g\ O_2}} \times \frac{4\ \cancel{mol\ NO}}{5\ \cancel{mol\ O_2}} \times \frac{30.0\ g\ NO}{1\ \cancel{mol\ NO}} = \boxed{3.00\ g\ NO}$$

Figure. 2

$$4.00\ \cancel{g\ O_2} \times \frac{1\ \cancel{mol\ O_2}}{32.0\ \cancel{g\ O_2}} \times \frac{4\ \cancel{mol\ NH_3}}{5\ \cancel{mol\ O_2}} \times \frac{17.0\ g\ NH_3}{1\ \cancel{mol\ NH_3}} = 1.70\ g\ NH_3$$

Figure. 3

$$2.00\ g\ NH_3\ \text{(original sample)} - 1.70\ g\ \text{(reacted)} = \boxed{0.30\ g\ NH_3\ \text{remaining}}$$

Figure 4.17**: Post-test response for Jacob on CT**

The second extract produced post the intervention was scored a 2 for basic TSPCK component interaction. In this response, Jacob mentions "learners are tempted to say one with the less sample mass has to be one that limits the reaction". In this statement, the pre-service teacher is explicitly aware of the learner prior knowledge about limiting reagent. It is important to note that the pre-service teacher was scored a 2 even though only one level of representation was used, i.e. symbolic. The reason associated with this score of 2 is the fact that there is a clear acknowledgement of learner misconception. Other than that, the Jacob still shows some lack of aspects of curriculum saliency.

In summary, the discussion above presented data showing positive shift in the quality of TSPCK, as depicted by the positive category shifts registered across all components of TSPCK. The results also show that pre-service teachers experienced most improvement in the quality of TSPCK in the component of

Representations and the least improvement in the component of Conceptual teaching strategy. The next section will engage the discussion on the second finding about the different levels of difficulty in engaging TSPCK from the perspective of the five components.

4.2.2. Different levels of difficulty in engaging the TSPCK components

The second finding as alluded in the summary statement above is that pre-service teachers experienced different levels of difficulty when engaging stoichiometry from the perspective of the five TSPCK components. The analysis of the average values revealed that TSPCK components were not engaged and discussed by pre-service teachers on the same level of difficulty. The Table 4.4 below shows the averaged scores per component and the calculated difference between the pre/post scores.

Table 4.2**: Average scores per TSPCK component and the difference from the pre and post average scores**

TSPCK Component	LPK	CS	WiD	Rep	TS
Mean values (Pre)	2	2	2	1	1
Mean values (Post)	3	3	3	3	2
Mean Difference	**1**	**1**	**1**	**2**	**1**

From the table, the component of Rep recorded a bigger jump; that is, two response categories post the intervention. Secondly, the component of TS recorded the least average score post the intervention. This least score in the TS component can be interpreted to mean that pre-service teachers find the level of engaging TSPCK to be difficult for this component. In addition, the component of Rep recorded a greatest jump as mentioned earlier. This is interpreted to mean that they have improved in this component more significantly than other components.

Furthermore, the comparison of pre and post probability measures form Rasch reveals a remarkable rank order of items in the TSPCK test. This rank order according to Mavhunga (2016) “reflects the extent of difficulty experienced by the pre-service teachers in answering each item in relation to another". In this case, an item refers to each TSPCK component. The table below represent values taken from Rasch.

Table 4.5**: Item measures of TSPCK components calculated from Rasch**

Item (TSPCK Component)	Pre-Rasch item measures	Post-Rasch item measures
Conceptual teaching strategies	2.53	1.54
Representations	1.76	0.17
Learner prior knowledge	0.53	-0.02
Curriculum Saliency	-1.14	-0.02
What is difficult	-3.67	-1.66

The pattern observed from Table 4.5 indicates a descending order of items, i.e. from more positive to less positive measures. This order is further shown clearly in Table 4.6 below.

Table 4.6**: Rank order of TSPCK components**

Pre – TSPCK rank order	***CT ≥ Rep ≥ LPK ≥ CS ≥ WiD***
Post – TSPCK rank order	***CT ≥ Rep ≥ LPK = CS ≥ WiD***

Both the pre and post rank orders are the same. The only difference observed is that in the post-test, pre-service seem to have engaged the component of "Learner prior knowledge at the same level of difficulty as the component of "Curriculum saliency" this conclusion was made since the item measure of the two components post the intervention was the same at -0.02. The rank order according to Boone and Rogan (2005) should be interpreted to say, that the more positive the measure, the more difficult the component. Therefore, this analysis from Rasch values confirms that conceptual teaching strategy was found to be the most difficult item. This conclusion is confirmed by the same inference drawn from analysis of average values. The component of “What is difficult to teach” was the least difficult component in stoichiometry. In summary, pre-service teachers were not able to engage TSPCK components at the same level of discussion. The component of “Conceptual teaching strategy” showed to be the most TSPCK where an interaction with other TSPCK component was least observed.

4.3. Conclusion

In this chapter the question - *What is the impact of an explicit intervention on developing the competence to transform content knowledge on the quality of pre-service teachers’ TSPCK in planning to teach stoichiometry* was explored. Two findings emerged; pre-service teachers experienced an overall positive improvement from a lower TSPCK quality category to higher order category.. This category difference is between “Basic” to “Developing” TSPCK quality categories. Secondly, it also emerged that the extent at which pre-service teachers engaged with the components of TSPCK in stoichiometry was experienced to be at different levels of difficulty. Among the five components, the component of Conceptual teaching strategy was found to be a more difficult component to engage. On the other hand, the component of “what is difficult to teach” was found to be the least difficult component.

CHAPTER 5: THE RETENTION OF TSPCK IN STOICHIOMETRY

In this chapter, I provide a response to a second research question, which explored the retention of the quality of TSPCK acquired in a pre-service teacher programme almost after a year of completion. I provide analysis and findings from completed TSPCK tools in Stoichiometry a year later after the intervention. This is the same tool completed by same pre-service teachers as a set of pre/post- tests in the intervention of the 2015 physical science methodology class.

5.1. Preamble

The literature review in Chapter 2 outlined that there is a lack of empirical studies exploring the retention of acquired PCK (Rozenszajn & Yarden, 2014), particularly PCK acquired in a pre-service teacher programme. As this study, is on TSPCK, a recent construct, studies on retention of TSPCK are by extrapolation also lacking. Rozenszajn & Yarden (2014) have examined the expansion of two components of PCK of three practicing teachers in the course of a professional development aimed at designing new teaching and learning materials. In their study, the notion of retention of major parts of the expanded PCK after one year of professional development provided an influential way for PCK expansion (Rozenszajn &Yarden, 2014), i.e. some aspects of PCK has the potential to grow a year after the developmental program. This development was influenced by continuous engagement with the notion of PCK.

In this study, the retention of TSPCK by pre-service teachers exposed to an intervention was explored for purposes of examining the impact of the intervention beyond the teacher education programme. Secondly, this is to inform the nature of future interventions in the same methodology course in chemistry. Therefore, this chapter explores responses for the question – *To what extent is the quality of the TSPCK in planning to teach stoichiometry retained by pre-service teachers a year later after the intervention*

This examination was carried out with the second set of data from TSPCK tools collected in 2016. In order to carry out this analysis, similar to the analysis in Chapter 4, average scores per TSPCK components were analysed and discussed for post/year later responses. The idea was that, equal averages per TSPCK component would signify retention and an increase in average scores of post intervention to retention averages scores was interpreted to signify growth in TSPCK a year later after the intervention. The section below therefore is aimed at outlining with evidence what this study has found under the notion of retention of TSPCK in stoichiometry.

5.2. The extent of retention of TSPCK in stoichiometry

In this study, three major findings were drawn. Firstly, the knowledge of four TSPCK components in stoichiometry was retained by the pre-service teachers a year later after the specific TSPCK intervention. Secondly, the component of representation was found to be the only component that experienced a positive shift of one quality response category into the next higher quality category of the TSPCK rubric. Thirdly, the component of conceptual teaching strategy was found to be persistently most difficult, a year later after the intervention. In the next sections, I will therefore provide a mix of quantitative and qualitative evidence to demonstrate these findings.

5.2.1. Retention of TSPCK in stoichiometry by pre-service teachers

As mentioned in the design chapter, this study employed MM data analysis. The following sections provide both quantitative and qualitative responses in order to support the findings generated. For this task, only 5 out of the 24pre-service teachers were followed, this was constrained by availability and employment opportunities as beginning teachers in the Johannesburg area. Four of the pre-service teachers investigated are doing their full-time honours study in the University of the Witwatersrand for the year 2016, one of them is currently working and doing the studies part-time. They were given the same TSPCK tool as completed in 2015. After completion, the tools were marked with the same TSPCK rubric used in Chapter4. Generated qualitative responses were converted to numerical values tabled as post/year later responses in Table 5.1 below. Following that, the average scores for each TSPCK component were compared against the post-intervention scores measured a year earlier, see Table 5.1 below.

5.2.1.1. Overview of quantitative data

Table 5.1 shows the comparison between the set of post-intervention responses and those generated a year later to determine retention of the quality of TSPCK acquired in the intervention. In this comparison, averages for each person and each TSPCK component were also generated for interpretation.

Table 5.1**: Comparison of post-pre-service programme intervention vs. a year later TSPCK scores**

TSPCK component	**LPK**	**CS**	**WiD**	**Rep**	**TS**	**Person averages**
Thabo	(3) 3	(4) 4	(3) 3	(2) 4	(2) 3	(3) 4
Kgomotso	(2) 2	(3) 3	(3) 3	(2) 3	(2) 2	(2) 3
Sharon	(3) 3	(3) 3	(4) 4	(3) 4	(4) 2	(3) 3
Michael	(3) 3	(2) 3	(3) 4	(3) 2	(2) 2	(3) 3
Tshepo	(3) 2	(2) 1	(2) 1	(2) 1	(2) 1	(2) 1
Average scores	**(3) 3**	**(3) 3**	**(3) 3**	**2 (3)**	**2 (2)**	**(3) 3**

Note: Values in brackets (post-intervention TSPCK scores), those outside are for a year later in practice and some in full-time post-graduate study.

The bottom row shows the average scores for post/retention TSPCK test per TSPCK component. They have been contrasted as done in Chapter 4 in order to explore if TSPCK in stoichiometry is retained a year later after the intervention. The big picture pattern emerges from this contrast as shown in the last row for individual TSPCK components and the last column for individual participants. When looking at the patterns for the TSPCK components, it is observed that for most of the TSPCK components, the average scores generated post the intervention are the same as the scores generated a year later after the intervention. An exceptional case is observed with component of "Representation"; this component registered a positive one-category jump in the quality of TSPCK. Generally, this pattern suggests that the then pre-service teachers have retained the quality of understanding of most of the TSPCK components in stoichiometry and experienced a registered growth in the component of Representation. It must be taken into account that this is the pattern observed at the scale of an overview, the general picture. At a closer look, an individual component and person scale depicts certain interesting patterns. The last column also shows the average scores for individual pre-service teacher across all TSPCK components. These average scores as argued in Chapter 4 are not understood to represent the quality of TSPCK through mathematically mixing/integrating the components but are a proxy of the overall component interactions measured for the observed interaction(s) of each component with others (as shown in the criteria of the TSPCK rubric, Appendix IV).

It is observed that from these person averages; two pre-service teacher, i.e. Thabo and Kgomotso registered growth in their overall quality of TSPCK. These then pre-service teachers are currently studying towards their Honours degree. Thabo is also practicing as a teacher and doing his studies part-time. Sharon and Michael retained their overall TSPCK.

Both Sharon and Michael are currently studying full-time and Sharon is practicing as a lab demonstrator. Noticeably, one pre-service teacher; Tshepo was found to have registered a negative shift in his overall TSPCK. Tshepho is currently studying full-time. This pattern further generated more interest to find out why these pre-service performed in this manner. Interviews were then conducted with three pre-service teachers. These were purposefully chosen as the represented three different cases: a case of positive shift, retention as well as negative shift in the quality of TSPCK. These interviews were conducted using the interview schedule; see Appendix IV.

Thabo registered growth in overall TSPCK, and he was followed for this purpose and interviewed. During interview, he was asked:

Interviewer: *What do you understands about TSPCK*?

Thabo: [*sigh*] *Okay... TSPCK, I was introduced into TSPCK during the methodology course. It was introduced as an approach that we can use during our classroom* *teaching. It consisted of five components that must be integrated for effective teaching.*

This response from Thabo indicates that he understood the concept of TSPCK a year later post the intervention. He mentioned that it consisted of five components, this means that in order to transform abstract CK to accessible forms for learners to comprehend, and it must happen through the interaction of the five components. On the other hand, when Tshepo who experienced a negative jump in the overall quality of TSPCK was asked the same question, his response was:

Thabo: aah well. TSPCK is part of PCK. That is pretty much that.

This response from Tshepo shows that key issues concerning TSPCK were not regarded a year later after the intervention. All that is mention is that it is part of PCK. Furthermore, these pre-service teachers were asked:

Interviewer: What are you currently occupied with in 2016?

Thabo: I am doing my Honours...

Interview: In your current engagement (mentioned earlier), how do you find TSPCK useful?

Thabo: Not that it is much useful since for teaching since I am not teaching in the moment, but I can say for my research it is useful because I am still doing PCK related research.

Thabo is doing his honours and he finds the idea of TSPCK relevant for his research work. This is possibly the reason why he has shown growth in his overall TSPCK. The then pre-service teachers performed differently in the components of TSPCK, see Table 5.1. Thus, they were further asked to mention which component they have found difficult before and after the intervention. The Table 5.2 below shows their responses as per the interviews:

Table 5.2**: Components found by pre-service teacher's difficult pre/post &year later responses**

	Component difficult before the intervention	**Component difficult after the intervention**	**Component difficult for retention**
Thabo	Conceptual Teaching Strategies	Conceptual Teaching Strategies	Conceptual Teaching Strategies
Sharon	Conceptual Teaching Strategies	Conceptual Teaching Strategies	Conceptual Teaching Strategies
Tshepo	Representations	Conceptual Teaching Strategies	Learner Prior Knowledge

The answers given by Tshepo as shown in Table 5.2 did not confirm what he produced in TSPCK tests, particularly for year later responses. In general, all pre-service teachers found the component of CT as difficult across the three stages of data collection. This observation was further analysed to mean that when pre-service teacher do not engage with PCK in a particular topic, they lose touch with the construct. Thabo registered growth whereas Sharon retained their overall TSPCK. Their responses as shown in Table 5.2 confirmed the observed trend in their TSPCK.

Just as done in chapter 4, the quantitative patterns observed per TSPCK component were also shown using extracts that indicate the qualitative evidence of retention or growth in each component.

5.2.1.2. Overview of qualitative data

Extracts from Learner Prior Knowledge showing retention of TSPCK

Post the intervention students registered a shift from "Basic" to "Developing" TSPCK component interaction as shown in chapter 4. The analysis of post/year later responses in this TSPCK component reveals that on average, pre-service teachers retained the knowledge of this component. Below is an extract of the response taken from Sharon:

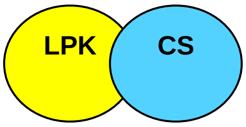
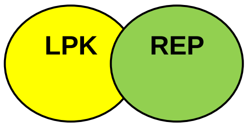
Extract from post responses	Extracts from year later responses
Response C provides the best explanation in comparison to the others and importantly, response C does not bluntly state that the learner is wrong but rather appropriately approaches the incorrect answer by offering scientifically presenting a conceptual understanding. The explanation provides learners with in-depth scientific reasons as to why there is one mole of a substance in a specific test cube. It also provides assistance as to how learners, in the future, should answer questions similar to this one. Apart from just providing a linguistic explanation regarding which cube has one mole or not the response also explains how to mathematically calculate the amount of substance in moles of the substances which do not contain one. Other concepts relating to the mole (States of Matter, Avogadro's Number) have also been chronologically sequenced and well integrated to explain why set A is the only set that contains one mole of the specific substance.	Response C provides the best explanation as compared to the others. In its explanation it provides learners with reasons has to why there is one mole of substance in a specific test cube. It also provides assistance as to how learners should further answer questions similar to this one. Apart from just providing a linguistic explanation regarding which cube has one mole or not the response also explains how to mathematically calculate the amount of mole in those cubes which do not contain one mole. Response C also makes use of important scientific concepts to explain the answer i.e. Avogadro's Number. It highlights the macroscopic features on the test-tubes (phases) thereafter proceeding to the microscopic explanation (use of science concepts both the technical and symbolic language).
	

Figure 5.1: **Extracts from Sharon who retained quality of TSPCK, example shows LPK interacting with one more component**

From the scores in Table 5.1 Sharon showed retention of TSPCK for both post/year later responses. The extracts compared in Figure 5.1 above are used as evidence of the retention of the knowledge TSPCK in the component of LPK. The post – TSPCK response generated indicate that learner misconception was implicitly outlined by drawing CTS from the standardised explanation offered in the TSPCK tool (check yellow shading). In addition Sharon acknowledges that in order to correct this misconception, concepts relating to the mole must be carefully taken into account. There is evidence of drawing form one other TSPCK component, i.e. CS. Check the blue shading.

A year after the intervention, Sharon chose the same response. Analysis of this response reveals that TSPCK was retained at "Developing" TSPCK component interaction. In this response, the she outlined learner misconception by drawing from a standardised response in the TSPCK tool and used one other TSPCK component to correct the misconception. What came interesting is the fact that Sharon now integrates LPK with Rep (see green shading) instead of CTS as done post the intervention. Regardless of the change in the nature of component interaction, both post and year later responses display interaction of LPK with one other component of TSPCK. This qualitative analysis confirms that the knowledge of the component of learner prior knowledge was retained a year later after the intervention.

The following section will also show evidence of retention in the component of curriculum saliency.

Extract(s) from Curriculum Saliency showing retention of TSPCK

From the TSPCK rubric, the student is scored 3 if at least 3 big ideas are identified. Secondly, subordinate ideas must be identified for all big ideas and provide logical sequencing. Thirdly, pre-concepts relevant to the topic must be correctly identified. Lastly, there must be evidence of drawing from one other TSPCK components. All these criteria are contained in the TSPCK rubric.

Post intervention, curriculum saliency as shown in chapter 4 was scored 3 on average for “Developing” TSPCK component interaction. Analysis of year later scores reveals that on average, the knowledge of this component was retained at score 3, for “Developing” TSPCK component interaction. However, during analysis, the most convincing response that was used as evidence of the average retention of “Developing” TSPCK component interaction was a response for Michael. This pre-service teachers was scored a 2 for basic TSPCK component interaction post the intervention, a year later response was scored a 3; an average score for the group. Below is an extract of these post/year later responses for Michael. Note that, the big ideas were correctly identified in both stages, viz.: the mole, limiting reagent and concentration. However, the pre-service teacher post the intervention was scored a 2, this follows that not all big ideas’ subordinate concepts were outlined and there was no attempt to link big ideas. Year later response saw an attempt to link big ideas with subordinate ideas. However, at this stage not all subordinate ideas were identified. Below, a scheme is shown that was produced form a TSPCK tool by the respondent to map these relationships:

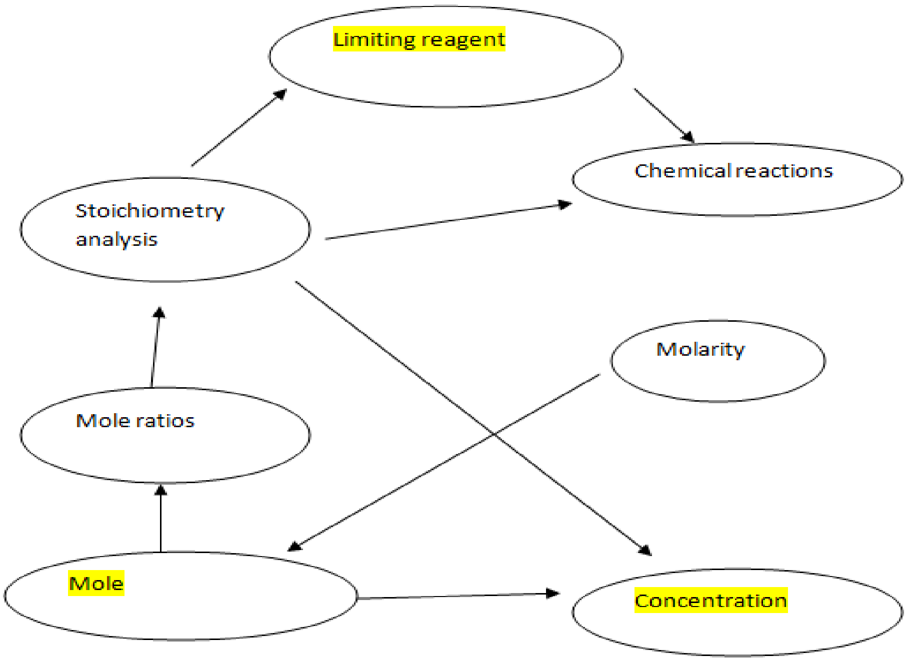


Figure 5.2**: Extract showing a mind map taken from Michael for component of curriculum saliency**

In this map, big ideas were highlighted with yellow. The mole is shown to have a link with other big ideas, i.e. concentration limiting reagent. At this stage the student was scored a 3 for "Developing" component interaction because from the descriptors in the rubric identified pre-concept were found to be relevant in the topic of stoichiometry. Post the intervention these pre-concepts indicated a deficit of what must be covered before stoichiometry is taught. The table below shows how this comparison was made.

List of pre-concept (post)	List of pre-concept (retention)
1. Phases of matter 2. Balancing of equations 3. Names and formula of substances 4. Pure substances	1. Balancing equation, 2. acids and bases, 3. phases of matter , 4. mixtures, 5. pure substances, 6. names and formulae of substance, 7. atomic mass and molar mass 8. metals and non- metals and metalloids 9. chemical bonding

Figure 5.3**: List of pre-concepts taken from Michael for the component of CTS**

Lastly, post the intervention, Michael did not register any response about the importance of the topic; however, a year later response registered that:

> "Stoichiometry is the best chemistry tool that we can use to predict the mass of a product of a chemical reaction, when we are given the masses of the reactants. We can also predict the volume of a gas which will be produced when given a certain amount of reactants. Therefore, this is a wonderful tool used in industry for the production of many chemicals."

This reason given for the importance of the topic implicitly include conceptual scaffolding in a manner that in other chemistry topics such as acids and bases, we use quantities form chemical fractions to determine masses of the salts that will be produced and volumes of solutions that are required.

Extracts from "What is difficult to teach" showing retention of TSPCK

The third component analysed is dealing with "what is difficult to teach". The average component score of 3; indicating developing component interaction was retained for post/year later responses. From the rubric, the descriptors within this category indicated that the student should be able to identify specific concepts leading to learner difficulty. Subsequently, the student must also give reasons related to one other TSPCK component in their justifications. For this component qualitative evidence from Thabo were used to support the notion of retention of TSPCK.

For this component, I have focused on the mole concept since it has been view by many authors as a difficult concept to teach. In both post intervention and year later responses Thabo identified the mole as a difficult concept to teach. The comparison of the post/a year later reasons given by Thabo accounting for "mole" difficulty are shown below:

Extract from post-TSPCK	Extracts from year later of TSPCK
...different authors have argued that by a definition, a unit for a physical quantity should elucidate how objective quantitative information on the physical quantity can be obtained by means of measurement but the mole differs in this respect since there is no method or instrument for measuring the mole.	...most of the science teachers teach mole in a traditional way as the "number of moles" represented by 'n', this confuses learners when they have to change from 'number of moles' to 'amount of substance' [SI-unit]. Therefore, learners do not see mole as SI unit but as a 'main concept' [quantity]

Figure 5.4**: Extracts from Thabo for the component WiD**

According to the Thabo, the fact that the mole cannot be physically measured makes it difficult for learners to comprehend and work with it. This amongst other justifications was given a score of 3 since it identifies specific concepts leading to complexity of teaching the concept. In this component, the issue of measurement of the mole is difficult to comprehend. Year later response reveals that the issue of representation is further adding to the complexity of mole conceptualisation. This response asserts that the mathematical (symbolic) representation of “n” as the number of moles distorts learner understanding between the ideas of the number of moles, contrasted to that of the amount of the substance. From these responses, it is evident that the knowledge of this TSPCK component was retained at a quality of developing TSPCK component interaction.

The last component that was analysed for retention of TSPCK was conceptual teaching strategy. Take into cognisance that post retention, this component was found to have a low average score 2 indicating “Basic” TSPCK component interaction. Chapter 4 has further alluded that this component was found to be the most difficult component for pre-service teachers to engage with in stoichiometry.

Extracts from Conceptual Teaching Strategies showing retention of TSPCK

The analysis of raw scores generated from the TSPCK rubric shows that the knowledge of this component was also retained at an average score of 2 for post/retention TSPCK. Below are the extracts of responses for Michael that represents conceptual teaching strategies for teaching the concept of limiting reagent.

The 1st learner looked at the balanced equation and then concluded that the reactant with less moles is limiting agent which is the misconception

The second learner looked at the mass of the substances and concluded that titanium chloride has bigger.

THE STRATEGY

The limiting reagent by definition is the reactant that is used up in the chemical reaction and determines the amount of the product to be formed. For example in the given equation:

$O_{3(g)}$ +NO(g) = $O_{2(g)}$+$NO_{2(g)}$, we can use it to calculate the amount in moles of ozone by using the n=m/M. The learners can be asked to look up in the periodic table the mass of oxygen, and nitrogen. Since ozone has three oxygen atom that will give us molar mass of 48 g/mole and using the mass (0.74g) given. We can easily use the n=m/M to find the amount in moles. n=0.74/48=0.015moles.
Likewise, we can easily calculate the amount in moles of nitrogen monoxide as follows: for example given that the mass of NO is 0.67g, and molar mass of NO is 30g/mol. Using the same formula n=m/M will be 0.67/30= 0.02 moles if we can compare the two moles calculated we can automatically see that Ozone is the limiting reagent because it will finish first.

Figure 5.5: **Conceptual Teaching Strategy taken from post TSPCK tool for Michael**

This teaching strategy was scored a 2 for “Basic” TSPCK. From the rubric, a pre-service teacher was given this score if they identified a misconception but did not confront it clearly. Additionally, this strategy incorporated only one level of representation, i.e. symbolic, check yellow shadings. Learners are further referred to the periodic table (table showing symbols of elements) to obtain the masses of atoms, and or molecules. The pre-service teacher uses only equations to teach limiting reagent. There is no evidence of using, two or three levels of representation to address a misconception, thus this response was scored a 2. The next extract was taken from the year later response:

Ideally from the equation there is 2 moles of Mg that reacts with $TiCl_4$. The calculated values of the molar ratio shows that there is about 2,5 moles of Mg that reacts with $TiCl_4$. A limiting reagent defined as a substance which is totally consumed when a chemical reaction is complete. The amount of product formed is limited by this substance, since the reaction cannot proceed further without it.

Therefore, $TiCl_4$ is a limiting reagent, because it gets completely used up before the reaction is complete. That is the equation says the ratio of Mg to $TiCl_4$ is 2;1, which realistically is not the case. There is about 2,5; 1 ratio which means more Mg is required to react with $TiCl_4$.

1) The strategy that I would use to explain to the learners above is the calculation strategy, then the answers would be used to show which one of the substances is the limiting reagent. The answers are the one that are going to tell us the correct answers. The reason why I think this strategy would work it's because the learners would not just guess but they would know how to find the liming reagent. So next time they won't have to look at the substance and just guess but they would know what to do.
2) The importance of my strategy is that learners would know how to go about finding the liming reagent.
3)

Figure 5.6**: Conceptual Teaching Strategy taken from a year later TSPCK tool for Michael**

Similarly, in the strategy above Thabo identified the misconception that the mole ratio does not help us to immediately conclude that the other substance is the limiting reagent. The aspects of sequencing were not taken into account during the year later response, thus the quality of TSPCK for this component was retained at 2 for basic component interaction. Another area that was raising attention in this response is the fact that the pre-service teachers opted for a "calculation strategy". This is analysed to be less conceptual as the teachers only uses algorithms to teach concepts.

The above sections have discussed that TSPCK was retained in the four components. In the following section, I will discuss the evidence of improvement in the knowledge of the component of Representation. Keep it in mind that this component is the one that registered a shift of two response categories post the TSPCK intervention.

5.2.2. Improvement in the quality of TSPCK in the component of Representations

As indicated above in Table 5.1 the component of representation registered a positive shift of one response category to another a year after the then pre-service teachers completed the intervention in stoichiometry.

Extracts from Representations showing a positive shift of 1 response category

This component deals with analogies, examples, demonstrations and illustrations (Hassard & Dias, 2009) used to transform abstract content in forms that are easily comprehended by learners (Geddis & Wood, 1997). As outlined in chapter 4, students were given 3 representations with different levels of representations, i.e. macroscopic, microscopic and symbolic. The descriptors from the rubric indicate that a student is scored a 3 if they combine macroscopic and symbolic representations and provide explanatory note linking the two levels. Additionally, a respondent must also demonstrate an ability to draw from other TSPCK component when they use their representation.

This component registered a positive jump from 2; indicating “Basic” TSPCK component interaction to 3; indicating “Developing” TSPCK component interaction. Extracts of responses from Kgomotso are shown below in Figure 5.7 as qualitative evidence of growth in the component of “Representation”. In both cases – post intervention and a year later, Kgomotso chose representation 3. The shift was registered when she was required to explain how she will use the representation to teach learners. In Figure 5.7 below the two explanations as they appeared in post/year later responses from the TSPCK tool are compared.

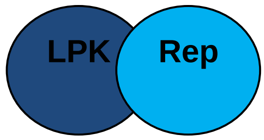
<table>
<tr><th>Extract from Rep (post)</th><th>Extract from Rep (a year later)</th></tr>
<tr><td>I would use it this representation to show learners how these three entities are related. Firstly I would use the microscopic representation that shows learners how a molecule of a substance would be presented and then use the symbolic representation to show them how to get the molecules.</td><td>First of all learners cannot picture atoms. Therefore I would use it [representation] to show learners how these three entities are related. Firstly I would bring in some jelly tots and toothpicks to macroscopically represent atoms. From that representation, learner can be able to see the atoms that make up molecules. Following that I will ask learners to draw diagrams representing molecules and atoms in the reaction. Finally use representation two and ask learners to calculate the amounts of the substances from the balanced chemical equations</td></tr>
<tr><td>No evidence of components interaction</td><td>
</td></tr>
</table>

Figure 5.7**: Extracts taken from Kgomotso for the component of Representation**

The post intervention response was scored a 2 because the Kgomotso states that she will use the two levels of representation, viz.: microscopic and symbolic representation, see yellow shading. Pre-service teachers were scored this score for “Basic” component interaction if they did provide explanatory notes on how these levels will be incorporated in a lesson. In contrast, a year later response shows that Kgomotso began to outline how these levels would be addressed in the lesson. Macroscopically, Kgomotso mentions that she will use jelly tots (atoms) and toothpicks (bonds) to show the structure of the molecules. Secondly, she also mentions that learners will be expected to draw diagrams representing molecules (particulate or microscopic level). Lastly, she lets learners work from the balanced chemical equation (symbolic level) to calculate the amount of the substances. Furthermore, a year later, Kgomotso shows evidence of TSPCK component interaction. Firstly, she acknowledges the idea of “What is difficult to teach”; see blue shading in Figure 5.7. Thus, Kgomotso was scored a three for this response. This analysis generally represents qualitative jump of one response category in the quality of TSPCK.

The last section of this analysis will deliberate on the finding that, a year later pre-service teachers continues to find the component of "Conceptual teaching strategies" to be difficult to engage.

5.2.3 More evidence of the difficulty of the component of conceptual teaching strategy

During analysis, the component of conceptual teaching strategy was confirmed to be the most difficult TSPCK component for the then pre-service teachers to engage with after one year of the intervention. This component registered an average score of 2 for both post and year later responses. Below I will show the challenges experienced by the then pre-service teachers to draw interactively on other TSPCK components when dealing with this component.

Learners believe that the compound with the least mass if [is] always the limiting reagent because they think that it will get finished faster. A practical can be done whereby all these substances can be reacted in order to see which the limiting reagent is. The experiment will help learners to know that Even if the mass of an[a] substance is lesser than the other substances it does not mean that it is always the limiting reagent.

Figure 5.9**: Teaching strategy extracted from Kgomotso's TSPCK response**

This strategy was scored a 2; in this response, the pre-service teacher acknowledges the student misconceptions, that is, the mass of the substance determines if it is limiting the reaction, see blue shading in Figure 5.9. However, in this strategy Kgomotso does not directly confronts the misconception. She mentions that a practical will be done to correct the misconception, see yellow shading. This teaching strategy lacks aspect of curriculum saliency and it is limited to only one level of representation, which is a macroscopic representation. Lastly, the extent at which learners are involved is very limited. Thus, for this component a score of 2 was given to indicate "Basic" TSPCK component interaction.

In the next extract, Figure 5.10 the teaching strategy from Michael was also scored a 2 for "Basic" component interaction.

1) The strategy that I would use to explain to the learners above is the calculation strategy, then the answers would be used to show which one of the substances is the limiting reagent. The answers are the one that are going to tell us the correct answers. The reason why I think this strategy would work it's because the learners would not just guess but they would know how to find the liming reagent. So next time they won't have to look at the substance and just guess but they would know what to do.
2) The importance of my strategy is that learners would know how to go about finding the liming reagent.

Figure 5.10**: Teaching strategy extracted from Michael's TSPCK response**

In this extract, it is noted that the component of "Conceptual teaching strategy" a year after the intervention experienced a least development in the interaction of TSPCK components. Michael only focused on an algorithmic approach (see yellow shading in Figure 5.10) to teach the concept of limiting reagent. The notion of algorithm approach (calculation strategy) is understood to be less conceptual. Both Figure 5.9 and 5.10 confirms that conceptual teaching strategy was found to be the most difficult TSPCK component for pre-service teachers to engage with a year after the intervention.

In the next section, a conclusion to this chapter is drawn by pulling together all the important points raised in this chapter.

5.3. Conclusion

Retention has been found to be the area that has received much less attention in PCK studies, more precisely PCK at a topic level for pre-service teachers. This study is mostly the first study to engage with the extent at which TSPCK is retained after a specific period, post intervention. It has therefore confirmed that in stoichiometry TSPCK is generally retained by pre-service teachers a year after the intervention.

Individual cases showed in Table 5.1 paints an interesting picture. There is evidence that what the then pre-service teachers are engaged with has a direct bearing on the retention and, or growth in their TSPCK. For an example, Thabo who registered growth is currently working with TSPCK in his postgraduate research work as confirmed by interviews. Other cases such as Tshepo showed some retraction in their TSPCK, this could be attributed to the fact that he is no longer engaged with the construct and possible his full-time focus on postgraduate studies is devoid of TSPCK.

A general overview of scores in this study confirmed that four components have retained the same quality of TSPCK. However, a year later one component registered an overall improvement, i.e. Representations. Representation has been argued to be the component that is the endpoint of the knowledge of learner prior knowledge, curriculum saliency and what is difficult to teach (Geddis et al., 1993), Thus in this analysis it is understood that growth or retention of TSPCK in these components would ideally influence the growth in the knowledge of “Representations”. Lastly, this chapter has further showed that after a year of exposure to an intervention that targets transformation of CK within the content-specific components, pre-service teacher find the engagement with CTS to be most difficult.

CHAPTER 6: CONCLUSION AND DISCUSSIONS

In this chapter, I begin by a brief overview of the study. This includes outlining the problem identified and hence the purpose of the study. Following that, I revise the question guiding this study. In this conclusion, I will therefore pull together the findings drawn in Chapter 4 & 5. These findings will be discussed in terms of both methodological and theoretical contribution they have brought in the PCK field. Subsequent to that, these contributions will be further explained in terms of their implications in the preparation of pre-service teachers. The last two sections will explain limitation and give prospects for future studies.

6.1. Overview of the study

Over the past three year, learner performance in key chemistry topics such as equilibrium, acids and bases, electrochemistry and others has been noted as poorly achieved in National Senior Certificate examinations (DoBE, 2013, 2014, 2015).. Stoichiometry has been widely ascertained to be the fundamental topic to other topic in chemistry as it is perceived as arithmetic behind chemistry (Kolb D. , 1978). Additionally it is perceived as the difficult topic for learners and to a certain degree, teacher to master (Furio et al., 2002). The literature indicates that stoichiometry is poorly conceptualised by a mainstream of teachers and thus preventing proper comprehension by learners (Furio et al., 2002)

Whilst Aydin et al., (2015) has argued that pre-service teachers have limited PCK, there have been reports on the ineffective teaching of mathematics and physical sciences by practicing teachers, leading to learners' inadequate performances (DoBE, 2015; Spaull, 2013). Thus It is asserted that if we want to produce optimal learning opportunities to learners, "we have to offer more powerful learning opportunities to teachers" (Feiman-Nemser, 2001p. 1014–1015), hence the need to prepare pre-service teachers effectively.

Following the above argument the purpose of this study was grounded on the examination of the development of pre-service teachers' professional knowledge for teaching science topics, called Topic Specific Pedagogical Content Knowledge (TSPCK). This knowledge was developed through exposing pre-service teachers to an intervention that targets the transformation of content knowledge by using components of TSPCK. Take note that different levels of generality at which PCK can be examined has be thoroughly been explored by Abel (2008) and Van Driel, Verloop, & De Vos (1998) argued that ‘‘the value of PCK lies essentially in its relation with respect to specific topics’’ (p. 691).This argument confirms the topic specificity of the theory. However, the study conducted by Park & Chen (2012) found that as much as PCK is specific at a level of the topic, it also depends not only on which components constitute a teacher's PCK for that topic. According to them, PCK at a topic can best be understood by the degree at which these components interact with each other as teachers plan or enact their teaching. Thus component interaction has been the key element used in this study to determine the extent of pedagogical content knowledge acquired and retained, as investigated by the research questions answered below.

6.2. Answering research questions

The first research question was– *What is the impact of an explicit intervention on developing the competence to transform content knowledge on the quality of pre-service teachers' TSPCK in planning to teach stoichiometry*? In answering this question, a set of pre and post TSPCK tools was compared for individual pre-service teacher. The generated scores were averaged for each TSPCK component. The average scores per component were compared for pre and post-tests. The scores generated from the TSPCK stoichiometry tool were interpreted for qualitative jump in the responses categories given by the descriptors contained in the TSPCK rubric, see Appendix II. An increase in an average score was interpreted to signify development in the knowledge of the component. A decrease in the average score was interpreted to signify a negative growth in the knowledge of the component. The finding in relation to this question was that pre-service teachers experienced a positive jump of one response category in the quality of their overall TSPCK. Additionally, pre-service teachers engaged the TSPCK components at different levels of difficulty contained in the TSPCK rubric.

The second research question was – *To what extent is the quality of the TSPCK in planning to teach stoichiometry retained by pre-service teachers a year later after the intervention*? This question explored the retention of the quality of TSPCK and aspect rarely investigated in the PCK literature, in particular for pre-service teachers. Post-tests were compared to test administered a year. After a period of about a year, the same pre-service teachers were followed as part of investigating the extent of TSPCK retention. Individual scores were averaged per component. New responses generated a year later were compared for retention, retraction or growth in their overall TSPCK. In relation to this question, the then pre-service teachers were followed, as they were busy with their post-graduate studies. Due to availability, 5 out of 24 pre-service teachers were investigated. The findings revealed that the then pre-service teachers generally retained the quality of TSPCK a year after the intervention. In addition, the component of retention was found to register a positive shift from “Basic” to “Developing” component interaction.

As a result of these two guiding questions, a sum of five empirical findings were generated post the intervention and a year after the intervention has taken place. In the sections below, I therefore discuss the theoretical and methodological contributions of this study in the PCK literature.

6.3. Contributions of the study

The findings in this study, contributed to both validation of newly reported findings on TSPCK in the literature and to new knowledge. Both these contributions are discussed in the sections below.

6.3.1. Theoretical contributions

(i) Validation of newly reported findings

The conceptualization of PCK at topic level is a relatively a new entry into the PCK literature (Mavhunga and Rollnick, 2013). While, there is an agreement in the literature about the topic specificity of PCK, full understanding on how it is defined differently from general knowledge is a relatively new discussion. It is only recently, in Leiden in December 2016, that science education researchers in PCK during the PCK Summit II, included Topic Specific PCK in the model to define the PCK construct (personal communication with attendee, unpublished). While introduce, the idea of a defined Topic Specific PCK already exists it still needs more empirical data to validate the claimed value (Mavhunga, 2016).

This study has advanced the validation of the conceptualisation of PCK at a topic level; it has shown that, pre-service teachers were found to have experienced an average shift of one response category in TSPCK in stoichiometry. This positive shift in TSPCK was analysed to signify a growth in knowledge for teaching the topic of stoichiometry. This finding was drawn on grounds that the average scores per TSPCK component post the intervention were found to have increased from the scores generated prior the intervention. This finding concurs with previous studies conducted in TSPCK. Mavhunga (2016) reported that the quality of pre-service teachers PCK in specific topics might be developed prior to practice.

The realisation of this finding revealed that while the focus was on reasoning about one content-specific component, consideration were made of another components after the intervention. This in turn confirmed the development of TSPCK as argued by Park & Chen (2012). They argue that PCK at a topic level depends on the degree of component interaction. In addition, the notion that pre-service teachers' PCK can be developed through focused intervention was also confirmed by Aydin, et al. (2015). They found that in the topic – reaction rates, pre-service teachers' interplay of content-specific components were found to be fragmented prior the practicum course. Post the practicum, the extent at which the interplay occurred was found to have improved, signifying a growth in the PCK for pre-service teachers. In addition to this concurrence, in 2013, the study by Mavhunga and Rollnick (2013) looked at the extent at which explicit teaching of transformation of concepts (intervention) in chemical equilibrium using TSPCK component influences the quality of PCK. They have found that PCK of pre-service teachers in the topic of chemical equilibrium improved because of the intervention. Thus this study has further added in the increasing call by Feiman-Nemser (2001) that teachers must be offered with valuable learning opportunities such that the can produce valuable teaching in their practice.

Secondly, the study established that pre-service teachers found the transformation of content knowledge in stoichiometry to happen at different levels of difficulty from the perspective of the five TSPCK components. The rank order generated from Rasch model (Boone & Rogan, 2005) ranked TSPCK components (items) at different values from more positive to less positive, signifying different levels of difficulty. Furthermore, this conclusion was also drawn from qualitative jumps in the quality of TSPCK component interaction made between pre and post TSPCK responses. The component of "Representations" registered a jump of two categories whereas the all the other components registered a jump of one response category.

Thirdly, in stoichiometry, the component of "Conceptual teaching strategy" was found to be the most difficult. The study that developed the TSPCK tool in stoichiometry argued that amongst other TSPCK components, "Conceptual teaching strategies" component requires teachers to go beyond the use of pedagogical strategies that requires the use of a combination of conceptual principles and is therefore the most difficult when compared to the other five components of TSPCK" (Malcolm et al., 2015). Similarly, this component was also found by Mavhunga (2014) for chemical equilibrium to be the most difficult component. In her review, the rank order was found to show the component of "Conceptual teaching strategies" to be the most difficult in both pre- and post-tests. Conversely, the component of "What is difficult" was found to be an easier component for pre-service teachers to engage. However, in Chemical Equilibrium Mavhunga (2014) found that the component of "Learner prior knowledge" was the least difficult whereas this study has found the component of "What is difficult" was the least difficult TSPCK components. There is some noticeable deference between the rank orders of TSPCK components for different topics. I have argued with reference above that PCK is best understood at a topic level and Aydin et al., (2014)asserts that the complexity and the nature of the topic influences the way in which the topic develops. For this reason, in order to arrive at a general consensus about the employability of the TSPCK as a rationale for teacher development in science education, a closer examination on *all* science topics is required with topic-specific components.

In addition to this finding, the component of "Representation" recorded a shift of two response categories form "Limited" to "Developing" TSPCK component interaction. This was analysed to mean that pre-service teachers found the growth in this component to be more significant than other TSPCK components. However, there was a limitation in drawing this conclusion. Prior the intervention, a number of pre-service teachers recorded "Limited" TSPCK component interaction because they left the TSPCK tools empty. This was interpreted to mean that they got tired as they were answering as this was towards the end. Secondly, it could be interpreted to say that they did not know what to write or maybe lacked interest in answering the tool.

(ii) Contribution to New Knowledge about TSPCK

The second research question discussed the extent of retention of TSPCK a year after the intervention was completed. Exploring this area was critical, as little is known in the literature about the retention of the quality of TSPCK by graduated pre-service teachers following their acquisition of the construct in an intervention. After one year, five pre-service teachers were found overall to have retained the quality of knowledge of TSPCK. These former pre-service teachers were enrolled in an honours programme that does not include a specific focus on TSPCK in stoichiometry, except for one participant who was a practicing teacher. On a closer analysis of the performance in individual TSPCK, this participant showed different pattern in his TSPCK. He showed positive shifts from “Basic” to “Developing .that retention in this case was based on average scores, a zoom to individual cases that is per respondents showed a different pattern. All the then pre-service teachers studied are engaged with postgraduate studied but one practicing. He personally showed evidence of growth after one year. Follow up interviews revealed that beside the experience, he continued to find the construct of TSPCK useful and his postgraduate study is anchored around it.

The components that retained the same level of quality of TSPCK are learner prior knowledge, curriculum saliency, what is difficult to teach and conceptual teaching strategies. These claims were also triangulated by interviews. Thus, this pattern is part of the closer analysis of the results. Secondly, the difficult component was conceptual teaching strategies and it was found to be difficult in the post-test. Therefore, this indicates a need to pay more focus that is explicit on this component when continuing with the implementation of the intervention in future programmes.

This finding is an important theoretical contribution of this study since PCK literature has paucity of empirical research on the extent of retention of PCK. The measurement of retention is essential in graduate pre-service teachers in order to evaluate the long-term impact of the explicit intervention on TSPCK.

6.3.2. Methodological Reflections

From a methodological point of view, this study continued to displays the opportunity to make PCK in a topic observable and accessible by using PCK maps, a pictorial representation of the interactions of the PCK components as argued by Park & Chen(2012).

In addition, the research design in which this study conformed to was suitable. Its methods followed a mixed method design. This is critical in this regard as if offers both qualitative and quantitative interpretation which goes beyond the just manipulation of variable but to a more holistic view of development of PCK.

6.4. Implications of the study

Based on the overall results of retention of the same quality based on the TSPCK rubric – there is value in implementing the TSPCK explicitly with specific topic. Secondly, based on the component of conceptual teaching strategies' difficulty there is a need to pay focus on this component when implementation of TSPCK based interventions are carries out. Hence, the inclusion of explicit examples and demonstration of known conceptual teaching strategies is paramount. Furthermore, research into the compilation of conceptual teaching strategies in the chemistry topics must be given attention. These research prospectively should not only be responding to misconceptions as these are there in the literature but – extending tools like the CoRes on topics where sample completed CoRes and examples of conceptual teaching strategies demonstrating an in-depth pulling together of the other TSPCK components are shown

As a result of this study and its attempt to strengthen the acquisition of PCK at a topic level, there are implications for teacher education raised. Firstly, for initial teacher education, the implication is therefore to situate courses such as methodology for teaching chemistry as TSPCK based intervention.

Secondly, more work need to be done in the examination of retention span of TSPCK. Thus, similar studies must be conducted in an effort to increase empirical evidence about the extent at which TSPCK is retained by beginning teachers.

6.5. Limitations of the study

This study employed a case study approach as mentioned in Chapter 3. Case studies have received many critics over the past years (Yin, 1994). They usually use a small sample, thus provides very limited grounds to scientifically generalise finding. Hence, the findings of this study cannot be generalised.

Secondly, the extent at which TSPCK was retained was investigated for only teachers who are doing their post-graduate studies. There was no evidence of following the TSPCK of teachers who are practicing in 2016. This follow up of practicing teachers was going to provide an in-depth comparison on the extent of retention between them and those in post-graduate full-time. In addition, case studies are generally understood to depend on the single case exploration, thus making it hard to reach a universal conclusion.

6.6. Prospects for future studies

For the same task, prospective studies can consider using a sample larger than this in order to measure the impact of the TSPCK based intervention using Rasch probability. In such a study, significance difference between pre and post-test scores should be measured and compared with qualitative data for such an examination.

Secondly, this study also examined the retention of TSPCK of pre-service doing their postgraduate studies as mentioned above; prospective research can be conducted in the same manner but expand its scope to compare the retention of TSPCK from both practicing teachers and those that are continuing with post-graduate studies and not in the classroom setup. This examination will be critical in order to measure the impact of classroom impact on the retention of TSPCK.

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Appendix I: Ethics Clearance Certificate

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Wits 2050, South Africa. Tel: +27 11 717-3064 Fax: +27 11 717-3100
E-mail: enquiries@educ.wits.ac.za Website: www.wits.ac.za

WITS UNIVERSITY

Date: 17 May 2016

Student Number: 584432

Protocol Number: 2016ECE022M

Dear Bongani Prince Ndlovu

Application for Ethics Clearance: Master of Science

Thank you very much for your ethics application. The Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate, has considered your application for ethics clearance for your proposal entitled:

Examining the Development of Topic Specific Pedagogical Content Knowledge in Stoichiometry in Pre-service Teachers

The committee recently met and I am pleased to inform you that clearance was granted.

Please use the above protocol number in all correspondence to the relevant research parties (schools, parents, learners etc.) and include it in your research report or project on the title page.

The Protocol Number above should be submitted to the Graduate Studies in Education Committee upon submission of your final research report.

All the best with your research project.

Yours sincerely,

MMaseko

Wits School of Education

011 717-3416

cc Supervisor - Dr Elizabeth Mavhunga

Appendix II: TSPCK Stoichiometry tool

University of the Witwatersrand Private Bag 3 Wits 2050 Johannesburg SA t+27 11 7173405 f+27867263424

STOICHIOMETRY TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE TOOL

The purpose of this research is to find the difficulties associated with the teaching of Stoichiometry. The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

Please write your responses directly into the response boxes.

Thank you for your valued input and assistance.

PCK Research group

Contact Person: Prof. Marissa Rollnick

E-mail: Marissa.Rollnick@wits.ac.za

Researcher: Mr. Stephen Andrew Malcolm

E-mail: stephen.malcolm@wits.ac.za

For any queries please feel free to contact me.

DEMOGRAPHIC INFORMATION

CODE:	

NAME:		
GENDER	Male	Female
CURRENT SUBJECTS TAUGHT		
NUMBER OF YEARS TEACHING SCIENCE		

QUALIFICATIONS

Degree / Diploma	Where Obtained	Main Subjects	Year

Have you taught stoichiometry?	**YES**		**NO**	

If yes, please indicate the grade and the number of years for each Grade.

Grade	Number of years	Years (e.g. 2008, 2009)

CODE:	

CATEGORY A: LEARNER'S PRIOR KNOWLEDGE

1. Before starting the section on reaction stoichiometry you give the learners a diagnostic test. One of the questions in the diagnostic test is reproduced below.

Each cube represents a volume of 22,4 dm^3 at STP. In which of the three pairs of cubes, Set A, Set B or Set C, is there 1 mole in each cube and in which of the three pairs cannot contain 1 mole in each cube?

Set A Cubes		Set B Cubes		Set C cubes	
N_2 (g)	H_2 (g)	O_2 (g)	Hg (ℓ)	SO_2 (g)	S (s)

How would you respond verbally to learners who state that all the cubes contain one mole?

Response A	At standard temperature, or 0°C and standard pressure, or 101,3 kPa one mole of any gas at STP occupies a volume of 22.4dm^3. This is called the molar volume but it only applies to gases at STP. Hence cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain 1 mole. The pair of cubes in Set B contains a liquid in one cube and the pair of cubes in Set C contains a solid in one cube. So, one of the Set C pair of cubes and the Set B pair of cubes contain other substances that are not gases. So Set B and Set C pairs do not contain one mole in each cube.
Response B	That is incorrect. All three pairs of cubes cannot contain one mole of substance. One mole of a gaseous substance occupies a volume of 22.4dm^3 at STP. So only the cubes of Set A contain one mole. The pairs of cubes in Set B and Set C do not have cubes that all contain one mole of substance since only one of the substances in the cubes of Set B and Set C are gaseous substances at STP.
Response C	It is important to check the phases of the substance. Molar gas volume only applies to substances in the gaseous phase. One mole of any gas at STP occupies 22.4dm^3. So the cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain one mole. There are exactly the same number of gas molecules, approximately 6,02 x 10^{23} particles in these cubes. The other substances in the pairs of cubes, Hg and S, are not in the gaseous phase. You would need to know the masses of mercury and sulphur in order to calculate if the cubes with these substances in Set B and Set C contain one mole of these substances. So, only in Set A is there one mole of substance in each cube in the set.
Response D	None of the above. I have another response which is

CODE:	

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response _______

2. After teaching the learners about concentration you give them an exercise to do for homework. In one question you ask learners the following question.

> During a practical lesson you have to make up molar solutions. You are provided with 10 g of sodium chloride, sodium bromide and sodium iodide. You dissolve each of these salts in a 100 ml volumetric flask.
>
> Do these solutions have the same or different molar concentrations? Explain your answer.

How would you respond in writing when giving feedback to the homework exercise to learners who provide the following answers?

The concentration of the three solutions will be the same because you dissolve the same amount of solute in the water.

THE CONCENTRATIONS ARE EQUAL BECAUSE YOU ARE DISSOLVING THE SAME MASS OF THE SALTS IN 100ML OF WATER.

CODE:

Response A	The mass of the salts does not mean that the number of particles is the same. The ions of the different salts have different relative atomic masses and therefore the molar mass of each salt is different and so the concentration of solutions will be different. Referring to the periodic table you can, by inspection, see that sodium chloride has a smaller molar mass than sodium iodide, and would therefore have a greater number of ions. Therefore the amount of salt, measured in moles, will also be different. Remember that just because the mass of each salt is the same the amount of salt, measured in moles will be different. Since concentration is the amount of substance per unit volume, the concentration of the sodium chloride solution will be greater than that of the sodium bromide, which would be greater than that of the sodium iodide. If you add ten grams of the salt to the same volume of solvent you are not adding the same number of ions for the different salts.
Response B	Concentration mathematically is the number of moles per unit volume. You need to calculate the number of moles for each of the three salts. This is done by dividing the mass of the sample by the molar mass of each salt or using the formula n = m /M. You need to refer to the periodic table to calculate the molar mass of each salt by adding the atomic mass of each element in the salt. So, firstly calculate the number of moles of each salt in 10 grams of the salt. Once you have calculated the number of moles of each substance then use the formula c = n /V to find the concentration of each solution. The concentration of the solutions will be different.
Response C	You need to understand what concentration is before you answer a question like this. So you were asked to dissolve three different salts in a given volume of water. Then you were asked if the concentration of these three solutions was the same or different. You must remember that concentration mathematically is the number of moles divided by the volume. So you need to workout how many moles of each salt and divide this by the volume of water you dissolved the salts in. The concentration of the three solutions cannot be same even if the mass of these salts is the same and the salts are dissolved in the same volume of water.
Response D	None of the above. I have another response which is

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response _______

CODE:	

CATEGORY B: CURRICULAR SALIENCY

3. The following questions relate to planning and sequencing of concepts.

3.1. What concepts in stoichiometry at Grade 11 do you believe are the main ideas[1] for understanding by students at the end of the instruction of this topic?

Choose at least three concepts from the provided list and place them in a sequence that depicts the best order of teaching. Provide reasons for both your choice and suggested sequence.

Theoretical yield is the amount of product that is formed when a reaction goes to completion based on the stoichiometry of the reaction.	**Molar ratios** can be used to determine the amount of reactants used or the yield of product formed.
Molar Mass of an element or compound expresses the equivalent relationship between one mole of a substance and its mass in grams.	**Balanced chemical equations** provide the combining ratios of reacting substances and their products in a chemical reaction.
Stoichiometric calculations combine balanced chemical equations and the concept of the mole to calculate the masses of all reactants required and products formed in a chemical reaction.	**Molar Volume** of a gaseous substance expresses the equivalent relationship between one mole of a gas and its volume of 22,4 dm^3 and standard temperature and pressure.
Conservation of mass is a chemical law that allows quantitative relationships to be established in chemical reactions.	**Dilution** is the process of decreasing the concentration of a solution by addition of solvent to a solution.
Concentration is a property of a solution and relates to the number of solute particles per unit volume.	The amount of substance in a given mass or volume can be expressed as a **constant amount of elementary particles.**
Limiting reagent is the reactant that used up in a chemical reaction and determines the amount of product formed.	**The mole** is the SI unit for amount of substance and allows us to connect the macroscopic scale of matter with the microscopic scale of matter and can used to help count elementary particles that make up substances.
Concentrated solutions have more particles per unit volume than **dilute solutions**.	
The **actual yield** of product formed depends on the reagent that limits the amount of the other reactant that reacts.	Gravimetric and volumetric analysis are **quantitative analysis methods** to determine the amount of substance.
Reaction stoichiometry involves the determination of molar ratios of the amount of reactants and products in a chemical reaction through balanced chemical equations.	**Avogadro's number** expresses the equivalent relationship between one mole of a substance and the number of entities it contains. **Avogadro's number has been experimentally** determined to be $6,02 \times 10^{23}$ particles
Volume is the amount of space occupied by a sample and from the volume of a gaseous substance the amount of substance can be determined.	**Mass** is the amount of matter contained in a sample and from the mass of a chemical substance the amount of substance can be determined.

[1]Main ideas are statements describing key understanding that must be learnt in a topic.

CODE:	

	Suggested concepts and sequence	Reasons
1.		
2.		
3.		

CODE:	

3.2. Make a map or a diagram showing how these three ideas link to subordinate concepts.

CODE:	

3.3. What topics/concepts must have been covered in chemistry before you can teach stoichiometry?

List of Topics/Concepts to be taught before Stoichiometry

3.4. Why is it important for learners to learn about stoichiometry? Identify reasons.

CODE:

CATEGORY C: UNDERSTANDING OF WHAT MAKES TOPIC EASY OR DIFFICULT TO UNDERSTAND

4. What concepts do you find difficult to teach in stoichiometry? Select your choice and provide reason(s) in the table below.

Concept	✓	Why is it difficult for learners to understand?
Amount of substance/mole		
Molar mass		
Molar volume		
Avogadro's number		
Concentration		
Dilution of solutions		
Molar ratios		
Stoichiometric calculations		
Limiting reagent		
Theoretical yield and actual yield		

CODE:

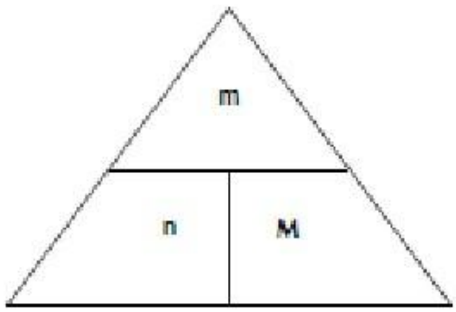
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

5. Below are possible representations for teaching the relationship between mass, mole and number of elementary particles.

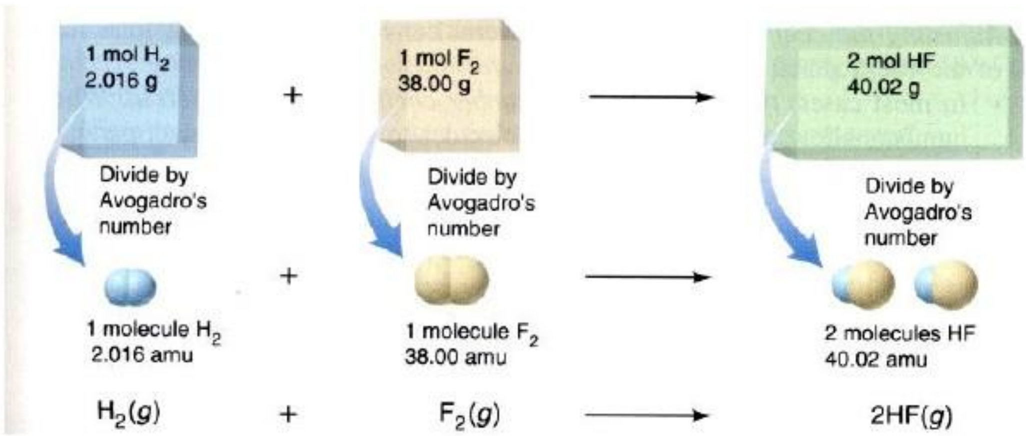
Representation 1

Items	Kind of Set	Number in Set
Socks, dice	Pair	2
Eggs, oranges	Dozen	12
Bottles, cans	Case	24
Brushes, pencils	Gross	144
Sheets of paper	Ream	500
Atoms, molecules	Mole	$6{,}02 \times 10^{23}$

Representation 2



Representation 3



CODE:	

5.1. Complete the table below by providing as many details as possible about each representation.

Representation No.	What I like	What I do not like

CODE:

5.2. Which representation do you like most?

5.3. How would you use the representation that you like most in a lesson?

CODE:	

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES

6. Learners are given the following question in the mid year examination.

> About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:
>
> $$TiCl_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgCl_2(\ell)$$
>
> In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.
>
> **Source: Department of Education (2007). Grade 11 Chemistry Paper, November Examination**

The learners are asked to determine the limiting reagent of the reaction, giving reasons for their answers. The learners provide the following answers.

Extract 1:	Extract 2:
Titanium (IV) chloride Limiting reagent is the reactant with the least number of moles in the equation	Magnesium This is the reactant present in the least amount according to mass.

Explain how you would assist these learners to move towards the correct answer, explaining what their errors are and highlighting the strategy you will use.
In your response:
(1) Explain why you think your strategy will work.
(2) Indicate what you consider as important in your strategy.

CODE:

THANK YOU. Your assistance is really appreciated in the development of this Instrument.

Appendix III: TSPCK memorandum in stoichiometry

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STOICHIOMETRY TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGETOOL

EXEMPLAR

PCK Research group

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For any queries please feel free to contact me.

CODE:

CATEGORY A: LEARNER'S PRIOR KNOWLEDGE

1. Before starting the section on reaction stoichiometry you give the learners a diagnostic test. One of the questions in the diagnostic test is reproduced below.

Each cube represents a volume of 22,4 dm^3 at STP. In which of the three pairs of cubes, Set A, Set B or Set C, is there 1 mole in each cube and in which of the three pairs cannot contain 1 mole in each cube?

Set A Cubes		Set B Cubes		Set C cubes	
N_2 (g)	H_2 (g)	O_2 (g)	Hg (ℓ)	SO_2 (g)	S (s)

How would you respond verbally to learners who state that all the cubes contains one mole?

Response A	At standard temperature, or 0°C and standard pressure, or 101,3 kPa one mole of any gas at STP occupies a volume of 22.4dm^3. This is called the molar volume but it only applies to gases at STP. Hence cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain 1 mole. The pair of cubes in Set B contains a liquid in one cube and the pair of cubes in Set C contains a solid in one cube. So, one of the Set C pair of cubes and the Set B pair of cubes contain other substances that are not gases. So Set B and Set C pairs do not contain one mole in each cube.
Response B	That is incorrect. All three pairs of cubes cannot contain one mole of substance. One mole of a gaseous substance occupies a volume of 22.4dm^3 at STP. So only the cubes of Set A contain one mole. The pairs of cubes in Set B and Set C do not have cubes that all contain one mole of substance since only one of the substances in the cubes of Set B and Set C are gaseous substances at STP.
Response C	It is important to check the phases of the substance. Molar gas volume only applies to substances in the gaseous phase. One mole of any gas at STP occupies 22.4dm^3. So the cubes containing nitrogen gas, hydrogen gas, oxygen gas and sulphur dioxide gas will contain one mole. There are exactly the same number of gas molecules, approximately 6,02 x 10^{23} particles in these cubes. The other substances in the pairs of cubes, Hg and S, are not in the gaseous phase. You would need to know the masses of mercury and sulphur in order to calculate if the cubes with these substances in Set B and Set C contain one mole of these substances. So, only in Set A is there one mole of substance in each cube in the set.
Response D	None of the above. I have another response which is

Adapted from Novick&Menis, 1976).

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response _______

CODE:	

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response C

Molar volume is only applicable to gases at STP. For liquids and solids more information such as the mass of the substances is required in order to determine the amount of sulphur and mercury. Or, from the volume the density of these substances can be used to find the mass, and then the amount of each substance.

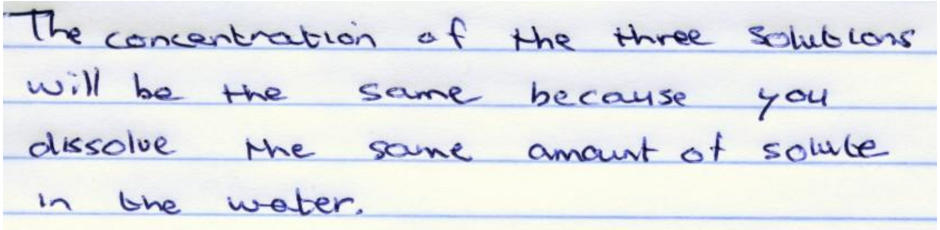
For the gases, one mole of each gas contains Avogadro's number of particles, which is approximately 6,02x1023. This is an approximation since this value has been determined experimentally and empirical data always has some degree of error. However, what is known is that the same volume of any gas at the same temperature and pressure contains the same number of elementary particles. Only the set of cubes containing two gases contain the same amount of substance.

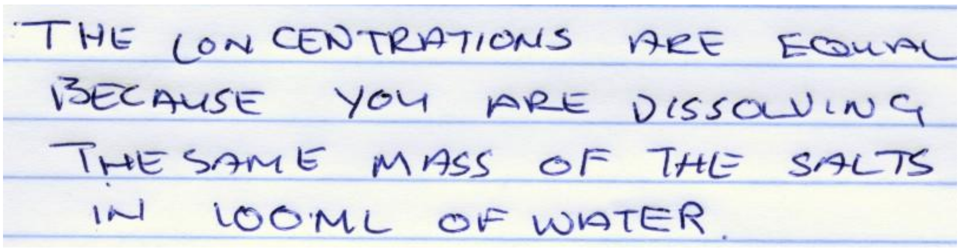
2. After teaching the learners about concentration you give them an exercise to do for homework. In one question you ask learners the following question.

During a practical lesson you have to make up molar solutions. You are provided with 10 g of sodium chloride, sodium bromide and sodium iodide. You dissolve each of these salts in a 100 ml volumetric flask.

Do these solutions have the same or different molar concentrations? Explain your answer.

How would you respond in writing when giving feedback to the homework exercise to learners who provide the following answers?


The concentration of the three solutions will be the same because you dissolve the same amount of solute in the water.


THE CONCENTRATIONS ARE EQUAL BECAUSE YOU ARE DISSOLVING THE SAME MASS OF THE SALTS IN 100ML OF WATER.

CODE:	

Response A	The mass of the salts does not mean that the number of particles is the same. The ions of the different salts have different relative atomic masses and therefore the molar mass of each salt is different and so the concentration of solutions will be different. Referring to the periodic table you can, by inspection, see that sodium chloride has a smaller molar mass than sodium iodide, and would therefore have a greater number of ions. Therefore the amount of salt, measured in moles, will also be different. Remember that just because the mass of each salt is the same the amount of salt, measured in moles will be different. Since concentration is the amount of substance per unit volume, the concentration of the sodium chloride solution will be greater than that of the sodium bromide, which would be greater than that of the sodium iodide. If you add ten grams of the salt to the same volume of solvent you are not adding the same number of ions for the different salts.
Response B	Concentration mathematically is the number of moles per unit volume. You need to calculate the number of moles for each of the three salts. This is done by dividing the mass of the sample by the molar mass of each salt or using the formula $n = m/M$. You need to refer to the periodic table to calculate the molar mass of each salt by adding the atomic mass of each element in the salt. So, firstly calculate the number of moles of each salt in 10 grams of the salt. Once you have calculated the number of moles of each substance then use the formula $c = n/V$ to find the concentration of each solution. The concentration of the solutions will be different.
Response C	You need to understand what concentration is before you answer a question like this. So you were asked to dissolve three different salts in a given volume of water. Then you were asked if the concentration of these three solutions was the same or different. You must remember that concentration mathematically is the number of moles divided by the volume. So you need to workout how many moles of each salt and divide this by the volume of water you dissolved the salts in. The concentration of the three solutions cannot be same even if the mass of these salts is the same and the salts are dissolved in the same volume of water.
Response D	None of the above. I have another response which is

Choose your response and indicate the reason(s) for your choice in the space below.

My choice is Response A
Conceptual understanding is more important than just explaining the mathematics. So, concentration is the amount of solute per unit volume. Of the three salts, by referring to the periodic table, the relative atomic mass increases for elements down a group. Of the halides, the chloride salt would have a smaller molar mass than the iodide salt. Since each salt contains the same cation, and each salt has a mass of 100g, the molar mass increases from the chloride to the iodide. The number of anions would therefore increase for substances with a smaller molar mass. So the smaller the molar mass, the greater the amount of substance, hence since the same mass of salt is dissolved in the same volume the concentration cannot be the same as there are different amounts of each solute.

CODE:

CATEGORY B: CURRICULAR SALIENCY

3. The following questions relate to planning and sequencing of concepts.

3.1. What concepts in stoichiometry at Grade 11 do you believe are the main ideas[1] for understanding by students at the end of the instruction of this topic?

Choose at least three concepts from the provided list and place them in a sequence that depicts the best order of teaching. Provide reasons for both your choice and suggested sequence.

Theoretical yield is the amount of product that is formed when a reaction goes to completion based on the stoichiometry of the reaction.	**Molar ratios** can be used to determine the amount of reactants used or the yield of product formed.
Molar Massof an element or compound expresses the equivalent relationship between one mole of a substance and its mass in grams.	**Balanced chemical equations** provide the combining ratios of reacting substances and their products in a chemical reaction.
Stoichiometric calculations combine balanced chemical equations and the concept of the mole to calculate the masses of all reactants required and products formed in a chemical reaction.	**Molar Volume** of a gaseous substance expresses the equivalent relationship between one mole of a gas and its volume of 22,4dm^3 and standard temperature and pressure.
Conservation of mass is a chemical law that allows quantitative relationships to be established in chemical reactions.	**Dilution** is the process of decreasing the concentration of a solution by addition of solvent to a solution.
Concentration is a property of a solution and relates to the number of solute particles per unit volume.	The amount of substance in a given mass or volume can be expressed as a **constant amount of elementary particles.**
Limiting reagent is the reactant that used up in a chemical reaction and determines the amount of product formed.	**The mole** is the SI unit for amount of substance and allows us to connect the macroscopic scale of matter with the microscopic scale of matter and can used to help count elementary particles that make up substances.
Concentrated solutions have more particles per unit volume than **dilute solutions**.	
The **actual yield** of product formed depends on the reagent that limits the amount of the other reactant that reacts.	Gravimetric and volumetric analysis are **quantitative analysis methods** to determine the amount of substance.
Reaction stoichiometry involves the determination of molar ratios of the amount of reactants and products in a chemical reaction through balanced chemical equations.	**Avogadro's number** expresses the equivalent relationship between one mole of a substance and the number of entities it contains. Avogadro's number has been experimentally determined to be 6,02 x10^{23} particles
Volume is the amount of space occupied by a sample and from the volume of a gaseous substance the amount of substance can be determined.	**Mass** is the amount of matter contained in a sample and from the mass of a chemical substance the amount of substance can be determined.

[1]Main ideas are statements describing key understanding that must be learnt in a topic.

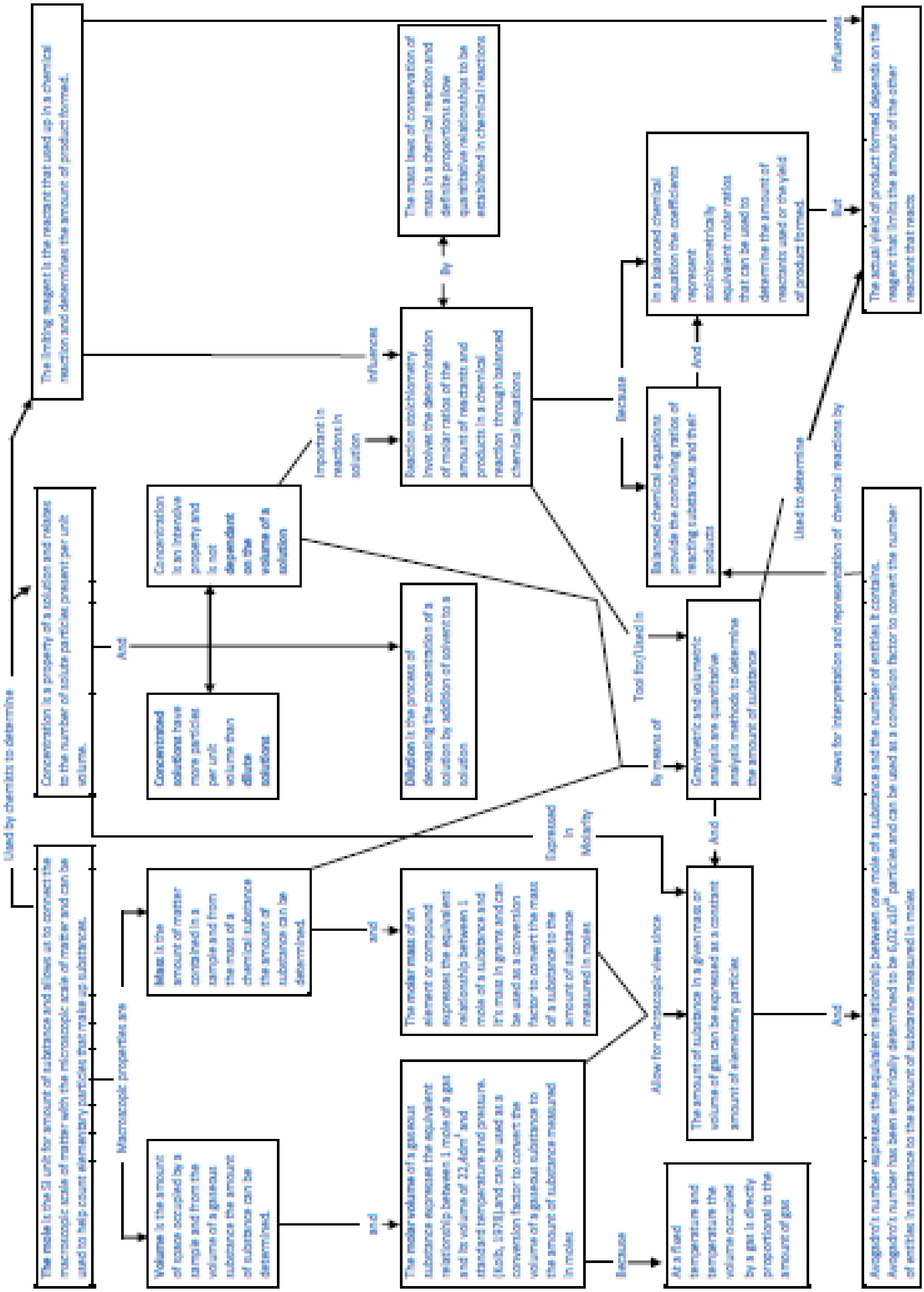
	Suggested concepts and sequence	Reasons
1.	The mole is the SI unit for amount of substance and connects the macroscopic scale of matter with the microscopic scale and can be used to count the number of elementary particles.	Understanding the amount of substance, measured in moles is fundamental to solving all stoichiometric problems. Introducing the mole as the unit for the amount of substance clearly begins stoichiometry at a level of measurement. From this learners can be told that in chemistry the amount of substance can be determined from macroscopic properties of mass and volume for gases, which can be measured and that the amount of substance can be determined through relationships of molar mass and molar volume of gases. Can start by measuring mass of substances and volume of gases, macroscopic properties, and show how these relate to amount of substance. Once the macroscopic view is understood, then the amount of substance can be related to the number of elementary particles and one mole of substance using the analogy of a counting unit like a dozen and linking Avogadro's constant to counting the number of particles. This idea of the mole and counting particles
2.	Concentration is a property of solutions and relates to the number of solute particles per unit volume.	

		can then be linked to concentration and the number of solute particles per unit volume. (The mole in a singular application) Once learners have seen the application if the mole to a singular entity, then the mole can be linked to chemical reactions. Real life application is more important so using examples of reactions where reagents are in excess the idea of a substance being used up and influencing the amount of other substances, formed or used can be introduced and then using the molar ratios that the mass, volume, concentration, number of entities can be calculated for products formed or reactants used.
3.	Limiting reagent is the reactant that is used up in a chemical reaction and determines the amount of product formed.	

Accept Reaction stoichiometry, or Quantitative analysis methods as a Big Idea if reasoning is logical.

CODE:	

3.2. Make a map or a diagram showing how these three ideas link to subordinate concepts.



3.3. What topics/concepts must have been covered in chemistry before you can teach stoichiometry?

List of Topics/Concepts to be taught before Stoichiometry
Before learning stoichiometry a learner needs to understand: 1. The amount of substance is a property that is measured in moles. 2. The mass of a substance can be measured. 3. The molar mass is used to convert mass to amount of substance 4. The molar mass can be determined by using the relative mass numbers of atoms from the periodic table. 5. The volume of a gas can be measured and the same amount of gases occupy the same volume at a given temperature and pressure. 6. Molar volume of gases is the volume occupied by one mole of gas and can be used to convert volume of a gas to the amount of gas. 7. One mole of any substance contains the same number of particles. These particles can be atoms, molecules, formula units for ionic substances. 8. Avogadro's number is a constant that represents a fixed number of particles that has been determined experimentally. 9. The molar mass of a substance represents the mass of one mole of substance and if divided by Avogadro's number gives the mass of a particle of that substance. 10. Concentration is determined by find the amount of particles of solute per unit volume. 11. Dilution refers to changing the volume of a solution and hence the concentration. 12. In a chemical reaction the mass and atoms are conserved. 13. A balanced chemical equation symbolically represents the number of particles and the molar ratio in which substances react. 14. In chemical reactions some substances are in excess and others are used up in a reaction. 15. The substance that is used up in a reaction is referred to as the limiting reagent. 16. Different gravimetric and volumetric analysis techniques can be used to determine the mass or concentration of substances. 17. If you know the mass, volume of a gaseous substance or the concentration of a solution in a chemical reaction the amount of that substance can be determined and vice versa. 18. If you know the amount of one reactant in a chemical reaction the molar ratios can be used to determine the amount of other reactants or products involved in the chemical reactions. 19. The theoretical yield can be determined using stoichiometry and actual yield using various analysis techniques.

CODE:

3.4. Why is it important for learners to learn about stoichiometry? Identify reasons.

Understanding the mole as a unit for the amount of substance is important for developing the correct conception of the mole required to develop conceptual understanding for reaction stoichiometry, understanding concentration and limiting reagent and understanding how to do stoichiometric calculations.

Understanding amount of substance is important is understanding the gas laws as the gas laws show properties of a fixed amount of gas under different conditions such as temperature, pressure and that volume gas occupies is related to amount of gas.

Understanding concentration is key to developing understanding of acids and bases. To understand ideas related to strength of acids and bases, dilute and concentrated acids and bases and calculating pH need to understand concentration.

Understanding concentration and amount of substance is important in developing an understanding of chemical equilibrium and calculating the equilibrium constant.

Rates of reaction often measured as rate of change of mass and rate of change of volume or rate of change of concentration require understanding of reaction stoichiometry.

Bond energy and exothermic and endothermic reactions and enthalpy change given as amount of energy per unit mole. Understanding that this value is a measurement of energy per mole of substance.

At tertiary level understanding of mole related to amount of electrons in redox reactions of galvanic cells and standard electrode potentials.

CODE:

CATEGORY C: UNDERSTANDING OF WHAT MAKES TOPIC EASY ORDIFFICULT TO UNDERSTAND

4. What concepts do you find difficult to teach in stoichiometry? Select your choice and provide reason(s) in the table below.

Concept	✓	Why is it difficult for learners to understand?
Amount of substance/mole		The amount of substance is not explicitly taught as a physical quantity and that the mole is the unit. So various incorrect conceptions of mole are held and reinforced in textbooks (i.e. n = number of moles).
Molar mass		The molar mass is the mass of one mole of substance determined by adding relative atomic mass of atoms from periodic table. No link or distinction made between mass of particles or molar mass.
Molar volume		Molar volume is thought to apply to all substances and not only gases. Only gases (based on properties) occupy the same volume if present in the same amounts under fixed temperature and pressure.
Avogadro's number		Number of particles is large and abstract so need to use an analogy. Books often equate one mole to an exact number of particles adding to confusion about the mole as a unit for the amount of substance.
Concentration		If learners do not have correct concept of amount of substance they may struggle with determining concentration and may think that the same mass in same volume equals same concentration.
Dilution of		Learners may have the misconception that if solutions are diluted concentration remains unchanged. Do not link

solutions		macroscopic view to microscopic view and the number of particles in a given volume.
Molar ratios		Learners often have the misconception that coefficients of balanced chemical equations do not represent reacting ratios. Struggle to link number of entities represented to ratios in terms of amount of substances that react in ratios
Stoichiometric calculations		Difficult if learners are not aware that if given mass, volume of gas, concentration of solutions that amounts of other substances can be determined. Difficult due to linking balanced equation and reacting ratios.
Limiting reagent		Misconceptions related to substance present in least mass, or molar ratio. Don't see importance of finding amount of substances to identifying limiting reagent.
Theoretical yield and actual yield		Stoichiometry dealt with out relating to real life applications and use in industry. So struggle to link yield from equation to real life situations.

CODE:

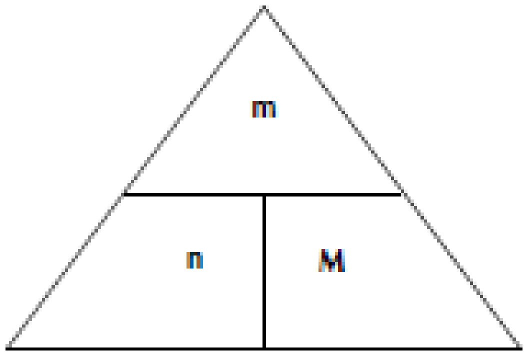
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

5. Below are possible representations for teaching the relationship between mass, mole and number of elementary particles.

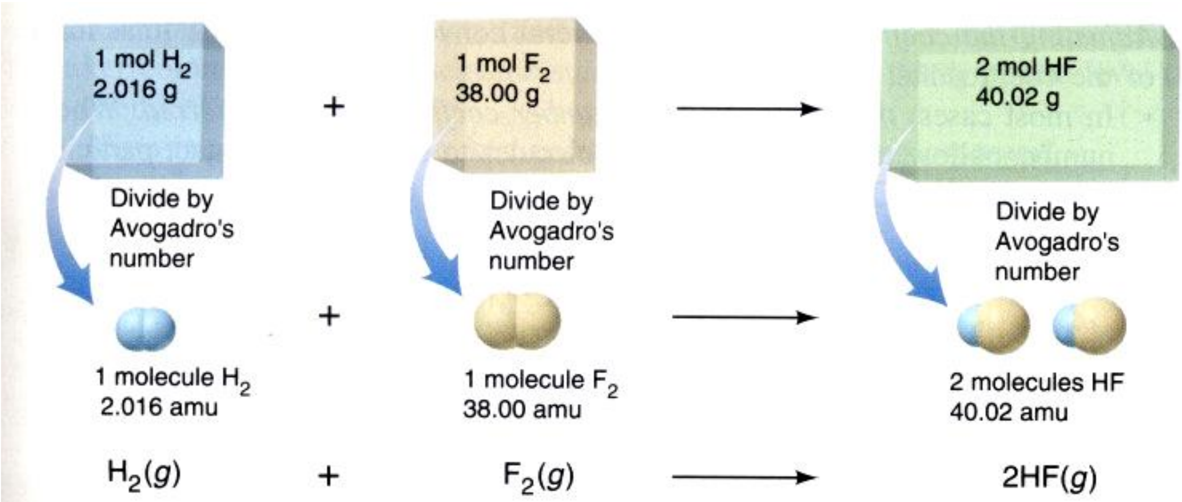
Representation 1

Items	Kind of Set	Number in Set
Socks, dice	Pair	2
Eggs, oranges	Dozen	12
Bottles, cans	Case	24
Brushes, pencils	Gross	144
Sheets of paper	Ream	500
Atoms, molecules	Mole	$6{,}02 \times 10^{23}$

Representation 2



Representation 3


1 mol H_2
2.016 g
1 mol F_2
38.00 g
2 mol HF
40.02 g
Divide by Avogadro's number
Divide by Avogadro's number
Divide by Avogadro's number
1 molecule H_2
2.016 amu
1 molecule F_2
38.00 amu
2 molecules HF
40.02 amu
$H_2(g)$ + $F_2(g)$ → $2HF(g)$

CODE:

5.1. Complete the table below by providing as many details as possible about each representation.

Representation No.	What I like	What I do not like
1	Provides useful analogies of counting units where the unit represents a different number of items. Provides concrete examples of counting units and links this to Avogadro's number.	Might reinforce the conception of the mole as equal to Avogadro's number of particles, or equal to a number. Need to reinforce that counting up to 12, 24, 500 is easy but that Avogadro's number is empirically determined and the exact number of particles is not established but that in one mole have same number of particles.
2	Illustrates the relationship between the amount of substance, mass and molar mass.	Can be used without understanding mathematical relationship between the values. Does not show the

		relationship between the values. Amount of substance central to stoichiometry and does not show relationship between volume, amount and molar volume of gases or number of entities and Avogadro's constant
3	Includes three levels of representation (macroscopic, sub-microscopic and symbolic. Shows link between conservation of mass and reaction stoichiometry. Shows link between molar mass and formula mass.	

CODE:

5.2. Which representation do you like most?

3**(Accept other representation if use shows links between three levels of representation.)**

5.4. How would you use the representation that you like most in a

Learner understanding begins at the macroscopic level. This representation can be used to introduce learners to the mole concept and reacting volumes of gases. Firstly, need to explain to learners that in this reaction the same volume of the reacting gases reacts and the volume of the product formed is twice that of the reactants. This can then be linked to molar volume and the amount of a gaseous substance. From the amount of gaseous substance the link between the amount of one mole of gas can be established in terms of the mass of one mole of gas and the molar mass. The link can be shown from the periodic table and to reinforce that in a chemical reaction mass is conserved. Once this link is established, the relationship between one mole of the gaseous substance and the number of particles and that the mole helps us to count the number of particles. Here the idea that one mole contains Avogadro's number of particles can be introduced.

The relationship between the mass of one mole of a substance and the relative formula mass can now be emphasized. Since one mole contains the same number of particles, if the molar mass is divided by this number the relative formula mass of one particle is obtained. This gives us the smallest number of particles involved in a reaction from which a chemical equation can be written to show the reaction.

From here need to move back to a macroscopic view and point out that chemists cannot see individual particles, but the balanced chemical equation also represents amounts we cab see (if we have Avogadro's number of particles) in terms of mass and volume which can be measured using different techniques and are easily handled.

CODE:

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES

6. Learners are given the following question in the mid year examination.

> About 15% of the world's titanium reserves are found in South Africa. The titanium is a strong, lightweight corrosion resistant metal. It is used in the construction of rockets, aircrafts and jet engines. The titanium is prepared by the reaction of molten magnesium with titanium(IV)chloride at temperatures of approximately 1 000 °C. The reaction is represented by the equation below:
>
> $$TiC\ell_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgC\ell_2(\ell)$$
>
> In a certain industrial plant 3 540 kg of titanium chloride was reacted with 1 130 kg of magnesium to produce 894,24 kg of titanium.
>
> Source: Department of Education (2007). Grade 11 Chemistry Paper, November Examination

The learners are asked to determine the limiting reagent of the reaction, giving reasons for their answers. The learners provide the following answers.

Extract 1:	Extract 2:
Titanium (IV) Chloride Limiting reagent is the reactant with the least number of moles in the equation	Magnesium This is the reactant present in the least amount according to mass.

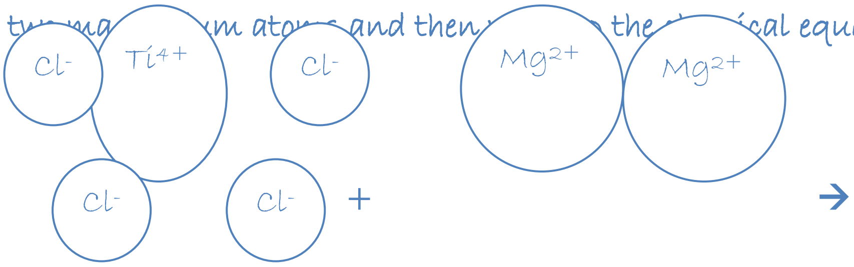
Explain how you would assist these learners to move towards the correct answer, explaining what their errors are and highlighting the strategy you will use.
In your response:
(1) Explain why you think your strategy will work.
(2) Indicate what you consider as important in your strategy.

Remember that the limiting reagent is the reactant that is used up in a reaction. When a chemical reaction occurs the particles in the substances rearrange to form a new substance. The balanced chemical equation shows the ratio of these particles that react and the number of product particles that form. So firstly, the limiting reagent cannot be determined from the molar ratios of the balanced chemical equation. The equation tells us that one particle of titanium chloride reacts with two magnesium atoms. Since both of these substances are made of different atoms the one particle of each reactant has different masses. A titanium atom has a larger atomic mass than magnesium. So one particle of titanium chloride has a larger mass than two atoms of magnesium. So you can't determine the limiting reagent based on the mass of substances present. You need to determine the amount of each reactant first. From the mass work out the amount.

Think about making ice-cream sundaes. One sundae needs two scoops of ice-cream, one hundred cherry and 250 ml of chocolate sauce. If I have twelve scoops of ice-cream, twenty cherries and 500 ml of chocolate sauce how many sundaes can we make? How did you determine this? I would point out that twelve scoops of ice-cream may have less mass than one hundred cherries, but that is not how we determined which substance limits the number of ice-cream sundaes we can make.

So let's do that first. Determine the amount of each reactant present in the given masses. First find the molar mass of one particle of each reactant using the relative atomic masses from the periodic table. Remember to find the amount of substance the mass given must be divided by the molar mass. Find the amount of substance using the formula $n = m/M$. The learners then determine the amounts and through questioning determine which substance is present in the least amount.

Now let's look at a submicroscopic view of the reaction. I would then draw up a particle view of the reaction to show one particle of titanium chloride reacting with two magnesium atoms and then [illegible] the chemical equation.



From here I would ask the learners based on the balanced equation for the amount of titanium chloride in the given mass how much magnesium would be needed using the molar ratios. The same would be done for the amount of magnesium present in the given mass and how much titanium chloride would be needed.

I would then ask the learners to determine which substance is the limiting reagent and let them determine the mass of titanium produced. I would then reinforce this [illegible]

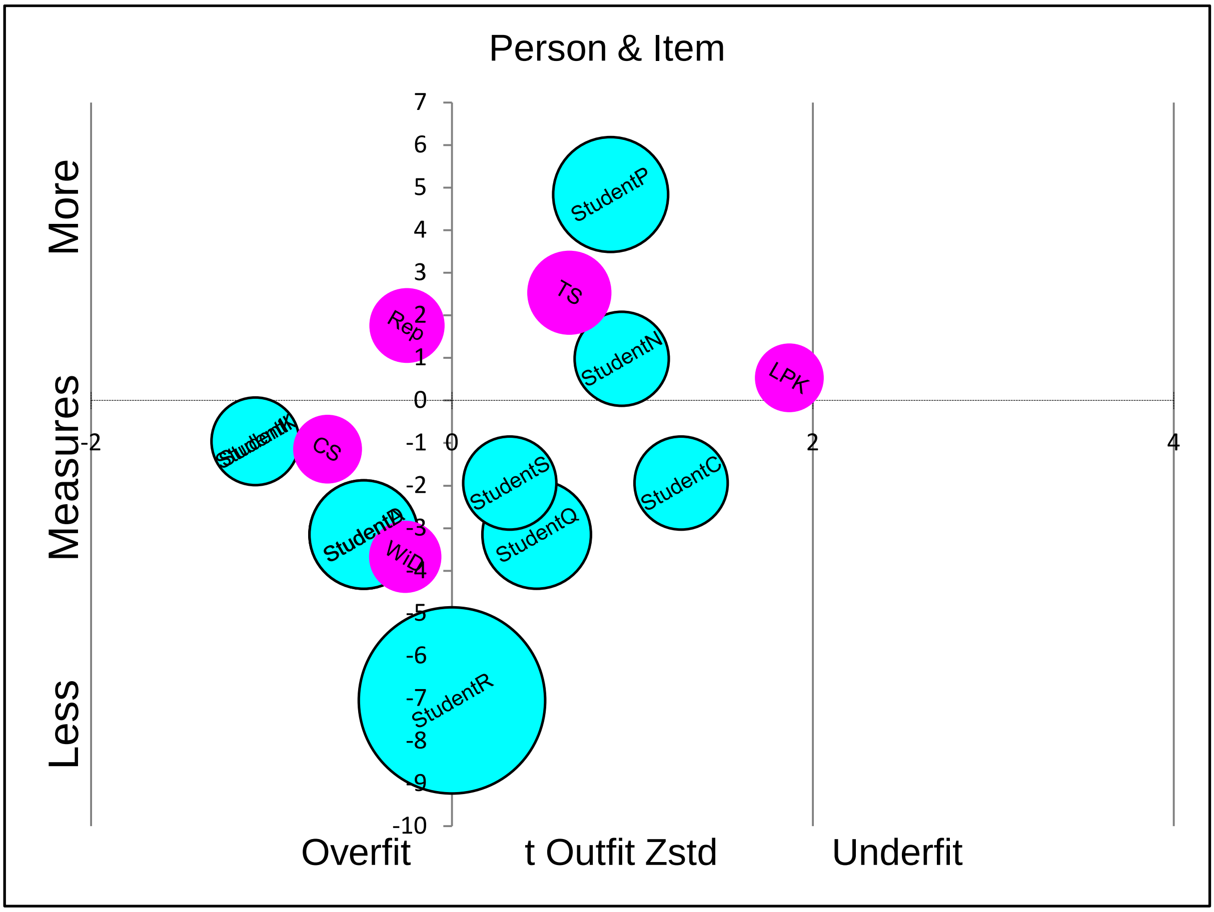
Appendix IV: TSPCK Rubric

	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • No attempt to address the misconception.	• Identifies misconception or prior knowledge • Provides standardized definition as a means to counteract the misconception • No evidence of drawing on other TSPCK components.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using one other component of TSPCK interactively.	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on two or more other component of TSPCK interactively.
Curriculum Saliency	• Identified concepts are a mix of Big Ideas and subordinate ideas • Identified pre-concepts are far from topic • Sequencing no value due to mixed concepts • Reasons given are generic - benefit of education.	• Identifies at least 3 Big Ideas • Not all 3 Big ideas subordinate concepts identified • Suggested sequencing has one or two illogical placing of Big Ideas. • Identified pre-concepts are far from the current topic • Reasons given for importance of topic exclude conceptual considerations and show no evidence of drawing on other TSPCK components.	• Identifies at least 3 Big Ideas • Subordinate concepts correctly identified for all Big Ideas • Provides logical sequence • Identifies pre-concepts relevant to the topic • Reasons given for importance of topic include reference to conceptual scaffolding/sequential development draw on one other TSPCK components e.g. what makes topic difficult.	• Identifies at least 3 Big Ideas • Subordinate concepts correctly identified for all Big Ideas with explanatory notes • Provides logical sequence of all three Big Ideas and with logical reasons • Identifies pre-concepts relevant to the current topic and explanatory notes given • Reasons given for importance of topic include conceptual scaffolding with reference to other TSPCK components e.g. Learner Prior Knowledge and what makes topic difficult.
What makes topic difficult	• Identifies broad topics without reasons and specifying the actual sub-concepts that are problematic.	• Identifies specific concepts but provides broad generic reasons such as 'abstract'.	• Identifies specific concepts leading to learner difficulty • Reasons given relate to one other TSPCK components.	• Identifies specific concepts with reasons linking to specific gate keeping concepts and to TSPCK components such as prior knowledge and aspects of curricular saliency.
Representations	• Limited to use of only macroscopic analogies, demos, etc.) representation with no explanation of specific links to the concepts represented	• Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.	• Use of macroscopic representation and use of scientific symbolic representation with explanatory notes linking the two representation to the aspect(s) of the concept being explained • Use of above representations combination with reference to one other TSPCK components e.g. learner prior knowledge	• Use of macroscopic representation or symbolic representation with sub-microscopic representation to enforce a specific aspect • Explicit link to other components of TSPCK e.g./emphasis of core aspect of CK demonstrated in the representations and learner prior knowledge
Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions • Lacks aspects of curriculum saliency • Use of representations limited to macroscopic or symbolic scientific symbolic representation	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy • Lacks aspects of curriculum saliency • Use of macroscopic and symbolic representations with no linking explanatory notes	• Considers confirmation/confrontation of student prior knowledge and/or misconceptions • Considers at least one aspect related to curriculum saliency e.g. sequencing or what not to discuss yet or emphasis of important concepts • Uses at least two different levels of representations to enforce understanding.	• Considers student prior knowledge and evidence of confrontation of misconceptions. • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding and may show awareness of learner difficulty.

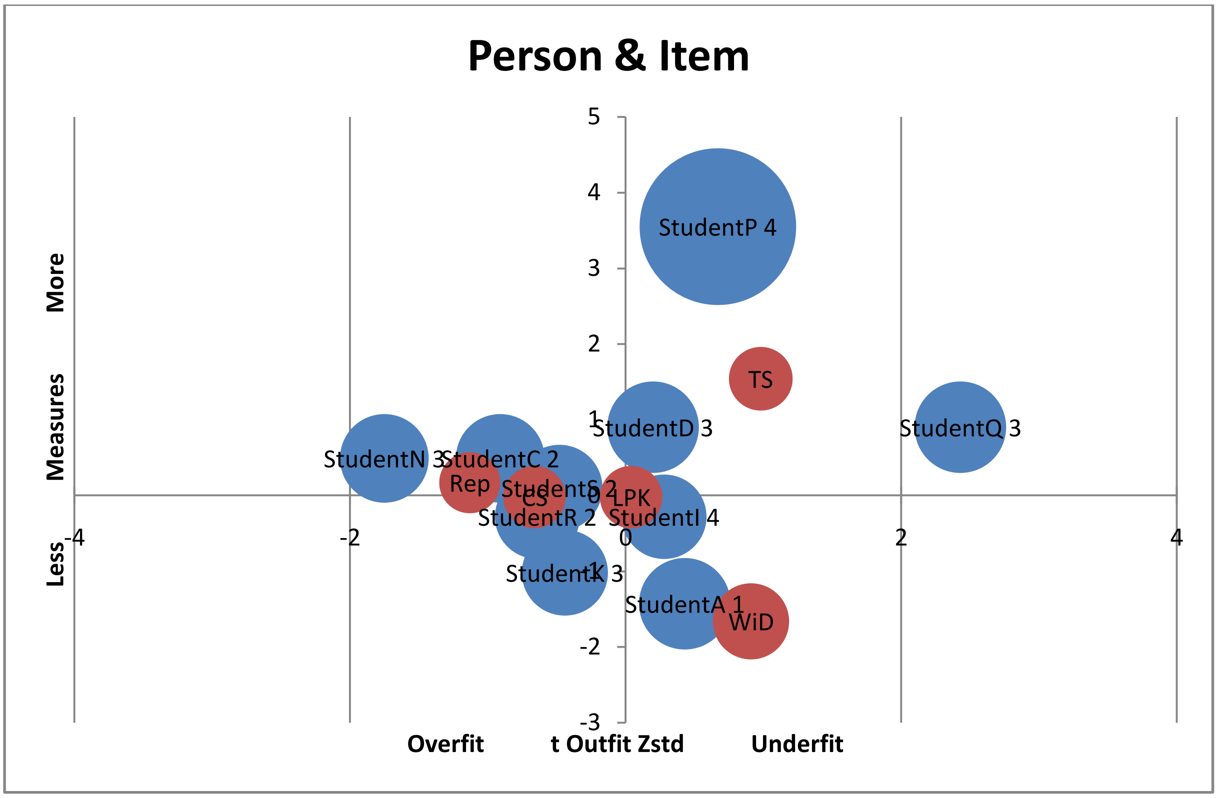
Appendix V: Interview schedule

i. What is your understanding of TSPCK?
ii. What are you currently engaged with?
iii. To what extent have you found this concept/theory useful in your current engagement?
iv. Which component of TSPCK you have found to be difficult?
v. Which component of TSPCK you have found to be easier?
vi. What has impacted on the growth if any/ retraction if any in the quality of your TSPCK
vii. To what extent would you recommend that methodology programs be carried out as TSPCK based interventions?

Appendix VI: Pre-TSPCK bubble plots



Appendix VII: Post-TSPCK bubble plots



Appendix VIII: Summary of items and persons reliability (Pre)

```
0TABLE 3.1 Pre-TSPCK scores in stoichiometry      ZOU422WS.TXT  Jul 19 2016 16:19
INPUT: 10 Person  5 Item  REPORTED: 10 Person  5 Item  3 CATS    MINISTEP 3.92.1
--------------------------------------------------------------------------------

     SUMMARY OF 9 MEASURED (NON-EXTREME) Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE   S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN       8.9       5.0      -1.05    1.10       .98     .0    .96     .1 |
| P.SD       2.2        .0       2.44     .11       .58    1.0    .64     .8 |
| S.SD       2.3        .0       2.59     .12       .61    1.0    .68     .9 |
| MAX.      14.0       5.0       4.84    1.27      1.84    1.3   1.95    1.3 |
| MIN.       7.0       5.0      -3.15     .97       .31   -1.2    .21   -1.1 |
|-----------------------------------------------------------------------------|
| REAL RMSE   1.25 TRUE SD    2.10  SEPARATION  1.68  Person RELIABILITY  .74 |
|MODEL RMSE   1.11 TRUE SD    2.18  SEPARATION  1.97  Person RELIABILITY  .80 |
| S.E. OF Person MEAN = .86                                                   |
-------------------------------------------------------------------------------
  MINIMUM EXTREME SCORE:      1 Person 10.0%

     SUMMARY OF 10 MEASURED (EXTREME AND NON-EXTREME) Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE   S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN       8.5       5.0      -1.65    1.20                                 |
| P.SD       2.4        .0       2.93     .31                                 |
| S.SD       2.5        .0       3.09     .32                                 |
| MAX.      14.0       5.0       4.84    2.06                                 |
| MIN.       5.0       5.0      -7.05     .97                                 |
|-----------------------------------------------------------------------------|
| REAL RMSE   1.35 TRUE SD    2.60  SEPARATION  1.92  Person RELIABILITY  .79 |
|MODEL RMSE   1.23 TRUE SD    2.66  SEPARATION  2.15  Person RELIABILITY  .82 |
| S.E. OF Person MEAN = .98                                                   |
-------------------------------------------------------------------------------
Person RAW SCORE-TO-MEASURE CORRELATION = .99
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .81  SEM = 1.04

     SUMMARY OF 5 MEASURED (NON-EXTREME) Item
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE   S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      17.0      10.0        .00     .81       .97    -.1    .96     .3 |
| P.SD       3.6        .0       2.22     .06       .52    1.2    .67     .9 |
| S.SD       4.1        .0       2.48     .07       .58    1.3    .75    1.0 |
| MAX.      23.0      10.0       2.53     .93      1.68    1.5   2.08    1.9 |
| MIN.      13.0      10.0      -3.67     .76       .38   -1.5    .28    -.7 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .91 TRUE SD    2.02  SEPARATION  2.23  Item   RELIABILITY  .83 |
|MODEL RMSE    .82 TRUE SD    2.06  SEPARATION  2.52  Item   RELIABILITY  .86 |
| S.E. OF Item MEAN = 1.11                                                    |
-------------------------------------------------------------------------------
Item RAW SCORE-TO-MEASURE CORRELATION = -1.00
Global statistics: please see Table 44.
UMEAN=.0000 USCALE=1.0000
```

Appendix XI: Summary of items and persons reliability indices (Post)

```
Post-TSPCK scores in stoichiometry     ZOU564WS.TXT  Jul 20 2016 13:43
INPUT: 10 Person  5 Item  REPORTED: 10 Person  5 Item  4 CATS    MINISTEP 3.92.1
--------------------------------------------------------------------------------

     SUMMARY OF 10 MEASURED Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    S.E.      MNSQ   ZSTD  MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      13.3       5.0         .34     .68        .95    -.1  1.02     .0 |
| P.SD       2.7        .0        1.29     .15        .66    1.1   .78    1.1 |
| S.SD       2.8        .0        1.36     .16        .69    1.1   .82    1.1 |
| MAX.      19.0       5.0        3.55    1.13       2.63    2.0  3.15    2.4 |
| MIN.       9.0       5.0       -1.43     .61        .15   -2.1   .22   -1.7 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .79 TRUE SD    1.03  SEPARATION  1.31  Person RELIABILITY  .63 |
|MODEL RMSE    .70 TRUE SD    1.09  SEPARATION  1.55  Person RELIABILITY  .71 |
| S.E. OF Person MEAN = .43                                                   |
-------------------------------------------------------------------------------
Person RAW SCORE-TO-MEASURE CORRELATION = .98
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .59  SEM = 1.71

     SUMMARY OF 5 MEASURED Item
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    S.E.      MNSQ   ZSTD  MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      26.6      10.0         .00     .47        .93    -.2  1.02     .0 |
| P.SD       4.8        .0        1.01     .04        .45    1.2   .40     .8 |
| S.SD       5.3        .0        1.13     .04        .50    1.4   .45     .9 |
| MAX.      34.0      10.0        1.54     .55       1.44    1.1  1.54    1.0 |
| MIN.      19.0      10.0       -1.66     .44        .29   -2.2   .53   -1.1 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .51 TRUE SD     .88  SEPARATION  1.71  Item   RELIABILITY  .75 |
|MODEL RMSE    .47 TRUE SD     .90  SEPARATION  1.91  Item   RELIABILITY  .79 |
| S.E. OF Item MEAN = .51                                                     |
-------------------------------------------------------------------------------
Item RAW SCORE-TO-MEASURE CORRELATION = -1.00
Global statistics: please see Table 44.
UMEAN=.0000 USCALE=1.0000
```

Appendix X: Item rank order (Pre-Test)

Pre-TSPCK scores in stoichiometry ZOU422WS.TXT Jul 19 2016 16:19
INPUT: 10 Person 5 Item REPORTED: 10 Person 5 Item 3 CATS MINISTEP 3.92.1

Person: REAL SEP.: 1.92 REL.: .79 ... Item: REAL SEP.: 2.23 REL.: .83

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
5	13	10	2.53	.93	1.47	.9	1.35	.7	.68	.71	66.7	82.0	CTS
4	14	10	1.76	.83	.81	-.3	.69	-.2	.79	.73	88.9	77.7	Rep
1	16	10	.53	.76	1.68	1.5	2.08	1.9	.60	.75	66.7	72.2	LPK
2	19	10	-1.14	.76	.52	-1.1	.40	-.7	.85	.77	88.9	73.1	CS
3	23	10	-3.67	.80	.38	-1.5	.28	-.3	.85	.74	100.0	76.0	WiD
MEAN	17.0	10.0	.00	.81	.97	-.1	.96	.3			82.2	76.2	
P.SD	3.6	.0	2.22	.06	.52	1.2	.67	.9			13.3	3.5	

TABLE 13.3 Pre-TSPCK scores in stoichiometry ZOU422WS.TXT Jul 19 2016 16:19
INPUT: 10 Person 5 Item REPORTED: 10 Person 5 Item 3 CATS MINISTEP 3.92.1

Item CATEGORY/OPTION/DISTRACTOR FREQUENCIES: MEASURE ORDER

ENTRY NUMBER	DATA CODE	SCORE VALUE	DATA COUNT	DATA %	ABILITY MEAN	P.SD	S.E. MEAN	INFT MNSQ	OUTF MNSQ	PTMA CORR.	Item
5	1	1	8	80	-2.42	2.21	.84	1.8	1.9	-.53	CTS
	2	2	1	10	-1.94	.00		4.5	2.4	-.03	
	3	3	1	10	4.84	.00		.8	.8	.74	
4	1	1	7	70	-2.91	1.92	.78	.9	.8	-.66	Rep
	2	2	2	20	-.48	1.46	1.46	1.1	.8	.20	
	3	3	1	10	4.84	.00		.6	.5	.74	
1	1	1	5	50	-3.44	1.88	.94	.7	.7	-.61	LPK
	2	2	4	40	-.06	2.96	1.71	2.0	2.4	.44	
	3	3	1	10	.98	.00		3.5	5.1	.30	
2	1	1	2	20	-5.10	1.95	1.95	.7	.6	-.59	CS
	2	2	7	70	-1.59	1.34	.55	1.0	.7	.03	
	3	3	1	10	4.84	.00		.0	.0	.74	
3	1	1	1	10	-7.05	.00		.0	.0	-.61	WiD
	2	2	5	50	-2.67	.60	.30	.4	.3	-.35	
	3	3	4	40	.98	2.37	1.37	.4	.4	.73	

ORDER OF DIFFICULTY

Appendix XI: Item rank order (Post-Test)

Post-TSPCK scores in stoichiometry ZOU564WS.TXT Jul 20 2016 13:43
INPUT: 10 Person 5 Item REPORTED: 10 Person 5 Item 4 CATS MINISTEP 3.92.1

Person: REAL SEP.: 1.31 REL.: .63 ... Item: REAL SEP.: 1.71 REL.: .75

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
5	19	10	1.54	.46	1.44	1.1	1.43	1.0	.67	.67	30.0	47.8	CTS
4	26	10	.17	.44	.53	-1.2	.53	-1.1	.85	.62	70.0	52.2	Rep
1	27	10	-.02	.45	1.09	.4	.95	.0	.59	.61	50.0	53.0	LPK
2	27	10	-.02	.45	.29	-2.2	.67	-.7	.63	.61	80.0	53.0	CS
3	34	10	-1.66	.55	1.31	.8	1.54	.9	.29	.47	60.0	61.7	WiD
MEAN	26.6	10.0	.00	.47	.93	-.2	1.02	.0			58.0	53.5	
P.SD	4.8	.0	1.01	.04	.45	1.2	.40	.8			17.2	4.5	

TABLE 13.3 Post-TSPCK scores in stoichiometry ZOU564WS.TXT Jul 20 2016 13:43
INPUT: 10 Person 5 Item REPORTED: 10 Person 5 Item 4 CATS MINISTEP 3.92.1

Item CATEGORY/OPTION/DISTRACTOR FREQUENCIES: MEASURE ORDER

ENTRY NUMBER	DATA CODE	SCORE VALUE	DATA COUNT	%	ABILITY MEAN	P.SD	S.E. MEAN	INFT MNSQ	OUTF MNSQ	PTMA CORR.	Item
5	1	1	5	50	-.12	.63	.31	1.1	1.2	-.35	CTS
	2	2	3	30	-.15*	.90	.64	1.5	2.2	-.25	
	4	4	2	20	2.22	1.32	1.32	1.7	1.7	.73	
4	1	1	2	20	-1.22	.20	.20	.5	.5	-.60	Rep
	2	2	2	20	-.28	.00	.00	.3	.3	-.24	
	3	3	4	40	.49	.29	.17	.3	.2	.10	
	4	4	2	20	2.22	1.32	1.32	.7	.8	.73	
1	1	1	1	10	-1.43	.00		.4	.4	-.46	LPK
	2	2	3	30	.10	.31	.22	1.2	1.1	-.12	
	3	3	4	40	.32	.79	.46	1.2	.8	-.01	
	4	4	2	20	1.63	1.91	1.91	1.5	1.4	.50	
2	2	2	3	30	-.91	.48	.34	.2	.2	-.63	CS
	3	3	7	70	.88	1.16	.47	.8	1.7	.63	
3	2	2	1	10	.90	.00		4.2	3.5	.14	WiD
	3	3	4	40	-.56*	.73	.42	.6	.4	-.57	
	4	4	5	50	.95	1.36	.68	.9	1.0	.47	

ORDER OF DIFFICULTY

* Average ability does not ascend with category score

Appendix XII: Information Sheet to Graduates

University of Witwatersrand
Science Education Division
MARANG centre for mathematics, science & technology education

INFORMATION SHEET GRADUATES FROM PHYSICAL SCIENCE PROGRAMME
DATE:

Dear NAME

My name is Bongani Prince Ndlovu and I am a researcher in the School of Education at the University of the Witwatersrand.

I am doing research on **Examining the Development of Topic Specific Pedagogical Content Knowledge in Pre-service Teachers in Stoichiometry.**

My research involves……
Using the TSPCK Stoichiometry tool that examines teachers' knowledge for teaching Stoichiometry, I will look at shifts from pre and post scores, however the same tool will be administered to participants after few months of practice to examine the retention of TSPCK. Stimulated recall interviews will be conducted to analyze the degree the extent at which TSPCK is retained after the intervention.

The reason why I have chosen you:
I have chosen to interview you as participant in my study as I consider that you completed an intervention program located in the chemistry methodology course that discussed components of TSPCK on Stoichiometry. The main objective of this intervention is to examine the degree of shifts in the quality of TSPCK after the intervention and its retention thereafter.

Your name and identity will be kept confidential at all times and in all academic writing about the study. Your individual privacy will be maintained in all published and written data resulting from the study.

All research data will be destroyed between 3-5 years after completion of the project.

You will not be advantaged or disadvantaged in any way. Your participation is voluntary, so you can withdraw your permission at any time during this project without any penalty. There are no foreseeable risks in participating and you will not be paid for this study.

Please let me know if you require any further information.

Thank you very much for your help.

Yours sincerely,

SIGNATURE: ________________________
NAME: Bongani Prince Ndlovu
ADDRESS: 25161 Olive Street; Protea Glen Ext 28
EMAIL: ndlovu@thepub.co.za
TELEPHONE NUMBERS: 0760274587

Appendix XIII: Graduates Consent Form

University of Witwatersrand
Science Education Division
MARANG centre for mathematics, science & technology education

Graduate's Consent Form

Please fill in and return the reply slip below indicating your willingness to be a participant in my voluntary research project called:

Examining the Development of Topic Specific Pedagogical Content Knowledge in Pre-service Teachers in Stoichiometry

I, ________________________ give my consent for the following:

Permission to be audio taped

I agree to be audio taped during the interview or observation lesson	YES/NO
I know that the audiotapes will be used for this project only	YES/NO

Permission to be interviewed

I would like to be interviewed for this study.	YES/NO
I know that I can stop the interview at any time and don't have to answer all the questions asked.	YES/NO

Permission to complete TSPCK tool

I agree to complete TSPCK tool.	YES/NO
I know that the Tool will be used for this project only.	YES/NO

Informed Consent

I understand that:

- My name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audiotape, photographed and/or videotape
- All the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_____________________________ Date___________________________

Appendix XIV: Requisition Letter to Course Coordinator

University of the Witwatersrand Private Bag 3 Wits 2050 Johannesburg sa t+27 11 7173414 f+27 11 7173259

MSc Student: Mr B. P Ndlovu
Student No.: 584432
Phone: 076 027 4587;
e-mail: ndlovu@thepub.co.za

A Request for Permission to the Course Coordinator of Course (SCED7000): To conduct a Research Study in the Physical Science fourth year PCK course EDUC4164)

Project Title:
Examining the Development of Topic Specific Pedagogical Content Knowledge in Pre-service Teachers in Stoichiometry

Principal Investigator: Mr B.P Ndlovu, Marang Centre for Maths and Science Education
Phone: 076 027 4587 E-mail: ndlovu@thepub.co.za

Dear Dr. M E Mavhunga

I kindly request permission to run a research study for a MSc. Research report in the EDUC4164 Curriculum Methodology programme. I am a part-time MSc student in Science Education in the second year of study. I am investigating pre-service teachers' perceptions about their own developing Topic Specific Pedagogical Content Knowledge.

Data will be collected through the use of TSPCK stoichiometry tool to investigate the impact of the intervention. This data will be supplemented with qualitative data from audio-taped interviews.

Appendix XV: Requisition Letter to Head of Division

University of the Witwatersrand Private Bag 3 Wits 2050 Johannesburg sa t+27 11 7173414 f+27 11 7173259

MSc Student: Mr B. P Ndlovu
Student No.: 584432
Phone: 076 027 4587;
e-mail: ndlovu@thepub.co.za

A Request for Permission to the Head of Division: To conduct a Research Study in the Physical Science fourth year PCK course EDUC4164)

Project Title:
Examining the Development of Topic Specific Pedagogical Content Knowledge in Pre-service Teachers in Stoichiometry

Principal Investigator: Mr B.P Ndlovu, Marang Centre for Maths and Science Education
Phone: 076 027 4587   E-mail: ndlovu@thepub.co.za

Dear Prof O. Oyoo

I kindly request permission to run a research study for a MSc. Research report in the EDUC4164 Curriculum Methodology programme. I am a part-time MSc student in Science Education in the second year of study. I am investigating pre-service teachers' perceptions about their own developing Topic Specific Pedagogical Content Knowledge.

Data will be collected through the use of TSPCK stoichiometry tool to investigate the impact of the intervention. This data will be supplemented with qualitative data from audio-taped interviews.

Appendix XVI: Requisition Letter to Head of School

University of the Witwatersrand Private Bag 3 Wits 2050 Johannesburg sa t+27 11 7173414 f+27 11 7173259

MSc Student: Mr B. P Ndlovu
Student No.: 584432
Phone: 076 027 4587;
e-mail: ndlovu@thepub.co.za

A Request for Permission to the Head of School: To conduct a Research Study in the Physical Science fourth year PCK course EDUC4164)

Project Title:
Examining the Development of Topic Specific Pedagogical Content Knowledge in Pre-service Teachers in Stoichiometry

Principal Investigator: Mr B.P Ndlovu, Marang Centre for Maths and Science Education
Phone: 076 027 4587 E-mail: ndlovu@thepub.co.za

Dear Prof. K. Brodie

I kindly request permission to run a research study for a MSc. Research report in the EDUC4164 Curriculum Methodology programme. I am a part-time MSc student in Science Education in the second year of study. I am investigating pre-service teachers' perceptions about their own developing Topic Specific Pedagogical Content Knowledge.

Data will be collected through the use of TSPCK stoichiometry tool to investigate the impact of the intervention. This data will be supplemented with qualitative data from audio-taped interviews.